Abstracts

Review of Progress in Quantitative NDE

Colorado School of Mines
Golden, Colorado
July 22 – July 27, 2007

Organized by:

Center for Nondestructive Evaluation
Iowa State University

In cooperation with:

Air Force Research Laboratories

American Society for Nondestructive Testing

Ames Laboratory - U.S. Department of Energy

Federal Aviation Administration

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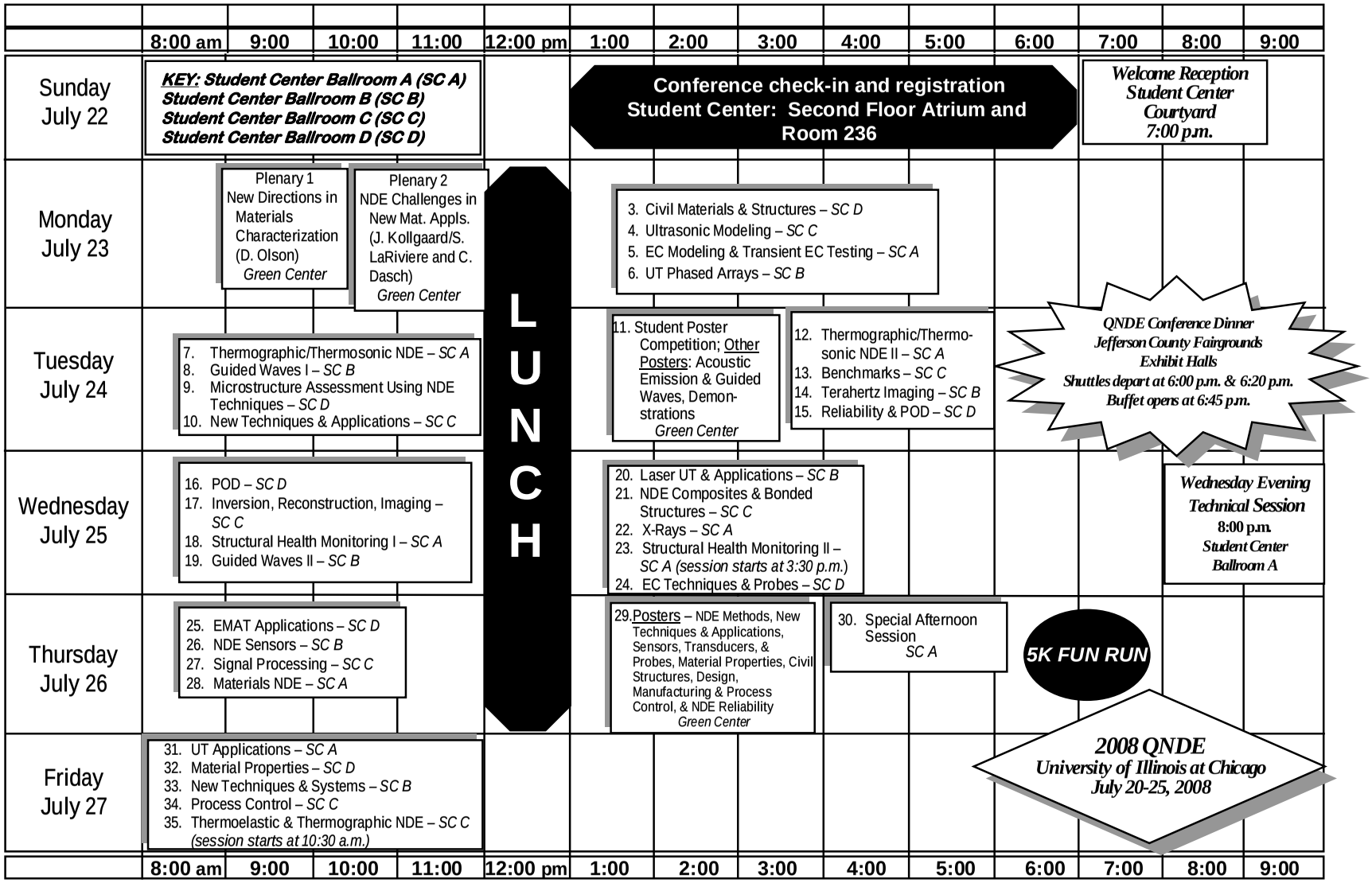
Industry/University Cooperative Research Centers

2007 Review of Progress in Quantitative NDE Program Summary



MONDAY

Plenary Sessions 1 and 2

REVIEW OF PROGRESS IN QUANTITATIVE NDE
Colorado School of Mines
Golden, Colorado

July 22 – July 27, 2007

PROGRAM

Monday, July 23, 2007

PLENARY SESSION 1
NEW DIRECTIONS IN MATERIALS CHARACTERIZATION
R. B. Thompson, Chairperson
Green Center

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

9:15 AM **Application of Interdisciplinary Fundamentals to Achieve New Insight Into Materials Properties, Stability, and Integrity**
---**D. L. Olson** and V. Kaydanov, Colorado School of Mines, Golden, CO 80401; A. Landau, Nuclear Research Center, Negev, Beer Sheva, 84109, Israel

10:10 AM ***Break***

PLENARY SESSION 2
NDE CHALLENGES IN NEW MATERIALS APPLICATIONS
D. E. Chimenti, Chairperson
Green Center

10:30 AM **NDE Challenges with Future Commercial Aircraft – A Boeing Perspective**
---**J. R. Kollgaard and S. G. LaRiviere**, The Boeing Company, P. O. Box 3707, Seattle, WA 98124-2207

11:20 AM **Automotive Lightweight Materials: The Roles of NDE in Bringing New Materials Into Production**
---**C. J. Dasch**, General Motors R&D Center, Materials and Processes Laboratory, MC 480-106-224, 30500 Mound Road, Warren, MI 48090

12:10 PM ***Lunch***

Please Note: The bolded authors throughout this program indicate the presenting author.

Application of Interdisciplinary Fundamentals to Achieve New Insight Into Materials Properties, Stability, and Integrity

---**David L. Olson** and Victor Kaydanov, Colorado School of Mines, Golden, CO 80401; Alex Landau, Nuclear Research Center, Negev, Beer Sheva, 84109, Israel

---Our understanding of condensed matter has reached new levels which allow the technical community to assess material integrity and behavior by measuring properties through sensitive electronic, magnetic, and elastic property measurements. Also, today's instrumentation offers new opportunities in achieving high accuracy measurements for correlations. Demanding integrity problems, such as material aging, higher-strength materials, and materials with complex engineered structures, require new solutions. These three events are making new opportunities in non-destructive evaluation possible. With the use of the proper combination of independent measurements, it is possible to accurately evaluate the microstructure and properties. The fundamental limitations of correlating microstructure and properties to these measurements result from both the numerous independent variables that each of these properties have and the number of intrinsic property measurements necessary to characterize the number of phases and the microstructural texture. Different electronic, magnetic, and elastic measurement combinations offer varied insights into material properties, and practices for their selection need to be developed for the appropriate applications. This advanced integration of physical phenomena measurements will result in new opportunities for the NDE community and the development of new analytical measurement equipment and practices. By developing advanced data acquisition and standards, for specific materials this knowledge can be apply to sense the early stages of microstructural evolution. These advances will give new opportunities to the non-destructive testing community including the development of new systems to assess in-situ by numerous property measuring tools.

NDE Challenges with Future Commercial Aircraft – A Boeing Perspective
---**Jeffrey R. Kollgaard** and **Stephen G. LaRiviere**, The Boeing Company, P. O. Box 3707, Seattle, WA 98124-2207

---Commercial aircraft has undergone revolutionary changes in design, configuration and materials. This produces new challenges to the NDE community ranging from process controls of raw materials to testing and fabrication of structural components to service damage assessments. As we drive NDE up the value stream, it will become imperative to understand various process parameters and their relationship to product quality. NDE may play a key role in assuring understanding of those parameters. In production, inspection has become a critical aspect in the processing of large, unitized structures. Penetrant, radiographic, and magnetic particle techniques are less applicable while ultrasonics has taken on a critical role, earlier in the build process. In many cases, NDE data is acquired over large areas far faster than previous thus challenging the time to conduct and document data analysis. Qualified inspectors, equipment and techniques are essential. In the field, eddy current and shear wave ultrasonic techniques, long a mainstay of aircraft maintenance, are beginning to yield to ultrasonic techniques involving C-scans and linear arrays. Emerging technologies will fide an application as needs arise. The building of new-generation airplanes has revealed shortcomings in existing NDE technology and in some cases enhanced the case for non-traditional methods. This paper will review Boeing's experience with NDE of advanced structures in the area of production and In-service and summarize the Boeing outlook for future NDE needs.

Automotive Lightweight Materials: The Roles of NDE in Bringing New Materials into Production

---**Cameron J. Dasch**, General Motors R&D Center, Materials and Processes Laboratory, MC 480-106-224, 30500 Mound Road, Warren, MI 48090

---The automotive industry is in the midst of a time of tremendous change. There is an almost perfect storm of changing governmental and market requirements seeking much higher fuel economy, low or no carbon dioxide emissions, and much higher crash and safety performance. Moreover, this occurs in a globe-spanning market that has more low-cost manufacturers than ever before. This confluence of factors leads to new vehicles with many new types of powertrains having unprecedented power densities and highly-engineered body structures with many new materials and joining methods. These are being turned out with shorter lead times, higher quality requirements, and continuous cost pressures. This talk will review the role in NDE in bringing new materials and processes to market, some of the applications in production, and to highlight some of the current NDE needs driven by these forces on the automotive industry.

Session 3

SESSION 3
CIVIL MATERIALS AND STRUCTURES
P. Cawley, Chairperson
Ballroom D

1:30 PM **A High Sensitivity Transformer Coupled System for the Detection and Imaging of Breaks in Prestressing Tendons in Concrete Pipes**
---**B. Fernandes**, G. Miller, M. Zaid, H. Hussin, F. El-Madaani, P. Gaydecki, and S. Quek, School of Electrical and Electronic Engineering, University of Manchester, P. O. Box 88, Manchester M60 1QD, United Kingdom

1:50 PM **Detection of Inclined Cracks Inside Concrete Structures by Ultrasonic SAFT**
---**Z. Hosseini**, M. Momayez, and F. Hassani, Sub-Surface Sensing Laboratory, Department of Mining, Metals and Materials Engineering, McGill University, Montreal, Quebec, Canada; D. Lévesque, Industrial Materials Institute, National Research Council Canada, Boucherville, Quebec, Canada

2:10 PM **Evaluating Rebar Corrosion Using Nonlinear Ultrasound**
---**C. Woodward** and M. N. Amin, New Mexico State University, Civil Engineering Department, Las Cruces, NM 88011

2:30 PM **New Developments in NDE Methods for Pavements**
---A. Gibson[1], N. Ryden[2], **J. S. Popovics**[3] and S. Alzate[3], [1]Geoforce Pty Ltd., 1/288 Victoria Road, Malaga, Western Australia, 6090; [2]Lund Institute of Technology, Lund University, Sweden; [3]The University of Illinois at Urbana-Champaign, Urbana, IL 61801

2:50 PM **Non-Contact Surface Wave Scanning of Pavements Using a Rolling Microphone Array**
---**N. Ryden**, Department of Engineering Geology, Lund Institute of Technology, Lund University, Box 118, S-221 00 Lund, Sweden; M. J. S. Lowe and P. Cawley, Department of Mechanical Engineering, Imperial College, London SW7 2AZ, United Kingdom

3:10 PM ***Break***

3:30 PM **Use of Larsen Effect to Study Slow Dynamics in Rocks and Cement**
---**O. I. Lobkis** and R. L. Weaver, University of Illinois, Department of Physics, Urbana, IL 61801

3:50 PM **Monitoring of the Stress-Free Temperature in Rails Using the Acoustoelastic Effect**
---S. Gokhale and **S. Hurlebaus**, Texas A&M University, Zachry Department of Civil Engineering, College Station, TX 77843-3136

4:10 PM **A Perturbation Approach to the Nonlinear Vibration of a Damaged Beam**
---**D. A. Mendelsohn** and S. Vedachalam, The Ohio State University, Department of Mechanical Engineering, 201 W. 19th Avenue, Columbus, OH 43210; C. Pecorari, Royal Institute of Technology, Department of Aeronautics and Vehicle Engineering, Stockholm, Sweden

4:30 PM **Application of Raman Spectroscopy for Nondestructive Evaluation of Composite Materials**
---**G. A. Washer** and T. M. B. Brooks, University of Missouri-Columbia, Columbia, MO 65211; R. Saulsberry, NASA, White Sands Test Facility

4:50 PM **Radio Frequency Scanning and Simulation of Oriented Strand Board Material Property**
---**X. Liu**, J. Zhang, and P. H. Steele, Department of Forest Products, Mississippi State University, Mississippi State, MS 39762; J. P. Donohoe, Department of Electrical & Computer Engineering, Mississippi State University, Mississippi State, MS 39762

A High Sensitivity Transformer Coupled System For The Detection And Imaging Of Breaks In Prestressing Tendons In Concrete Pipes

---**B. Fernandes**, G. Miller, M. Zaid, H. Hussin, F. El-Madaani, P. Gaydecki, and S. Quek, School of Electrical and Electronic Engineering, University of Manchester, P. O. Box 88, Manchester M60 1QD, United Kingdom

---A system has been developed, described here, which can detect and image localised faults and breaks in the pre-stressing tendons of large bore concrete pipes, intended for the transport of water. The system exploits the principle of magnetic field transformer coupling, in which a low frequency time varying field is transmitted over the region being inspected. Perturbations in the amplitude and phase of the signal that arise from variations in the coupling conditions are detected by a receiving system and fed to instrumentation for processing, image reconstruction and interpretation. The system has been field trialled in 4 m diameter pipes in the Sahara desert. Results confirm that it is capable of detecting and imaging as few as two adjacent tendon breaks, in which the diameter of the tendon was 7 mm and the pitch was 20 mm.

Detection Of Inclined Cracks Inside Concrete Structures By Ultrasonic SAFT

---**Zahra Hosseini**, Ferri Hassani, and Moe Momayez, Sub-Surface Sensing Laboratory, Department of Mining, Metals and Materials Engineering, McGill University, Montreal, Quebec, Canada; Daniel Lévesque, Industrial Materials Institute, National Research Council Canada, Boucherville, Quebec, Canada

---Concrete deteriorates over time due to environmental changes and/or poor construction processes which can eventually lead to partial or total failure of a structure. Deterioration in concrete manifests itself under different forms such as corrosion of embedded metals, freeze and thawing, chemical attack, alkali-aggregate reactivity, and surface and internal defects. Detection of internal defects is a difficult task as these anomalies are not always observable at the surface, yet have the potential to expand and damage the structure. The focus of this work is to locate and characterize inclined cracks inside a concrete mass which is essential in monitoring the integrity of many civil structures. For this purpose three concrete slabs were constructed each having a different sub-horizontal crack. To obtain high resolution images of the concrete interior, an extension of the ultrasonic nondestructive technique known as SAFT has been used. SAFT has shown great potential to produce detailed 3D images of tendon ducts, holes and flaws inside concrete structures. The results of this study show that cracks with angles varying from 5 to 15 degrees can be accurately located inside a concrete slab having a thickness of up to 20 cm.

Evaluating Rebar Corrosion Using Nonlinear Ultrasound

---**Clinton Woodward** and Md. Nurul Amin, New Mexico State University, Civil Engineering Dept., Las Cruces, NM 88011

---The early detection of rebar corrosion in reinforced concrete is difficult using current methods. This pilot study investigated the viability of using nonlinear ultrasound to detect rebar corrosion in its early stages. The study utilized three accelerated corrosion specimens and one control specimen. After each corrosion cycle, the specimens were evaluated using a Rayleigh wave. Results showed that when corrosion developed in the area isonified by the Rayleigh wave, nonlinear parameters increased. In this study, transducers were positioned so the direction of wave propagation was parallel to the rebar. Further studies are needed to examine the effects of wave propagation at various angles to the rebar.

New Developments In NDE Methods For Pavements

---Alexander Gibson[1], Nils Ryden[2], **John S. Popovics**[3]* and Sara Alzate[3], [1]Geoforce Pty Ltd., 1/288 Victoria Road, Malaga, Western Australia 6090; [2]Lund Institute of Technology, Lund University, Sweden; [3]The University of Illinois at Urbana-Champaign, Urbana, IL 61801

---Work on accurate in-place non-destructive concrete pavement thickness and material property characterization is described in this paper. Three newly developed techniques are applied and evaluated through field tests carried out on several different pavement types. The full-scale pavement sites vary in material type, thickness, inter-layer bond condition and underlying base material type. The following NDE methods are considered: multi-channel analysis of surface waves (MASW) with both contact and non-contact sensors, and a hybrid seismic/guided wave method. The evaluation of MASW data is based on a Lamb wave approach in frequency domain utilizing both propagating and non-propagating waves. In the hybrid seismic/guided wave method the velocity of guided waves are evaluated in time-domain and the thickness is estimated from the combined measured velocity and resonant frequency of the S1 Lamb wave. The technical bases, equipment, data interpretation and field testing procedure are described for each method. The results from the NDE methods are presented and compared to ground-truth values obtained core samples drawn from each testing locations. The performance and accuracy of the NDE methods are evaluated for each pavement type.

Non-Contact Surface Wave Scanning of Pavements Using a Rolling Microphone Array

---**Nils Ryden**, Department. of Engineering Geology, Lund Institute of Technology, Lund University, Box 118, S-221 00 Lund, Sweden; Michael J. S. Lowe and Peter Cawley, Department of Mechanical Engineering, Imperial College, London SW7 2AZ, United Kingdom

---Pavements are constructed using several layers of materials, and their durability depends mainly on the stiffness modulus of these strata. Surface wave testing is an effective tool to measure the stiffness and thickness of pavement layers. However, measurements are still based on spot testing with fixed receivers and source. These measurements are relatively time consuming and rely on good coupling between the receiver and the pavement surface. The typical large size of pavements and the cost of closing down roads to make stationary time consuming testing makes these measurements impractical. We present experiments where a multichannel array of microphones and an automatic source are attached on a small trolley so that measurements can be taken almost continuously while moving. Leaky air-coupled surface waves are measured and processed using the Multichannel Analysis of Surface Waves (MASW) technique. Results show that microphones can be successfully used to produce a phase velocity spectrum with correct dispersion curves even while moving along the surface. This opens up the possibility for faster on-the-fly surface wave testing of pavements since surface contact is no longer required. The paper will present some theoretical background along with experimental results of the application to non-destructive testing of pavements.

Use of Larsen Effect to Study Slow Dynamics in Rocks and Cement

---**Oleg I. Lobkis** and Richard L. Weaver, University of Illinois, Department of Physics, Urbana, IL 61801

---A simple feedback circuit with two ultrasonic transducers is applied to an elastic body. At sufficient gain, the circuit rings with a pure tone (Larsen effect). Theoretical analysis predicts that linewidth is proportional to the ratio between the spectral power density of the background noise and the intensity of ultrasound. In a high-Q elastic body this is of the order of micro-Hz at megahertz range of frequencies. The frequency of the tone depends on the nonlinear electronics, on characteristics of transducers, and also on the acoustic properties of the object. Because the spectrum of this tone is extraordinarily narrow and stable, it can be used for high precision measurements of miniature changes in elastic solids. The measurement is used here to monitor the evolution of the effective modulus of mesoscopically elastic bodies (cements and stones) after brief transient loads. In according with other investigations it is found that the modulus drops after the load, but then recovers in a characteristic manner, as the logarithm of time. The present technique can be used for higher frequencies (~500 KHz) and extends slow dynamics of such materials to early times of the order of milliseconds.

Monitoring Of The Stress Free Temperature In Rails Using The Acoustoelastic Effect

---Shailesh Gokhale and **Stefan Hurlebaus**, Texas A&M University, Zachry Department of Civil Engineering, College Station, TX 77843-3136

---Continuous welded rails (CWR) are typically long members which are susceptible to failure caused by temperature changes. Such rail temperature changes will, at best, cause considerable disruption to the network and, in the worst case cause catastrophic derailment of high speed trains. This research presents a technique to identify the residual stress and, hence, the stress free temperatures in rails using the acoustoelastic effect. First, a sensitivity analysis of the acoustoelastic effect of shear, longitudinal, Rayleigh and Lamb waves in rail steel is performed. Then, an analytical model is developed to predict the effect of residual stresses on the different wave speeds and polarization of Rayleigh waves. Furthermore, this analytical model predicts the dispersion curves for the symmetric and antisymmetric Lamb modes as a function of residual stress.

A Perturbation Approach to the Nonlinear Vibration of a Damaged Beam

---**Daniel A. Mendelsohn** and Sridhar Vedachalam, The Ohio State University, Department of Mechanical Engineering, 201 W. 19th Avenue, Columbus, OH 43210; Claudio Pecorari, Royal Institute of Technology, Department of Aeronautics and Vehicle Engineering, Stockholm, Sweden

---The nonlinear free vibration of a beam with a plane of damage represented by nonlinear shear and bending springs is considered. Spring laws that are initially linear and then soften, possibly reaching a peak followed by a negative stiffness regime are studied. Artificially generated spring laws and laws resulting from a damage plane consisting of an edge-crack with a softening cohesive zone are considered. The damage plane is loaded statically into the nonlinear region and small amplitude free vibrations about this load state are analyzed using Euler-Bernoulli beam theory. The solution is written as an asymptotic expansion in a small parameter depending on both the ratio of the zeroth and first order coefficients of the Taylor expansion of the nonlinear spring law about the static load state, and on the ratio of the small vibration amplitude to a characteristic dimension of the damage plane. The zeroth order problem leads to the linear eigenvalue problem corresponding to linear spring behavior along the local tangent of the nonlinear spring law. The first order problem yields the amplitude of the generated second harmonics. A least squares inverse method is presented for determining the parameters of a nonlinear spring law from the dynamic results.

Application of Raman Spectroscopy for Nondestructive Evaluation of Composite Materials

---**Glenn A. Washer** and Thomas M. B. Brooks, University of Missouri-Columbia, Columbia, MO 65211, Regor Saulsberry, NASA - White Sands Test Facility

---This paper will present an overview of efforts to investigate the application of Raman spectroscopy for the characterization of Kevlar materials. Raman spectroscopy is a laser technique that is sensitive to molecular interactions in materials such as Kevlar, graphite and carbon used in composite materials. The overall goal of this research reported here is to evaluate Raman spectroscopy as a potential nondestructive evaluation (NDE) tool for the detection of stress rupture in Kevlar composite over-wrapped pressure vessels (COPVs). Characterization of the Raman spectra of Kevlar yarn and strands will be presented and compared with analytical models provided in the literature. Results of testing to investigate the effects of creep and high-temperature aging on the Raman spectra will be presented.

Radio Frequency Scanning and Simulation of Oriented Strand Board Material Property

---**Xiaojian Liu**, Jilei Zhang, and Philip H. Steele, Dept. of Forest Products, Mississippi State Univ., Mississippi State, MS 39762; J. Patrick Donohoe, Dept. of Electrical & Computer Engineering, Mississippi State Univ., Mississippi State, MS 39762

---Oriented strandboard (OSB) is a wood composite product with the largest market share in U.S. residential and commercial construction. Wood specific gravity (SG) and moisture content (MC) play an important role in the OSB manufacturing process. They are the two of the critical variables that manufacturers are required to monitor, locate, and control in order to produce a product with consistent quality. In this study, radio frequency scanning nondestructive evaluation (NDE) technologies evaluated the local area MC and SG of OSB panels following panel production by hot pressing. A finite element software simulation tool was used to optimize the sensor geometry and for investigating the interaction between electromagnetic field and wood dielectric properties. Our results indicate the RF scanning response is closely correlated to the MC and SG variations in OSB panels. Radio frequency NDE appears to have potential as an effective method for insuring OSB panel quality during manufacturing.

Session 4

SESSION 4

ULTRASONIC MODELING (SCATTERING, PROPAGATION)

A. Lhemery, Chairperson

Ballroom C

1:30 PM **The Use of an Orthogonality Relation for Reducing the Size of Finite Element Models of 3D Guided Waves Scattering Problems**
---**L. Moreau** and M. Castaings, Universite Bordeaux 1 UMR CNRS 5469, Laboratoire de Mécanique Physique, 351, Cours de la Libération, 33405 Talence Cedex, France

1:50 PM **Interaction Between Acoustic and Elastic Waves in a 2D Fluid-Anisotropic Solid System**
---**S. Hirose** and K. Kimoto, Department of Mechanical and Environmental Engineering, Tokyo Institute of Technology, Tokyo 152-8552, Japan; C.-Y. Wang, Schlumberger K. K. Fuchinobe, Sagamihara 229-0006, Japan

2:10 PM **Excitation and Scattering of Guided Waves – Relationships Between Solutions for Plates and Pipes**
---**A. Velichko** and P. D. Wilcox, University of Bristol, Department of Mechanical Engineering, Bristol, United Kingdom

2:30 PM **Ultrasonic Guided Wave Propagation in Curved Plate-Like Structures**
---F. Yan and **J. L. Rose**, The Pennsylvania State University, Department of Engineering Science and Mechanics, University Park, PA 16802

2:50 PM **A Large Scale Analysis for Ultrasonic Wave Propagation Using Parallelized FDTD Method**
---**K. Nakahata** and J. Tokunaga, Ehime University, Department of Civil and Environmental Engineering, Matsuyama, Ehime, Japan; K. Kimoto and S. Hirose, Tokyo Institute of Technology, Department of Mechanical and Environmental Informatics, Meguro, Tokyo, Japan

3:10 PM ***Break***

3:30 PM **Effect of a Fluid Wedge on the Wave Propagation Along a Fluid-Solid Interface**
---C. M. Dao, S. Das, S. Banerjee, and **T. Kundu**, University of Arizona, Civil Engineering and Engineering Mechanics Department, Tucson, AZ 85721

3:50 PM **Crack Detection in Plates Using Coupled Rayleigh-Like Waves**
---**B. Masserey** and P. Fromme, University College London, Department of Mechanical Engineering, Torrington Place, London WC1E 7JE, United Kingdom

4:10 PM **Discrimination Between Surface-Breaking and Subsurface Cracks in Pressurized Water Pipes**
---**M. Poznic** and C. Pecorari, The Royal Institute of Technology, The Marcus Wallenberg Laboratory for Sound and Vibration Research, Stockholm, Sweden

4:30 PM **Simulation of Disoriented Flaws Inspected Using TOFD Configuration Using GTD Approach**
---M. Darmon, S. Chatillon, and **S. Mahaut**, CEA LIST, CEA Saclay, 91191 Gif-sur-Yvette, Cedex, France; L. Fradkin and A. Gautesen, London South Bank University, Waves and Fields Research Group, London, SE10AA, United Kingdom; A. Gautesen, Iowa State University, Mathematics Department, Ames, IA 50011

4:50 PM **Modeling of Lamb Waves for Damage Detection and Temperature Dependence**
---**P. Haldipur**, J. E. Michaels, and T. E. Michaels, Georgia Institute of Technology, School of Electrical and Computer Engineering, Atlanta, GA 30332

The Use of an Orthogonality Relation for Reducing the Size of Finite Element Models of 3D Guided Waves Scattering Problems

---**L. Moreau** and M. Castaings, Universite Bordeaux 1 UMR CNRS 5469, Laboratoire de Mécanique Physique, 351, Cours de la Libération, 33405 Talence Cedex, France

---The scattering of guided waves by complex shaped defects in three-dimensional (3D) waveguides is considered. For such problems, analytical solutions do not exist, and modal decomposition techniques based on the establishment of the displacement and stress fields in the vicinity of the scatterer are extremely heavy and complicated. On the other hand, Finite Elements based methods are known to be very memory consuming. This paper proposes a post-processing technique, based on a 3D orthogonality relation, to decompose a complex acoustic field produced by a scatterer and predicted by a 3D Finite Element model, into plane waves, the amplitudes of which are quantified. This technique allows huge reductions of the Finite Element model size to be obtained. Applications of guided waves scattering in an Aluminum plate are presented, where zero and first order Lamb and SH modes compose the scattered field. In order to demonstrate the potential of this method, defects having simple circular or complex geometry are investigated.

Interaction Between Acoustic and Elastic Waves in a 2D Fluid-Anisotropic Solid System

---**S. Hirose** and K. Kimoto, Department of Mechanical and Environmental Engineering, Tokyo Institute of Technology, Tokyo 152-8552 Japan; C.-Y. Wang, Schlumberger K.K., Fuchinobe, Sagamihara 229-0006, Japan

---The interaction between acoustic and elastic waves is investigated for a two dimensional model of a fluid region sandwiched by half space domains of anisotropic elastic solids. A time domain boundary element method is developed to analyze the interaction problem numerically. Both monopole and dipole point sources are used to generate an initial pressure wave in fluid. Some snapshots of the transient wave behavior near the fluid-solid interface are shown for different anisotropic constants in the solid. The effect of the anisotropic constants on pressure waveforms in the fluid is discussed by investigating the dispersive property of guided waves propagating in the fluid-anisotropic solid system. The numerical analysis gives basic information on material evaluation of anisotropic ground or rock by means of sonic measurement.

Excitation and Scattering of Guided Waves - Relationships Between Solutions For Plates and Pipes

---**Alexander Velichko** and Paul D. Wilcox, University of Bristol, Department of Mechanical Engineering, Bristol, United Kingdom

---The majority of guided wave modeling in pipes is based on the normal mode expansion method. This technique gives the amplitude coefficients for the propagating modes and in general can be performed only by numerical calculations. However, in many important industrial applications the diameter of a pipe is much more than wall thickness. In this case the approximate theory is applicable, when a pipe is considered as an unwrapped isotropic plate and the transducer is replaced by a periodic array of transducers with inter-element distance equal to the pipe circumference. In this paper, a technique for obtaining pipe mode amplitudes in terms of the solution to the forced 3D problem on a plate is presented. The relationship between circumferential mode amplitudes in a pipe and directivity function of a transducer on a plate is obtained. The approximate solution is compared with the exact solution for a hollow cylinder and the applicability range of an approximation is discussed. The same principle can be extended to relate guided wave scattering from defects in plates to scattered circumferential modal amplitudes from defects in pipe. Results are shown that illustrate the application of the method to reflection from through thickness circumferential cracks in pipes.

Ultrasonic Guided Wave Propagation In Curved Plate-Like Structures

---Fei Yan and **Joseph L. Rose**, The Pennsylvania State University, Department of Engineering Science and Mechanics, University Park, PA 16802

---Ultrasonic guided waves have been proven as a promising tool in nondestructive evaluation (NDE) and structural health monitoring (SHM), especially for plates and plate-like structures. However, many plate-like structures which are subject to NDE and SHM are curved. The curvature plays an important role in guided wave propagation. The objective of the work presented in this paper is to investigate the influence of curvature on guided wave propagation. A semi-analytical finite element (SAFE) technique is employed to analyze the dispersion curves for both isotropic and anisotropic multi-layer composite plate-like structures with different curvatures. The changing of the wave structures with curvature is investigated as well. Based on the wave mechanics study, a guided wave inspection strategy for the NDE and SHM for curved plate-like structures is proposed.

A Large Scale Analysis for Ultrasonic Wave Propagation Using Parallelized FDTD Method
---**Kazuyuki Nakahata** and Jyunichi Tokunaga, Ehime University, Department of Civil and Environmental Engineering, Matsuyama, Ehime, Japan; Kazushi Kimoto and Sohichi Hirose, Tokyo Institute of Technology, Department of Mechanical and Environmental Informatics, Meguro, Tokyo, Japan

---It is useful to calculate ultrasonic wave propagation and scattering process explicitly in time domain. The finite difference time domain (FDTD) method is based on a grid-based time domain differential technique, in which wave equations are solved in a leapfrog manner. It is required to discretize a whole target domain into computational grids of adequate size. Therefore the computational burden increases in case of large field problems or high frequency range. To address this problem, we show a parallel computing of the FDTD method using the OpenMP. The OpenMP is an interface for parallelizing programs in a shared memory environment. In this study, FDTD analyses of large-scale 2-D elastodynamic problems and some applications of FDTD to ultrasonic testing such as beam propagations by a phased array transducer are demonstrated.

Effect of a Fluid Wedge on the Wave Propagation Along a Fluid-Solid Interface
---Cac Minh Dao, Samik Das, Sourav Banerjee, and **Tribikram Kundu**, University of Arizona, Civil Engineering and Engineering Mechanics Department, Tucson, AZ 85721

---Semi-analytical technique called Distributed Point Source Method (DPSM) is adopted for modeling ultrasonic field in a wedge shaped fluid structure on a solid half space. This study is important for analyzing ultrasonic waves used for underwater communications and inspections. Better understanding of the elastic wave propagation in water and in submerged marine strata near the sea shore requires extensive investigations of such problem geometries. The semi-analytical technique developed here considers a bounded acoustic beam striking a fluid-solid interface near a fluid wedge meeting a solid half-space. Solution of this problem is beyond the scope of the currently available analytical methods. However, it is important to consider the effect of bounded beams because in all underwater communications and inspections bounded beams are used. Currently only numerical method (Boundary Element Method or Finite Element Method) based packages (e.g. PZFlex) are in principle capable of modeling ultrasonic fields in such structures. However, these packages are very CPU intensive; those require huge amount of computation memory and time for their executions that DPSM technique can avoid. Effect of the angle variation between the fluid-solid interface and the free fluid surface on the wave propagation characteristics is studied and presented in this paper.

Crack Detection in Plates Using Coupled Rayleigh-Like Waves

---**B. Masserey** and P. Fromme, University College London, Department of Mechanical Engineering, Torrington Place, London WC1E 7JE, United Kingdom

---The use of coupled Rayleigh-like waves in aluminum plates with a view towards applications for the non-destructive inspection of aircraft has been investigated experimentally and theoretically. Such waves are generated using standard Rayleigh wave transducers at frequencies, so that the Rayleigh wavelength corresponds to approximately half the plate thickness. In that frequency-thickness range the Rayleigh-like wave, which can be interpreted as the superposition of the fundamental Lamb modes A0 and S0, transfers energy between both surfaces with a characteristic distance called the beatlength. A simple analytical model and Finite Difference (FD) calculations are used to describe the reflection of the Rayleigh-like wave at small surface defects. In the experiments the reflected wave is recorded using either standard pulse-echo or laser measurements. Excellent sensitivity for the detection of small defects on both surfaces has been found. The spectrum of the reflected Rayleigh-like wave shows frequencies, for which the wave propagates through the defect region without perturbation. This phenomenon is used for the remote detection of defects in areas, where access is restricted by surface features. By selecting appropriate excitation frequency and position, a significant part of the energy can be transmitted behind the obstacle and reflected at the defect, allowing detection.

Discrimination Between Surface-Breaking And Subsurface Cracks In Pressurized Water Pipes

---**Milan Poznic** and Claudio Pecorari, The Royal Institute of Technology, The Marcus Wallenberg Laboratory for Sound and Vibration Research, Stockholm, Sweden

---The discrimination of surface-breaking from subsurface cracks in pipes carrying pressurized water is paramount because the growth rate of the former is substantially higher than that of the latter. The difference between growth rates is due corrosion caused by water penetrating a surface-breaking crack. Here, we present some result of an ongoing investigation which examines the effect of water trapped within a surface-breaking crack on the scattering properties of the defect. One-dimensional, surface-breaking, fatigue cracks of different depth are modulated by a continuous, low frequency vibration while a SV wave at 45 degree incidence monitors their scattering properties. In qualitative agreement with the predictions of an earlier theoretical model, the amplitude of the signal backscattered by a water-confining, surface-breaking crack is observed to be much more sensitive to the modulation than that backscattered by the same crack when it is dry. However, aspects which are not predicted by the model, which accounts for only the water-induced increase of the crack's static stiffness, are also observed. In particular, evidence that dynamic effects linked to the modulation play a relevant role is also presented.

Simulation of Disoriented Flaws Inspected Using TOFD Configuration Using GTD Approach

---M. Darmon, S. Chatillon, and **S. Mahaut**, CEA LIST, CEA Saclay, 91191 Gif-sur-Yvette Cedex, France; L. Fradkin and A. Gautesen, London South Bank University, Waves and Fields Research Group, London, SE10AA, United Kingdom; A. Gautesen, Iowa State University, Mathematics Department, Ames, IA 50011-2064

---The TOFD Technique is commonly used to detect and to characterize embedded disoriented flaws using their edge diffraction echoes. Simulation can be very helpful in improving methods of inspection and analysis of significant defect parameters (tilt, disorientation, skew). Such features have to be available for simple planar (rectangular) or complex (for instance, CAD) planar flaws, while the specimen itself may be of complex shape. We present a TOFD simulation module which includes GTD coefficients allowing predicting diffraction echoes from embedded planar flaws. Some of those developments have been carried out in collaboration with Larissa Fradkin's group at London South Bank University. Besides diffraction echoes, other dedicated development have been added in the CIVA software platform, in order to simulate lateral surface waves and backwall echoes and take into account shadowing effects from flaws. Experimental validations have been performed on various specimen containing rectangular and CAD contour planar flaws with different possible disorientations (tilt, skew, vertical disorientation). Simulation results have been compared to experimental results and show an overall good agreement.

Modeling of Lamb Waves for Damage Detection and Temperature Dependence

---**Pranaam Haldipur**, Jennifer E. Michaels, and Thomas E. Michaels, Georgia Institute of Technology, School of Electrical and Computer Engineering, Atlanta, GA 30332

---Structural health monitoring using ultrasonic guided waves is being investigated for aerospace structures to reduce the need for inspection and maintenance without compromising safety. This study investigates the propagation of Lamb waves in plate-like structures representative of wing skins, and considers their interaction with artificial defects in combination with temperature changes. Even small changes in temperature bring about significant time-dependent time shifts in the Lamb waves due to the resulting thickness, stiffness and density changes. Wave propagation in the structural component under consideration, a finite aluminum plate, is analyzed via a finite element method (FEM). Simulations are carried out using a commercial FEM package based on explicit dynamic analysis, and the maximum propagation time considered is sufficient to include some of the edge reflections. The time history of the waves received at a series of equally spaced positions provides insight on the interaction of multiple Lamb wave modes with hole and notch type defects and the effect of temperature. The type and magnitude of the signal changes due to defects and temperature, both singly and in combination, are examined, and the effect of temperature on detection of damage is analyzed.

Session 5

SESSION 5

EDDY CURRENT MODELING AND TRANSIENT EDDY CURRENT TESTING

J. Bowler, Chairperson
Ballroom A

1:30 PM **Residual Stress Profiling in DP718 Ni-Base Superalloy Using Eddy Current Measurements**
---**W. Hassan** and D. Ryan, Honeywell Aerospace, 111 S. 34th Street, MS 503-118, Phoenix, AZ 85034

1:50 PM **Residual Stress Measurement Using Rectangular Spiral Coils**
---**H. Sun** and Y. Plotnikov, GE Global Research Center, Niskayuna, NY 12309

2:10 PM **Eddy Current Inspection of Composite Overwrap Pressure Vessels**
---**P. Williams** and B. Wincheski, NASA Langley Research Center, Hampton, VA 23681-0001; J. Simpson, Lockheed Martin

2:30 PM **Analysis of Eddy Current Capabilities for the Detection of Outer Diameter Stress Corrosion Cracking in Small Bore Metallic Structures**
---**B. Wincheski** and P. Williams, NASA Langley Research Center, Hampton, VA 23681; J. Simpson, Lockheed Martin

2:50 PM **Eddy Current Inspection of Components with Complex Geometries**
---**Y. Plotnikov**[1], C. Wang[1], W. S. McKnight[2], and U. Suh[2], [1]GE Global Research Center, Nondestructive Technologies Laboratory, 1 Research Circle, Niskayuna, NY 12309; [2]GE Aviation M&STD, 10270 St. Rita Lane, Cincinnati, OH 45215

3:10 PM ***Break***

3:30 PM **Evaluation of Eddy Currents in Cylindrical Structures Containing Cracks**
---**J. R. Bowler**[1] and T. Theodoulidis[2], [1]Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011; [2]West Macedonia University, Kozani, Greece

3:50 PM **The Feasibility of Eddy Current Conductivity Spectroscopy for Near-Surface Cold Work Profiling in Titanium Alloys**
---**B. A. Abu-Nabah** and P. B. Nagy, Department of Aerospace Engineering, University of Cincinnati, Cincinnati, OH 45221-0070

4:10 PM **Recent Improvements in High-Frequency Eddy Current Conductivity Spectroscopy**
---**B. A. Abu-Nabah** and P. B. Nagy, Department of Aerospace Engineering, University of Cincinnati, Cincinnati, OH 45221-0070

4:30 PM **Rotating Permanent Magnet Induced Eddy Currents for Pipeline Inspection**
---**J. B. Nestleroth** and R. J. Davis, Battelle, 505 King Avenue, Columbus, OH 43201

4:50 PM **Advances in Swept High Frequency Eddy Current Residual Stress Characterization**
---**Y. Shen**, A. M. Frishman, S. J. Lee, C. C. H. Lo, and N. Nakagawa, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

Residual Stress Profiling in DP718 Ni-Base Super Alloy Using Eddy Current Measurements

---**Waled Hassan** and Daniel Ryan, Honeywell Aerospace, 111 S. 34th Street, Mail Stop 503-118, Phoenix, AZ 85034

---Near surface residual stresses directly influence the fatigue life of critical engine rotating components. Depending on sign and magnitude a near surface residual stress gradient can either inhibit or accelerate fatigue initiation and crack propagation. Shot peening is a common surface treatment that can enhance machining residual stresses by increasing the magnitude and depth of compression. Shot peening is intended to create a uniform, consistent, and reliable sub-surface compressive residual stress layer. Recently, it has been demonstrated that, in contrast with most other materials, shot-peened nickel-base super alloys exhibit an apparent increase in eddy current conductivity at increasing inspection frequencies, which can be exploited for nondestructive residual stress assessment of subsurface residual stresses. Honeywell Aerospace is particularly interested in DP718 Ni-base superalloy as it is the main Ni alloy used in the manufacturing of critical rotating components in its engines. We will present the results of the process used to build sets of flat and curved samples with graduated residual stress profiles. The process, which utilizes design of experiment (DOE) approach, targets producing samples with four different stress profiles namely, as shot peened, 25% reduction in peak stress from the as shot peened case, 50% reduction in peak stress from the as shot peened case, and finally 75% reduction in peak stress from the as shot peened case. Thermal relaxation of the stress profiles is used to achieve these different levels. The model that relates the temperature and time parameters to the peak compressive stress level will also be presented and discussed. X-ray diffraction measurements will be used to quantify the generated profiles and the results will be compared to the residual stress profiles obtained using eddy current measurements at high frequencies (up to 80 MHz).

Residual Stress Measurement Using Rectangular Spiral Coils

---**Haiyan Sun** and Yuri Plotnikov, GE Global Research Center, Niskayuna, NY 12309

---Shot peening process provides compressive residual stress within a depth of about 150~200um from the surface. It has been demonstrated that multi-frequency eddy current measurement can be effectively used for the residual stress estimation on Ni-based superalloys. In order to measure the stress profile over the entire compressive zone, the probe needs to work in a wide frequency range from 0.1MHz to above 50MHz. Due to its wide bandwidth and highly repeatable fabrication process, spiral coils fabricated on flexible substrate using photolithographic technology are good candidate for this task. It is useful to develop a coil model in order to optimize coil design, minimize liftoff effect and maximize coil gauge factor. In this work, a 3D analytical model was used to simulate rectangular spiral coil response on a half-space conductor. The results were compared with commercial available 3D finite element software and experimental results. The analytical model was also used to simulate 4-point calibration process that was used to calculate apparent eddy current conductivity (AECC). The experimental setup was described and AECC profile was obtained for shot-peening samples with different peening intensity and different heat treatment.

Eddy Current Inspection of Composite Overwrap Pressure Vessels

---**Phillip Williams** and Buzz Wincheski, NASA Langley Research Center, Hampton, VA 23681-0001; John Simpson, Lockheed Martin

---Aging composite overwrapped pressure vessels (COPVs) have been a recent focus of comprehensive evaluation to provide a better quantification of their reliability and likelihood of failure. As part of this evaluation effort, eddy current sensors have been employed to measure through-the-thickness strains in both the composite overwrap and the metallic liner during pressurization of the vessel. Parametric studies of the probe response have been performed using computer modeling and simulation techniques. Finite and boundary element methods were used to investigate the probe response to factors including conductivity, permeability, and layer thicknesses. Validation of the numerical data with simple test cases has been done as a basis to analyze potential measurement errors due to effects such as strain dependent permeability. Based on these results, the probe was optimized for the sensitivity to thickness change as well as for the ability to measure independently the liner and the overwrap effects. This work has advanced the deployment of a COPV eddy current inspection system and has enabled thickness measurements of less than 12μm in both the liner and the overwrap at overwrap thicknesses greater than 20 mm.

Analysis of Eddy Current Capabilities for the Detection of Outer Diameter Stress Corrosion Cracking in Small Bore Metallic Structures

---**Buzz Wincheski** and Phillip Williams, NASA Langley Research Center, Hampton, VA 23681; John Simpson, Lockheed Martin

---The use of eddy current techniques for the detection of outer diameter damage in tubing and many complex aerospace structures often requires the use of an inner diameter probe due to a lack of access to the outside of the part. In small bore structures the probe size and orientation are constrained by the inner diameter of the part, complicating the optimization of the inspection technique. Detection of flaws through a significant remaining wall thickness becomes limited not only by the standard depth of penetration, but also geometrical aspects of the probe. Recently, an orthogonal eddy current probe was developed for detection of such flaws in Space Shuttle Primary Reaction Control System (PRCS) Thrusters. In this case, the detection of deeply buried stress corrosion cracking by an inner diameter eddy current probe was sought. Probe optimization was performed based upon the limiting spatial dimensions, flaw orientation, and required detection sensitivity. Analysis of the probe/flaw interaction was performed through the use of finite and boundary element modeling techniques. Experimental data for the flaw detection capabilities, including a probability of detection study, will be presented along with the simulation data. The results of this work have led to the successful deployment of an inspection system for the detection of stress corrosion cracking in Space Shuttle Primary Reaction Control System (PRCS) Thrusters.

Eddy Current Inspection of Components with Complex Geometries

---**Yuri Plotnikov**[1], Changting Wang[1], William S. McKnight[2], and Ui Suh[2], [1]GE Global Research Center, Nondestructive Technologies Laboratory, 1 Research Circle, Niskayuna, NY 12309; [2]GE Aviation M&STD, 10270 St. Rita Lane, Cincinnati, OH 45215

---Eddy current (EC) technique is a common inspection method for the detection of open surface cracks and subsurface anomalies. While manual EC inspection is quite reliable on parts with flat (or large curvature) surfaces and parts with consistent subsurface geometry, EC inspection of parts having more complicated surface and subsurface profiles has to rely on automated scan/data collection and post-processing. Examples of the structures with complex geometries are aircraft engine rotating parts and multi-layer aircraft structures (lap joints). Data collection for such structures in most cases can be performed by using a single sensor EC probe with multi-frequency excitation. To improve productivity of the inspection, arrays of EC sensors are applied during inspection for surface flaws. In this work, the flexible ECAP (EC array probe) with sensitivity to the cracks of variable orientations is presented. To resolve the complex subsurface geometry of the aircraft skin, pulsed excitation is employed. This makes for a faster data collection and full post-processing capabilities. Conversion to multi-frequency (multi-layer) image analysis is done when data collection is completed. The subsurface flaws present in a particular layer of a riveted lap joint become evident from several EC images, which cannot be accomplished by manual inspection.

Evaluation of Eddy Currents in Cylindrical Structures Containing Cracks

---**John R. Bowler**[1] and Theodoreos Theodoulidis[2], [1]Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011; [2]West Macedonia University, Kozani, Greece

---The impedance variation of coils in bore holes and tubes containing cracks have been calculated. The approach uses a scalar decomposition of the field into transverse electric and transverse magnetic potentials defined with respect to the axial direction of the structure. The effect of a crack is represented by a current dipole layer orientated normal to the crack surface. An integral equation determines the dipole density on the crack using a kernel that is constructed from the transverse electric and transverse magnetic components of the dipole field. A solution is found using numerical methods. The probe impedance variation is computed for both closed ideal cracks and open cracks/slots.---This material is based upon work supported by the Air Force Research laboratory under Contract #FA8650-04-C-5228 at Iowa State University's Center for NDE.

The Feasibility of Eddy Current Conductivity Spectroscopy for Near-Surface Cold Work Profiling in Titanium Alloys

---**Bassam A. Abu-Nabah** and Peter B. Nagy, Department of Aerospace Engineering, University of Cincinnati, Cincinnati, OH 45221-0070

---The NDE community has been investigating the feasibility of numerous nondestructive inspection methods for residual stress profiling in surface-treated nickel-base superalloys for a couple of years. Because of direct exposure to erosion and foreign body impact damage, nondestructive characterization of low-temperature inlet fan and compressor blades, which are usually made of titanium alloys, is even more important than that of high-temperature turbine components downstream, which are usually made of nickel-base superalloys. One of the main reasons why titanium alloys were originally thought to be less promising candidates for eddy current inspection is that they crystallize preferentially in hexagonal symmetry, therefore exhibit significant texture-induced electric anisotropy on the order of 3-4% relative conductivity variation. On the other hand, although crystallographic anisotropy does not affect the electric conductivity of cubic materials, such as nickel-base superalloys, as-forged Waspaloy and IN718 components were found to exhibit as much as 4-6% relative conductivity variation caused my microstructural inhomogeneities. It has been shown that self-referencing can very effectively eliminate such essentially frequency-independent apparent eddy current conductivity (AECC) variations so that they do not interfere significantly with near-surface residual stress assessment. On the other hand, it has been illustrated recently by means of measuring the electroelastic coefficient that isotropic plane stress produces negligible electric conductivity variation in titanium alloys, which makes eddy current inspection techniques more suitable for cold work characterization. In this presentation we will report the first step in this direction by investigating the feasibility of eddy current conductivity spectroscopy for near-surface cold work profiling in shot-peened titanium alloys.

Recent Improvements in High-Frequency Eddy Current Conductivity Spectroscopy

---**Bassam A. Abu-Nabah** and Peter B. Nagy, Department of Aerospace Engineering, University of Cincinnati, Cincinnati, OH 45221-0070

---Eddy current measurements exploit the so-called piezoresistivity effect, i.e., the stress-dependence of electric conductivity, to map near-surface residual stress profiles in surface-treated components. To capture the peak compressive residual stress in moderately shot-peened (Almen 4-8A) nickel-base superalloys, the eddy current inspection frequency has to be as high as 50-80 MHz. Recently, we have reported the development of a new high-frequency eddy current conductivity measuring system that offers an extended inspection frequency range up to 80 MHz. Unfortunately, spurious self- and stray-capacitance effects render the complex coil impedance variation with lift-off more nonlinear as the frequency increases, which makes it difficult to achieve accurate apparent eddy current conductivity (AECC) measurements with the standard four-point linear interpolation method beyond 25 MHz. A simple model is proposed to illustrate the capacitive effect of lift-off variations on high-frequency AECC measurements. We will demonstrate that reducing the coil size reduces its sensitivity to capacitive lift-off variations, which is just the opposite of the better known inductive lift-off effect. In addition, we will demonstrate that quadratic interpolation during instrument calibration further minimizes the sensitivity of AECC measurements to lift-off uncertainties. These modifications allow us to do much more robust measurements up to as high as 80-100 MHz with the required high relative accuracy of 0.1%.

Rotating Permanent Magnet Induced Eddy Currents for Pipeline Inspection

---**J. Bruce Nestleroth** and Richard J. Davis, Battelle, 505 King Ave, Columbus, OH 43201

---This paper will present an eddy current inspection method that enables the internal inspection of pipelines that currently cannot be examined using established methods such as magnetic flux leakage and ultrasonics. Specifically, the method induces electrical current in the pipe wall by rotating pairs of high-strength permanent magnets around a shaft. Recent advances in high-strength permanent magnet technology have made the concept practical. This method is capable of overcoming many of the barriers that prevent the use of current inspection tools on many pipelines. This paper will review the theory of operation of the method and present detection and sizing data from corrosion defects. Fundamental finite element modeling analysis and experimental investigations performed during this development have led to the derivation of a first-order analytical equation for designing rotating exciters and positioning sensors. The rotating permanent magnet system has the potential for broader application because the sensor configurations can be small in physical size, allowing them to pass obstructions that currently prevent inspection using available NDE implementations.

Advances in Swept High Frequency Eddy Current Residual Stress Characterization

---**Y. Shen**, A. M. Frishman, S. J. Lee, C. C. H. Lo, and N. Nakagawa, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---We report on recent progress of a swept high frequency eddy current (SHFEC) technique for nondestructive characterization of residual stresses in engine materials with specific applications to shot-peened superalloy components. The technique determines conductivity depth profiles by model-based inversion of SHFEC data, and converts them into residual stress profiles using a material-based model which generally includes the piezoresistivity (PR) and possibly other non-PR effects. Improvements in detection coil and upgrades to the measurement system have extended the effective frequency upper bound to 70 MHz. A faster forward model that treats the peening-induced conductivity deviations as small perturbation has been derived to replace the analytical Cheng-Dodd-Deeds, and is shown to reduce the computation time of SHFEC data inversion significantly without sacrificing the accuracy. A modified piezo-resistivity theory, including the effect of texture on stress-induced conductivity changes, was developed in light of the experimental evidences of shot-induced changes of texture in peened Inconel 718 samples. The theory was applied to convert the conductivity profile to a residual stress depth profile, which agrees with the data taken by the standard layer removal XRD method.---This material is based upon work supported by the Air Force Research Laboratory under contract # FA8650-04-C-5228 at Iowa State University Center for NDE.

Session 6

SESSION 6
UT PHASED ARRAYS
R. C. Addison, Jr., Chairperson
Ballroom B

1:30 PM **Model Based Reconstruction of UT Array Data**
---**P. Calmon**, E. Lakovleva, A. Fidahoussen, and S. Chatillon, Commissariat à l'Energie Atomique, CEA LIST, Saclay, France

1:50 PM **Comparative Study on Ultrasonic Imaging Methods with Array Transducers**
---**C. Matsuoka** and K. Nakahata, Ehime University, Department of Civil and Environmental Engineering, Matsuyama, Ehime, Japan; A. Baba and N. Kono, Hitachi, Ltd., Power and Industrial Systems R&D Laboratory, Hitachi, Ibaraki, Japan; S. Hirose, Tokyo Institute of Technology, Department of Mechanical and Environmental Informatics, Meguro, Tokyo, Japan

2:10 PM **Methods for Characterizing the System Functions of Ultrasonic Linear Phased Array Inspection Systems**
---**R. Huang**[1] and L. W. Schmerr, Jr.[2], [1,2]Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011; [2]Department of Aerospace Engineering

2:30 PM **Wave Equation Based 3D Imaging of Ultrasonic Data Theory and Practice**
---**N. Pörtzgen**, Applus-RTD, Non-Destructive Testing and Inspection – Technological Centre, Rotterdam, Zuid-Holland, The Netherlands; R. Baardman, E. Verschuur, and D. Gisolf, Delft University of Technology, Acoustical Imaging and Sound Control, Delft, Zuid-Holland, The Netherlands

2:50 PM **Predicting Spot Weld Button Area Using an Ultrasonic Phased Array**
---**W. D. Davis** and D. L. Hopkins, Lawrence Berkeley Laboratory, MS 46A-1123B, One Cyclotron Road, Berkeley, CA 94720

3:10 PM ***Break***

3:30 PM **A Post-Processing Technique for Guided Wave Array Data for the Inspection of Plate Structures**
---**A. Velichko** and P. D. Wilcox, University of Bristol, Department of Mechanical Engineering, Bristol, United Kingdom

3:50 PM **Development of Phased Array Probes for Austenitic Weld Inspections Using Multi-Gaussian Beam Modeling Simulation**
---**N. Kono** and A. Baba, Power and Industrial Systems R&D Laboratory, Hitachi, Ltd., 7-2-1 Omika-cho, Hitachi-shi, Ibaraki-ien, 319-1221, Japan

4:10 PM **Further Development of a Conformable Phased Array Device for the Inspection of Irregular Surfaces**
---**R. Long** and P. Cawley, Imperial College London, Mechanical Engineering, London, United Kingdom

4:30 PM **Phased Array Method for the Inspection of French Rails Repairs**
---**P. Bredif** and C. Poidevin, CEA/LIST, France; J. Plu and P. Pouligny, SNCF, France

4:50 PM **Improvement of Subharmonic Phased Array for Crack Evaluation (SPACE) and its Practical Applications**
---**Y. Ohara**, S. Yamamoto, T. Mihara, and K. Yamanaka, Tohoku University, Department of Materials Processing, Sendai City, Miyagi, Japan

5:10 PM **Application of Optimized Transducer Design Tools to Two-Dimensional**
---**V. Lupien**, 27 Eaton Street, Wakefield, MA 01880

Model Based Reconstruction of UT Array Data

---**Pierre Calmon**, Ekaterina Lakovleva, Alex Fidahoussen, and Sylvain Chatillon, Commissariat à l'Energie Atomique, CEA LIST, Saclay, France

---Beyond the detection of defects, their characterization (identification, positioning, sizing) is one goal of great importance often assigned to the analysis of NDT data. The first step of such analysis in the case of ultrasonic testing amounts to image in the part the detected echoes. This operation is in general achieved by considering time of flights and by applying simplified algorithms which are often valid only on canonical situations. In this communication we present an overview of different imaging techniques studied at CEA LIST and based on the exploitation of direct models which enable to address complex configurations and are available in the CIVA software plat-form. The different adopted approaches are quite dependent on the operating mode of the array at which correspond different types of data. Thus, besides the usual application of electronic delays at emission and reception, more complete operating mode involving independent storage of the signals received by the elements are more and more encountered in NDT applications. We will discuss in particular ray-model based algorithms, algorithms derived from classical synthetic focusing and processing of the full inter-element matrix (algorithm MUSIC).

Comparative Study on Ultrasonic Imaging Methods With Array Transducers

---**Chihiro Matsuoka** and Kazuyuki Nakahata, Ehime University, Dept. of Civil and Environmental Engineering, Matsuyama, Ehime, Japan; Atsushi Baba and Naoyuki Kono, Hitachi, Ltd., Power and Industrial Systems R&D Laboratory, Hitachi, Ibaraki, Japan; Sohichi Hirose, Tokyo Institute of Technology, Dept. of Mechanical and Environmental Informatics, Meguro, Tokyo, Japan

---Ultrasonic phased array transducers have the advantage of receiving flaw echoes simultaneously at various piezoelectric elements. In current phased array UT, the B-scan method based on flight time and amplitude of echoes is widely used for flaw imaging. However the flaw imaging with much higher resolution and sensitivity is possible if flaw echoes measured at many receivers are coherently superposed. In this study, comparative studies on some ultrasonic imaging methods with array transducers are shown. We focus on two types of imaging methods; one is the superposition method of sectorial scanning images using time domain flaw signals, and the other is inverse scattering imaging methods based on the frequency domain approach. Here the flaw imaging methods are applied to both waveforms calculated by numerical simulations and experimentally measured waveforms. By comparing these imaging results, performance and accuracy of flaw imaging methods are discussed.

Methods for Characterizing the System Functions of Ultrasonic Linear Phased Array Inspection Systems

---Ruiju Huang[1] and Lester W. Schmerr, Jr.[2], [1,2]Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011; [2]Department of Aerospace Engineering

---Phased array transducers are very attractive in ultrasonic nondestructive testing since the beam generated by the arrays can be electronically focused and steered, eliminating much of the need for mechanical scanning. However, it is very challenging to model a phased array ultrasonic testing system because of the complexity of the electronics and the number of array elements involved. This work will study the procedures needed to characterize all the electrical and electromechanical aspects of a linear phased array system, using a matrix of system functions that can be obtained from the measured response of the array in a simple reference experiment. The full matrix of these system functions will be examined to determine the extent of variability of these functions. Since there are a very large number of element pairs that need to be characterized in this fashion even for a linear array, a simpler procedure where the array is characterized by a single system function, as done for ordinary single element transducers, is discussed. The variation of this single system function with the number of elements firing in the array as well as the variation of this function with changes of the delay law used will be described. It will be demonstrated that such a single system function for an array can be used in a complete ultrasonic measurement model to accurately predict the response of a reference reflector in an immersion setup.

Wave Equation Based 3D Imaging of Ultrasonic Data Theory and Practice

---**Niels Pörtzgen**, Applus-RTD, Non-Destructive Testing and Inspection - Technological Centre, Rotterdam, Zuid-Holland, the Netherlands; Rolf Baardman, Eric Verschuur, and Dries Gisolf, Delft University of Technology, Acoustical Imaging and Sound Control, Delft, Zuid-Holland, the Netherlands

---Non-destructive inspection (NDI) based on ultrasonic wave propagation is a well-known method for the detection of defects in steel components such as girth welds. Although the detection of defects can be done reliably, characterization and sizing of defects remain problematic. For accurate sizing, 2D imaging techniques with ultrasonic array measurements have been developed and demonstrated in practice. With advances in computer technology and ultrasonic array design, the step towards 3D imaging also becomes feasible. This paper describes a 3D imaging procedure that consists of two 2D imaging steps in two orthogonal directions (the ‘two-pass’ method). The procedure will be illustrated with real data obtained from ultrasonic linear array measurements. For 3D imaging, measurements over a surface area are required. Therefore, the linear array was shifted with small increments to cover a surface area. In the direction parallel to the linear array (the ‘in-line’ direction), all combinations of source-receiver elements were measured. This was repeated for a sufficient number of positions in the scan direction perpendicular to the linear array (the ‘cross-line’ direction). The measurements were taken from carbon steel test pieces and an actual weld with an intentional defect (an embedded tungsten fragment). Significantly improved resolution in the cross-line direction was obtained as a result of the cross-line aperture synthesis.

Predicting Spot Weld Button Area Using an Ultrasonic Phased Array

---**William D. Davis** and Deborah L. Hopkins, Lawrence Berkeley Laboratory, MS 46A-1123B, One Cyclotron Road, Berkeley, CA 94720

---In automobile manufacturing, the quality of spot welds joining thin mild steel sheets is assessed primarily by the diameter of the button remaining after destructive teardown, relative to the thickness of the sheets. To facilitate a comparison with destructive testing, several features of ultrasonic images of spot welds were assessed for their ability to predict weld button area. Two experiments were performed in which representative weld test coupons were imaged with ultrasound, and then torn down destructively and their buttons measured. Features of the ultrasonic images were then examined for their ability to predict the corresponding button areas. These features included: transmissive area; a proxy for reflectivity; and dimensions of the surface indentation caused by the welding electrode. Regression models with these explanatory variables predicting button area all achieve 90% or better fits. Button diameters were predicted with 95% confidence to an accuracy of 1 mm or less. Preliminary small-sample estimates of the repeatability and reproducibility of the inputs into and predictions from these models, indicate that the measurement system is sufficiently accurate for weld quality assessment in automotive manufacturing.

A Post-Processing Technique for Guided Wave Array Data for the Inspection of Plate Structures

---**Alexander Velichko** and Paul D. Wilcox, University of Bristol, Department of Mechanical Engineering, Bristol, United Kingdom

---The paper describes a general approach for processing data from a guided wave transducer array on a plate-like structure. The raw data set from such an array contains time-domain signals from each transmitter-receiver combination. The technique is based on linear superposition of signals in the frequency domain with some amplitude and phase factors and can be applied to any array geometry and any types of array elements. The problem of finding optimal coefficients, which allow the best resolution to be achieved with the minimum number of array elements, is investigated. It is shown that improvements in resolution are obtained at the expense of sensitivity to noise. A method of quantifying this sensitivity is presented. Results are shown that illustrate the application of the technique to a linear array and an array of circular geometry (containing a single ring of elements). Experimental data obtained from a guided wave array containing electromagnetic acoustic transducers (EMAT) elements for exciting and detecting the S0 Lamb wave mode in a 5-mm thick aluminium plate are processed with different algorithms and the results are discussed. Generalization of the technique for the case of multimode media is suggested.

Development of Phased Array Probes for Austenitic Weld Inspections Using Multi-Gaussian Beam Modeling Simulation

---**Naoyuki Kono** and Atsushi Baba, Power and Industrial Systems R&D Laboratory, Hitachi, Ltd., 7-2-1 Omika-cho, Hitachi-shi, Ibaraki-ken, 319-1221, Japan

---Ultrasonic inspection using phased array (PA) techniques has been applied to depth sizing of flaws or cracks in welds, especially stainless steels and nickel based alloy. PA techniques are capable of providing high SN ratio and high resolution by means of focal beams with various depths, positions and angles. In this study, a design method for array probes using simulation is developed to optimize parameters on focal beams. Acoustical fields are calculated based on a Fresnel-Kirchhoff Diffraction Integral model and a multi-Gaussian model. Simulation results are compared to experimental results measured with a laser interferometer. Good agreement between simulation and experiment is shown around the mail lobe of the focal beams.

Further Development of a Conformable Phased Array Device for the Inspection of Irregular Surfaces

---**Robert Long** and Peter Cawley, Imperial College London, Mechanical Engineering, London, United Kingdom

---Following initial work presented at QNDE 2006, further development of a conformable phased array device that allows reliable ultrasonic inspection of components with irregular surfaces such as weld caps has been undertaken. The device uses a standard linear phased array transducer which is coupled to the surface under test by a water path encapsulated by a low loss synthetic rubber membrane. The reservoir of water encapsulated in the device can be subjected to either constant pressure, by use of a header tank, or constant volume. The profile of the surface under test is measured utilizing the phased array incorporated into the device. The computation of updated delay laws, required to recover the inspection performance when inspecting over an irregular surface, has been improved by employing the Fermat minimum time principle. The research incorporated beam modeling using the CEA CIVA software and comparisons with experimental measurements. It is shown that the conformable membrane device using a standard array transducer provides a solution for ultrasonic inspection around the weld region of welded pipes.

Phased Array Method for the Inspection of French Rails Repairs

---**Philippe Bredif**, Clarisse Poidevin, CEA/LIST, France; Julia Plu and Philippe Pouligny, SNCF, France

---French national railways (SNCF) proceeds to operations of repairs on rails damaged on the surface. Gas inclusions present in repairs may induce cracking, which could affect the rail integrity. This paper presents a NDT phased-array method developed to detect and characterize small gas inclusions in the volume of the repair. The method is based on the implementation of a contact phased-array transducer associated with a specific processing. The transducer is articulated in order to conform as much as possible to the non-nominal rail sections. The phased-array probe allows to limit mechanical displacements to only one axis, along the longitudinal plan of the rail. The zone coverage in the plan perpendicular to the axis of the rail is performed through electronic commutation and beam steering. The data analysis is done using CIVA software. A processing based on ultrasonic field computation was developed. The method was experimentally assessed in laboratory on real repairs. Experiments proved the ability of the method to detect, locate and classify gas inclusions according to several ranges of sizes.

Improvement of Subharmonic Phased Array for Crack Evaluation (SPACE) and Its Practical Applications

---**Yoshikazu Ohara**, Setsu Yamamoto, Tsuyoshi Mihara, Kazushi Yamanaka Tohoku University, Department of Materials Processing, Sendai City, Miyagi, Japan

---Although nonlinear ultrasound using superharmonics (2f) has been studied for many years to evaluate closed cracks since the pioneering work [1], its practical use has yet to progress owing to the limited signal-to-noise (S/N) ratio and the low temporal resolution. The subharmonics (f/2) have been applied to a C-mode imaging [2], but the measurement of closed-crack depth in thickness direction has never been achieved. In this situation, we developed the subharmonic phased array for crack evaluation (SPACE) [3] based on the high temporal resolution and S/N ratio of the subharmonics [4] and verified it in closed fatigue cracks [3]. In this study, we applied SPACE to closed and tilted cracks generated in an industrial material processing (rolling) of Ni-Cr-Mo steel, by implementing a SPACE with a backscattering configuration. Then, we succeeded in clearly imaging the tilted and branched cracks in the subharmonic images, some of which were deeper than those observed in the fundamental frequency (f) image. Therefore the SPACE could precisely evaluate closed-crack depths which linear ultrasonic phased arrays underestimate. In addition, we developed a SPACE with a laser array, where the receiving array is composed by arbitrary number or position of points by scanning a laser interferometer. The laser array can realize not only a linear array with a flexible number of elements but also a 2D array sensor with a flexible in-plane configuration, resulting in an improved spatial resolution. Then we succeeded in imaging closed fatigue cracks more clearly than using a piezoelectric array. The laser array could also be useful in imaging cracks with a complex shape such as in the stress corrosion cracking, a serious problem in industrial power plants.

Application of Optimized Transducer Design Tools to Two-Dimensional Arrays

---**Vincent Lupien**, 27 Eaton Street, Wakefield, MA 01880

---The added complexity of phased array over conventional transducers has motivated the creation of sophisticated computational aids that help engineers develop and validate both ultrasonic transducers and inspection approaches. A common characteristic of these aids is their reliance on a forward simulation philosophy useful for mimicking the evolution of physical phenomena from known initial and boundary conditions. Regrettably, the inputs and outputs of the model are exactly the reverse of what an ultrasonic NDT professional wants. It is most often already known what the desired ultrasonic response should be, while the unknowns are the necessary array design and overall ultrasonic inspection approach such as transducer positioning and movement. As a result, in practice the forward modeling approach must be used in an iterative, somewhat clumsy manner to arrive at a transducer design which, while verifiably adequate, cannot be ascertained to be uniquely optimal in any sense. We have shown in previous work that software tools can be developed to obtain objectively optimal geometrical transducer designs automatically for annular arrays. Recently the formalism has been extended to two-dimensional array geometries; we present applications of this extended formalism to more challenging inspection scenarios involving three-dimensional beam steering and inspection of complex geometry components.

TUESDAY

Session 7

SESSION 7
THERMOGRAPHIC AND THERMOSONIC NDE
X. Han, Chairperson
Ballroom A

8:30 AM **Lateral Heat Flow Infrared Thermography for Thickness Independent Determination of Thermal Diffusivity in Carbon Fiber Reinforced Polymer Composites**
---N. Tralshawala, D. R. Howard, B. Knight, Y. Plotnikov, and **H. I. Ringermacher**, GE Global Research Center, Non-Destructive Technologies Laboratory, 1 Research Circle, KWD254, Niskayuna, NY 12309

8:50 AM **Analysis of Data from On-Orbit Infrared Measurements on Reinforced Carbon-Carbon Composites**
---P. A. Howell, **W. P. Winfree**, and K. E. Cramer, NASA Langley Research Center, Nondestructive Evaluation Sciences Branch, Hampton, VA 23681-2199

9:10 AM **Air Coupled Acoustic Thermography Inspection Technique**
---**J. N. Zalameda**, U. S. Army Research Laboratory, Vehicle Technology Directorate, Hampton, VA 23681; W. P. Winfree and W. T. Yost, NASA Langley Research Center, Hampton, VA 23681

9:30 AM **Mechanisms and Models for Crack Detection with Induction Thermography**
---**J. Vrana**, M. Goldammer, J. Baumann, and M. Rothenfusser, Siemens AG, Corporate Technology, Otto-Hahn-Ring 6, D-81730 Munich, Germany; J. Vrana and W. Arnold, Fraunhofer Institut for Non-Destructive Testing (IZFP), Building E 3.1, University D-66123 Saarbrucken, Germany

9:50 AM **Finite-Element Modeling of Sonic IR Imaging of Cracks in Aluminum and Titanium Alloys**
---**X. Han** and W. Li, Wayne State University, Department of Electrical and Computer Engineering, Detroit, MI 48202; A. S. Ajanahalli, Z. Ahmed, and G. Newaz, Wayne State University, Department of Mechanical Engineering, Detroit, MI 48202; L. D. Favro, Wayne State University, Institute for Manufacturing Research, Detroit, MI 48202; R. L. Thomas, Wayne State University, Department of Physics and Astronomy, Detroit, MI 48202

10:10 AM ***Break***

10:30 AM **Toward a Viable Strategy for Estimating Vibrothermographic Probability of Detection (POD)**
---**S. D. Holland**, C. Uhl, and J. Renshaw, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

10:50 AM **Full-Field Vibration Measurement for Vibrothermography**
---**J. Renshaw**, S. D. Holland, and C. Uhl, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

11:10 AM **Study of Diminutive and Subsurface Cracks Using Sonic IR Inspection**
---K. Lick, J. Urcinas, and **J. C. Chen**, Rowan University, Department of Mechanical Engineering, 201 Mullica Hill Road, Glassboro, NJ 08028-1701

11:30 AM **Flash Thermography Modeling Based on IR Camera Noise**
---**S. M. Shepard** and J. R. Lhota, Thermal Wave Imaging, Inc., 845 Livernois, Ferndale, MI 48220

11:50 AM **Thermal Imaging Analysis of Material Structures and Defects**
---**J. Sun**, Nuclear Engineering Division, Argonne National Laboratory, Argonne, IL 60439

12:10 PM ***Lunch***

Lateral Heat Flow Infrared Thermography for Thickness Independent Determination of Thermal Diffusivity in Carbon Fiber Reinforced Polymer Composites

---Nilesh Tralshawala, Donald R. Howard, Bryon Knight, Yuri Plotnikov, and **Harry I. Ringermacher**, GE Global Research Center, Non-Destructive Technologies Laboratory, 1 Research Circle, KWD254, Niskayuna, NY 12309

---Infrared thermography is one of the non-destructive evaluation techniques for non-contact quantification of porosity, voids, and delaminations in thin-walled carbon fiber reinforced polymer composite aircraft structures. Determining porosity using thermography is based on the calculation of thermal diffusivity, which in turn requires thickness information. Recently GE has been experimenting with the use of lateral heat flow to determine thermal diffusivity and porosity, without thickness information. We have developed appropriate theoretical models and a new data analysis framework to experimentally determine all three components of thermal diffusivity from these temperature measurements. The analysis did not require any curve fitting to the temperature profile and was based on the creation of thermal time-of-flight (tof) images from the stripe edge. Experimental validation was done using anisotropic carbon fiber reinforced polymer (CFRP) composites. We found that in the CFRP samples used, the in-plane component of diffusivity is ~ 4-5 times larger than the through-thickness component. The data indicate that the in-plane component of diffusivity is as sensitive to porosity as the through-thickness component. We thus have a method to quantify porosity where two-sided access to structure is not needed.

Analysis of Data from On-Orbit Infrared Measurements on Reinforce Carbon-Carbon Composites

---Patricia A. Howell, **William P. Winfree**, and K. Elliott Cramer, NASA Langley Research Center, Nondestructive Evaluation Sciences Branch, Hampton, VA 23681-2199

---This paper will discuss an infrared camera inspection system that has been developed to allow astronauts to demonstrate the ability to inspect reinforced carbon-carbon (RCC) components on the space shuttle as part of extra-vehicular activities (EVA) while in orbit. An EVA camera system was developed that when combined with solar heating enables the inspection of damaged RCC specimens and NDE standards. Data was acquired during space shuttle flights STS-121 and STS-115 as well during a staged EVA from the International Space Station (ISS). The EVA camera system was able to detect flat-bottom holes as small as 2.54cm in diameter with 25% material loss. Results obtained are shown to be comparable to ground-based thermal inspections performed in the laboratory using the same camera and simulated solar heating. Data on both the time history of the specimen temperature and the ability of the inspection system to image defects due to impact will likewise be presented. Comparison of the results to simulation predictions will be shown.

Air Coupled Acoustic Thermography Inspection Technique

---**Joseph N. Zalameda**, U.S. Army Research Laboratory, Vehicle Technology Directorate, Hampton, VA 23681; William P. Winfree and William T. Yost, NASA Langley Research Center, Hampton, VA 23681

---Vibrothermography or Sonic Thermography is a technology where acoustic energy is coupled to the structure, typically by means of an acoustic transducer in contact with the part. The conversion of acoustic energy to thermal energy is relatively higher at damage sites. The temperature increase at the surface is detected with an infrared camera. This technology makes possible detection of defects, such as cracks in metallic structures heretofore undetectable with conventional flash thermography techniques. The scope of this effort is to determine the viability of a new heating technique using a noncontact acoustic excitation source. Because of low coupling between air and the structure, a synchronous detection method is employed. Any difference in the out of plane stiffness improves the acoustic coupling efficiency and as a result, defective areas have an increase in temperature relative to the surrounding area. Measurement results indicate that air coupled acoustic excitation enables the detection of core damage in sandwich honeycomb structures. Core damage is difficult to detect with conventional flash thermography. A vibrating membrane model is developed and compared with the experimental results.

Mechanisms and Models for Crack Detection with Induction Thermography

---**Johannes Vrana**, Matthias Goldammer, Joachim Baumann, and Max Rothenfusser, Siemens AG, Corporate Technology, Otto-Hahn-Ring 6, D-81730 Munich, Germany; Johannes Vrana, and Walter Arnold, Fraunhofer Institut for Non-Destructive Testing (IZFP), Bldg E 3.1, University, D-66123 Saarbrücken, Germany

---Induction thermography is a non-contacting, non-destructive evaluation method with a wide range of applications. A deeper understanding of the detectability of cracks requires fundamental knowledge about the induced current-density distribution in the component under test. A calculation of the current distribution provides information on how much current is flowing at what location of the sample, how a crack disturbs the current density, how much heat is produced at what location of a sample, and how the heat diffuses to the surface. The heating process depends on the type of crack. On the one hand there are cracks which can be detected mainly by direct observation of the heating process due to an increased current density, and on the other hand there are cracks which can be detected mainly by modification of the heat diffusion. This paper presents an analytical model for the calculation of the current distribution, including the back-flow current along with finite-element calculations. Furthermore, two new crack models are presented for a better description of real cracks.

Finite-Element Modeling of Sonic IR Imaging of Cracks in Aluminum and Titanium Alloys
---**Xiaoyan Han** and Wei Li, Wayne State University, Department of Electrical and Computer Engineering, Detroit, MI 48202; Abhijith S. Ajanahalli, Zeeshan Ahmed, and G. Newaz, Wayne State University, Department of Mechanical Engineering, Detroit, MI 48202; L. D. Favro, Wayne State University, Institute for Manufacturing Research, Detroit, MI 48202; R. L. Thomas, Wayne State University, Department of Physics and Astronomy, Detroit, MI 48202

---We have described Sonic IR Imaging and presented both experimental and theoretical work using induced chaotic sound within the targets in previous conferences. We have demonstrated that the induced chaotic sound is much more effective in producing heat in the defects than the single frequency input sound, and thus resulting bigger IR signals. Therefore, for the same defect, the chance to detect the defect with chaotic sound is much higher than the non-chaotic sound. In this presentation, we will present our finite element study on the vibration and heating in aluminum and titanium to resolve the effect of target materials quantitatively. We allow both friction and plastic deformation as sources of heating in our models.

Toward A Viable Strategy for Estimating Vibrothermographic Probability of Detection (POD)
---**Stephen D. Holland**, Christopher Uhl, and Jeremy Renshaw, Iowa State University, Center for NDE, Ames, IA 50011

---Vibrothermography is a technique for finding cracks and delaminations through infrared imaging of vibration-induced heating. While vibrothermography has shown remarkable promise, it has been plagued by persistent questions about its reproducibility and reliability. Fundamentally, the crack heating is caused by the vibration, and therefore to understand the heating process we must first understand the vibration process. We lay out the problem and begin the first steps toward relating detectability to the local motion around a crack as well as the crack size. A particular mode, the third-order free-free flexural resonance, turns out to be particularly insensitive to the presence of clamping and transducer contact. When this mode is excited in a simple bar geometry the motions of the part follow theoretical calculations quite closely, and a single point laser vibrometer measurement is sufficient to evaluate the motion everywhere. Simple calculations estimate stress and strain anywhere in the bar, and these can then be related to observed crack heating.

Full-Field Vibration Measurement for Vibrothermography

---**Jeremy Renshaw**, Stephen D. Holland, and Christopher Uhl, Iowa State University, Center for NDE, Ames, IA 50011

---Vibrothermography is a nondestructive technique for finding defects through vibration induced heating imaged with an infrared camera. To model the crack heating process in Vibrothermography, it is essential to first understand the vibration that triggers the heating. We describe a method for calculating internal motions from surface vibrometry measurements. A reciprocity integral and Gauss's law allow representation of internal motion by a surface integral of boundary motion times the Green's function. We present experimental results showing internal motions calculated from measured surface motions of a vibrating sample. This will ultimately allow estimation of the detectability of a hypothetical crack at an arbitrary location in a specimen.

Study of Diminutive and Subsurface Cracks Using Sonic IR Inspection

---Kyle Lick, Joseph Urcinas, and **John C. Chen**, Rowan University, Department of Mechanical Engineering, 201 Mullica Hill Road, Glassboro, NJ 08028-1701

---Currently sonic IR inspection has been used to detect cracks of significant sizes and this process has been proven to be successful. This is in part because cracks in this configuration are aided by the geometry of the sample and the crack which promotes frictional heating. However, what about a crack or defect that is considered very small in size or a crack that is buried beneath the viewing surface? In this study our goal is to determine the limits of sonic IR inspection by making very small cracks to the thousandth of an inch and producing buried subsurface cracks. These will then be tested for the efficacy of inspection via sonic IR. This will be the basis of the next step in the project which is characterizing the cracks produced and how these characteristics differ under sonic IR. This presentation will discuss our approach to this experiment, its design, and the data collected.

Flash Thermography Modeling Based on IR Camera Noise

---**Steven M. Shepard** and James R. Lhota, Thermal Wave Imaging, Inc., 845 Livernois, Ferndale, MI 48220

---Modeling of the flash thermography process typically requires a priori knowledge of the thermophysical properties of the sample and likely defect mechanisms, as well as the amount of energy used to excite the sample. Often, this information is not readily available to the NDT practitioner. Furthermore, since flash thermography is often performed with infrared cameras that do not provide absolute temperature data, it may be difficult to correlate modeling predictions of the surface temperature to experimental results. We have developed a simple model that takes into account the noise characteristics of the camera, and uses that as a basis for predicting camera response. Input energy is expressed as a multiple of noise, and can be measured from the data without the use of additional instrumentation. The method also predicts minimum detectable flaw diameters as a function of depth, noise and input energy, and provides a basis for the widely used "rule of thumb" used in thermography.

Thermal Imaging Analysis of Material Structures and Defects

---**Jiangang Sun**, Nuclear Engineering Division, Argonne National Laboratory, Argonne, IL 60439

---Pulsed thermal imaging has been widely used for nondestructive characterization of internal defects in composite materials. Recently advances in thermal imaging methods allowed for accurate determination of defect depth, thermal property and thickness in layered materials, and even 3D imaging of internal structures. Unlike the one-sided (pulse-echo) ultrasonic technique in which the depth and severity of a property change (e.g., a defect) is directly related to the time of flight and amplitude in the return signal, thermal imaging data consist of the convolution of both depth and severity information of a defect as well as the heat diffusion effect that increases with heat propagation distance. In this paper, a numerical 1D heat-transfer model is used to demonstrate the complexity of thermal imaging data from materials with multilayer structures and several types of defects. Analysis results are compared with experimental data from layered ceramic-coating specimens.

Session 8

SESSION 8

GUIDED WAVES I

J. L. Rose, Chairperson

Ballroom B

8:30 AM **Guided Waves With and Without Dispersion**
---**N. R. Joshi**, 1735 Bryant Way, Beaumont, TX 77706

8:50 AM **Two Efficient Methods of Mode Selection in a Waveguide Insonified by a Transducer Mounted on its Section**
---**A. Lhémery** and K. Jezzine, CEA LIST, Laboratoire de Simulation et de Modélisation, CEA-Saclay, bât. 611, Point Courier 120, 91191 Gif-sur-Yvette, Cedex, France

9:10 AM **Detection of Axial Cracks in Tube and Pipe Using Torsional Guided Waves**
---**H. Kwun** and S. Y. Kim, Southwest Research Institute, San Antonio, TX 78238; S. Vinogradov, IHI Southwest Technologies, Inc., San Antonio, TX 78238

9:30 AM **Guided Wave Normal Modes in Hollow Cylinders with Viscoelastic Coatings**
---**J. Mu** and J. L. Rose, The Pennsylvania State University, Department of Engineering, Science, and Mechanics, University Park, PA 16802

9:50 AM **Long-Range Defect Detection with Guided Waves for Bottom Edges of Rails**
---**T. Hayashi**, Y. Miyazaki, K. Kataoka, and M. Takikawa, Nagoya Institute of Technology, Gokiso Showa, Nagoya, 466-8555, Japan

10:10 AM ***Break***

10:30 AM **Monitoring of Plate Structures Using Guided Ultrasonic Waves**
---**P. Fromme**, University College London, Department of Mechanical Engineering, Torrington Place, London, WC1E 7JE, United Kingdom

10:50 AM **FE Simulations of the Generation of Guided Waves by Air-Coupled Transducers**
---**B. Hosten** and C. Biateau, Laboratoire de Mécanique Physique, Université Bordeaux 1, UMR CNRS 5469, 351 cours de la Libération, 33405 Talence, Cedex, France

11:10 AM **A Transitional Waveguide for Bondline Inspection of Complex Structures**
---**E. T. Hauck** and J. L. Rose, The Pennsylvania State University, Department of Engineering Science and Mechanics, 212 Earth and Engineering Sciences Building, University Park, PA 16802; C. A. Moose, Composite Materials Division, Applied Research Laboratory, The Pennsylvania State University, P. O. Box 30, North Atherton Street, State College, PA 16804

11:30 AM **Guided-Wave Defect Signal Simulation Based on Transmission Line Model**
---**H. Kwun** and S. Y. Kim, Southwest Research Institute, San Antonio, TX 78238

11:50 AM **Imaging Hidden Corrosion Using Ultrasonic Nondispersive Higher Order Guided Wave Modes**
---**K. Balasubramaniam**, J. Chandrashekaran, B. W. Maxfield, and L. Satyanarayan, Centre for Nondestructive Evaluation and Department of Mechanical Engineering, Indian Institute of Technology-Madras, Chennai, India

12:10 PM ***Lunch***

Guided Waves with and Without Dispersion
---**N. R. Joshi**, 1735 Bryant Way, Beaumont, TX 77706

---The propagation of guided waves in the ultrasonic frequency range with or without dispersion depends upon the relationship between the wavelength of the type of ultrasonic wave launched and characteristic dimension of the structure under inspection. In many recent pipeline inspections guided waves are selected by using theoretically calculated dispersion curves. On the other hand in the inspection of thick bolts and anchor studs, the ultrasonic wavelength is many times greater than the thickness of the object under inspection and hence there is no dispersion but the wave is still guided by the walls of the object. In addition the mode converted signals are present which can be put to variety of uses during inspection. In this paper distinction is made between guided waves without dispersion and those with dispersion and certain novel applications are discussed.

Two Efficient Methods of Mode Selection in a Waveguide Insonified by a Transducer Mounted on Its Section
---**Alain Lhémery** and Karim Jezzine, CEA LIST, Laboratoire de Simulation et de Modélisation, CEA-Saclay, bât. 611, Point Courier 120, 91191 Gif-sur-Yvette, Cedex, France

---The multimodal and dispersive nature of elastic guided waves (GW) makes the interpretation of NDE measurements difficult: a relation between the time-of-flight of a contribution and the position of a defect cannot be easily exhibited. Possible means to solve this consist in -i) using excitations of narrow bandwidth so that only modes existing in this bandwidth can propagate -ii) operating a selection among existing modes in that bandwidth by imposing a source to favor one mode relatively to the others. GW-NDE generally involves sources acting from the guiding surface. For these cases, various methods of mode selection have been developed involving spatially periodic sources or phase velocity coincidences. There are cases where the guiding surface is not accessible so that sources act from the guide section. In this paper, two original (patented) methods of mode selection are described where the transducer is mounted on the guide section. A simulation study is conducted to exhibit for various guide geometries, frequencies where the modal tangential stress vanishes or is negligible. By mimicking the modal normal stress in the section using a multiple-element transducer, one generates solely the mode chosen. Numerical examples show the effectiveness of these approaches. Applications to NDE are discussed.

Detection of Axial Cracks in Tube and Pipe Using Torsional Guided Waves

---**Hegeon Kwun** and Sang Y. Kim, Southwest Research Institute, San Antonio, TX 78238; Sergey Vinogradov, IHI Southwest Technologies, Inc., San Antonio, TX 78238

---Guided-waves are now widely used for long-range inspection of piping and tubing for detection of corrosion metal loss areas and circumferential cracks. The reflection coefficient of guided-waves from a defect is proportional to the circumferential cross-sectional area of the defect. Since axial cracks have negligibly small circumferential cross-sectional area, they are usually undetectable. However, when the depth of axial crack reaches about 70-perecent of wall thickness, the interaction mechanism between the torsional wave and the axial crack changes and the crack begins to produce detectable signals accompanied with characteristic tailing signals. Experimental data from various sized pipes including a seam-welded pipe with lack of fusion are presented and potential interaction mechanisms are discussed.

Guided Wave Normal Modes in Hollow Cylinders with Viscoelastic Coatings

---**Jing Mu** and Joseph L. Rose, The Pennsylvania State University, Department of Engineering Science and Mechanics, University Park, PA 16802

---Guided wave propagation in free hollow cylinders with viscoelastic coatings is solved by a semi-analytical finite element (SAFE) method. Guided wave dispersion curves and attenuation curves including both axisymmetric and flexural modes are obtained. The dispersion and attenuation curves agree quite well with analytical solutions. It is proved that the guided wave modes in a viscoelastic coated hollow cylinder are orthogonal to each other. This orthogonality is also verified through numerical calculations. The wave structures and cross section deformations are also provided and discussed for a better understanding of wave mechanics in multilayered cylindrical structures containing viscoelastic materials. Practical inspection values of such a study are discussed.

Long-Range Defect Detection with Guided Waves for Bottom Edges of Rails

---**Takahiro Hayashi**, Yusuke Miyazaki, Keita Kataoka, and Mitsunobu Takikawa, Nagoya Institute of Technology, Gokiso Showa, Nagoya, 466-8555, Japan

---Bottom edges of rails, one of the easiest damaged areas in a rail due to contact with fastenings and soil, are blind zones which rail inspection cars with wheel probes cannot be inspected. Therefore, our group has investigated guided wave testing for it. A lot of guided wave modes were able to be obtained by our calculation technique and some dominant modes of bottom-edge vibration were selected among many guided wave modes and were applied to inspection for bottom edges. Vertically vibrating modes show very good results where large reflection from a notch at a bottom edge can be obtained when fastenings are loose. However, once fastenings are fixed, such reflections were not obtained due to large attenuation and multiple reflections at the fastenings. Therefore, using horizontally vibrating modes at the bottom edge gave good results even in a rail with fastenings, and we could find artificial notch at a bottom edge of a rail up to 10.5 m away.

Monitoring of Plate Structures Using Guided Ultrasonic Waves

---**P. Fromme**, University College London, Department of Mechanical Engineering, Torrington Place, London, WC1E 7JE, United Kingdom

---Many technical structures contain large plate-like components with structural features, e.g., stiffeners on the hull plates of a ship. Damage like severe corrosion and the development of fatigue cracks can occur during the service life of the structure due to adverse environmental and loading conditions. Efficient permanent nondestructive monitoring of the integrity of such structures can be achieved using arrays of distributed sensors for guided ultrasonic waves. The validity of the measurement concept has been demonstrated experimentally using distributed sensors for the first anti-symmetric Lamb wave mode A0 in a plate. The sensitivity for the detection and localization of defects is discussed and the influence of the number of sensors and evaluation concept studied. Good results have been found for defects in a simple plate and the measurements were validated by a comparison to synthetic data from Finite Element simulations using ABAQUS. The influence of structural features on the sensitivity for damage detection in realistic plate-like structures has been investigated by introducing artificial defects at a plate with a welded stiffener.

FE Simulations of the Generation of Guided Waves by Air-Coupled Transducers

---**Bernard Hosten*** and Christine Biateau, Laboratoire de Mécanique Physique, Université Bordeaux 1, UMR C.N.R.S. 5469, 351 cours de la Libération, 33405 Talence Cedex, France

---Since the spatial and frequential fields generated by an air-coupled transducer and its efficiency can be measured, a realistic field can be simulated with a commercial FE software. The transducer is simulated as a pressure, second member in the Helmholtz equation that is used to compute the propagation from the transducer to a plate in the air, along a direction that makes an incident angle θ with the normal of the plate. Inside the plate the propagation is simulated with the dynamic equations of equilibrium and a complex stiffness tensor to take into account the viscoelastic anisotropy of the material. The two physics are coupled by introducing the boundary conditions at the interface fluid/solid. The θ angle is varied continuously for investigating the generation of guided waves and the efficiency of the air coupled technique. Experimental and numerical results will be given in terms of normal displacements in function of the incidence and the position for a Perspex plate in order to justify the model.

A Transitional Waveguide for Bondline Inspection of Complex Structures

---**Eric T. Hauck** and Joseph L. Rose, The Pennsylvania State University, Department of Engineering Science and Mechanics, 212 Earth and Engineering Sciences Building, University Park, PA 16802; Clark A. Moose, Composite Materials Division, Applied Research Laboratory, The Pennsylvania State University, P.O. Box 30, North Atherton Street, State College, PA 16804

---The use of adhesive bonded joints is increasing in aerospace and naval applications as designers strive to reduce weight, manufacturing and maintenance costs, stress concentrations, and corrosion initiation sites in the final assembled structure. Verification of a proper bond is necessary for quality control of the structure at the time of manufacture and later nondestructive evaluation of the bonded joint to assure small defects will not lead to catastrophic failure. Traditional normal beam ultrasonic NDE methods have been used to locate volumetric cohesive defects, but adhesive zero-volume defects are not as easily identified. The structure of a bonded joint lends itself to the propagation of ultrasonic guided waves. The guided waves have the benefit of using shear energy at interfaces in order to locate defects. The accessible face of the joint for the impingement of ultrasonic energy into the structure is not always parallel with that of the interfaces to be interrogated. Therefore, a transitional waveguide is used to select appropriate wave modes that are sensitive to interfacial defects. A three dimensional structure with a taper perpendicular to the wave propagation direction is analyzed using a hybrid semi analytical finite element technique to develop an artificial waveguide.

Guided-Wave Defect Signal Simulation Based on Transmission Line Model

---**Hegeon Kwun** and Sang Y. Kim, Southwest Research Institute, San Antonio, TX 78238

---An analytic approach for simulating the guided-wave signal reflected from a volumetric defect of arbitrary shape in piping based on the transmission line model is described. In this approach, the guided-wave interaction with a defect is treated as the one-dimensional problem of plane wave reflection from a boundary of multi-layered media of different acoustic impedances in a transmission line. Examples of simulated and experimentally measured defect signals are presented and capabilities and limitations of the approach are discussed.

Imaging Hidden Corrosion Using Ultrasonic Nondispersive Higher Order Guided Wave Modes

---**Krishnan Balasubramaniam**, J. Chandrashekaran, Bruce W. Maxfield, and L. Satyanarayan, Centre for Nondestructive Evaluation and Department of Mechanical Engineering, Indian Institute of Technology-Madras, Chennai, India

---Hidden corrosion detection is a problem that must be addressed using advanced NDE methods. Such methods are made more difficult by the lack of accessibility of the defect to conventional NDE methods.. The ultrasonic guided waves have been used extensively to address such problems in a long range mode for the rapid evaluation of corrosion damage in pipes, rods, and plate like structures using the ultrasonic guided waves in the low frequency ranges (20-200 kHz). In this paper, the effectiveness of detecting corrosion in hidden regions in pipes and tank floors was studied using the non-dispersive regions of excitation of higher order guided wave modes for the detection and characterization of corrosion under pipe support regions and tank bottom floors that are not inspectable using traditional NDT methods. Since, the nature of loss of material differs in each type of corrosion, the same mode excited cannot be effective in characterizing all the defect types, although they all may indicate the presence of defect. The effective modes are identified for each type of corrosion and their defect characterizing sensitivity was studied. The validity of this technique was tested with field samples.

Session 9

Tuesday, July 24, 2007

SESSION 9

MICROSTRUCTURE ASSESSMENT USING NDE TECHNIQUES

D. L. Olson, Chairperson

Ballroom D

8:30 AM **The Future of Microstructural Characterization: An Electronic Metallography Laboratory**
---**J. E. Jackson**, B. Mishra, and D. L. Olson, Colorado School of Mines, Golden, CO 80401; A. N. Lasseigne-Jackson and T. A. Siewert, National Institute of Standards and Technology, Boulder, CO 80305; Y.-D. Park, Department of Advanced Materials Engineering, Dong-Eui University, Busan 614-714, Republic of Korea

8:50 AM **Kinetic Study of Aging in Uranium-Titanium Eutectoids Alloy, Using Thermoelectric Power Measurement**
---**B. Herrmann** and A. Landau, Nuclear Research Center-Negev, Beer-Sheva, Israel ; Y. Gelbstein and G. Kimmel, Dept. of Materials Eng., Ben-Gurion Univ., Beer-Sheva 84105, Israel

9:10 AM **Advanced Nondestructive Measurement Schemes to Actively Monitor Hydrogen Content in Steel Pipelines**
---**A. N. Lasseigne-Jackson**, J. M. Anton, and T. A. Siewert, National Institute of Standards and Technology, Materials Reliability Division, Boulder, CO 80305; D. L. Olson, B. Mishra, and J. E. Jackson, Colorado School of Mines, Dept. of Metallurgical and Materials Engineering, Golden, CO

9:30 AM **Monitoring Homogenization of Cerium-Lanthanum Alloys Using Thermoelectric Power and Electrical Resistivity**
---**D. E. Dooley**, Los Alamos National Laboratory, Los Alamos, NM; D. L. Olson, Colorado School of Mines, Golden, CO; F. E. Gibbs, CH2M-HILL, Greenwood Village, CO

9:50 AM **Quantitative Nondestructive Evaluation (QNDE) of the Elastic Moduli of Porous TiAl Alloys**
---**O. Yeheskel**, Nuclear Research Center-Negev, P. O. Box 9001, Beer Sheva, 84190, Israel

10:10 AM ***Break***

10:30 AM **Developing a Monitoring Tool to Assess the Fatigue Damage in Ni-Based Superalloys Using Thermoelectric Electric Power Measurements**
---**A. Landau** and M. Pinkas, Nuclear Research Center-Negev, Beer Sheva 84190, Israel; A. N. Lasseigne-Jackson and D. L. Olson, Colorado School of Mines, Golden, CO 80401

10:50 AM **Hydrogenization of Intermetallic Compounds Characterized by Magnetic Susceptibility and Thermoelectric Power Measurement**
---**S. Niyomosoan**, P. Termsuksawad, D. L. Olson, and B. Mishra, Colorado School of Mines, Golden, CO 80401; R. B. Goldfarb, National Institute of Standards and Technology, Boulder, CO 80305; G. Zamir, Nuclear Research Center-Negev, Beer-Sheva 84190, Israel

11:10 AM **Applying TEP Measurements to Assess the Aging Stage of a Maraging 250 Steel**
---Y. Snir, **M. Pinkas**, and A. Landau, Nuclear Research Center-Negev, Beer Sheva, 84190, Israel; Y. Gelbstein, Dept. of Materials Eng., Ben-Gurion University of the Negev, Beer-Sheva, Israel

11:30 AM **A PAL & Optical Transmission Study of Damage Evolution in Irradiated Sapphire (á-Al2O3)**
---**I. Israelashvily**, S. May-Tal Beck, O. Shahal, Z. Berant, and A. Beck, Physics Department, Nuclear Research Center-Negev, P. O. Box 9001, Israel; M. Ganor, Material Engineering Department, Nuclear Research Center-Negev, P. O. Box 9001, Israel; A. Moalem, Physics Department, Ben-Gurion University of the Negev, P. O. Box 653, Beer-Sheva, Israel

11:50 AM **Study on In-Situ Diffusible Hydrogen Sensor for Welded HSLA Steel**
---**Y.-D. Park**, Department of Advanced Materials Engineering, Dong-Eui University, Busan 614-714, Republic of Korea; Y.-D. Kim, School of Materials Science and Engineering, Pusan National University, Busan 609-735, Republic of Korea; Y.-S. Kim, Korea Institute of Industrial Technology, Busan Research Center Advanced Manufacturing Technology Team, Busan, 609-735, Republic of Korea; D. L. Olson, Colorado School of Mines, Golden, CO 80401

12:10 PM ***Lunch***

The Future of Microstructural Characterization: An Electronic Metallography Laboratory

---**Joshua E. Jackson**, Brajendra Mishra, and David L. Olson, Colorado School of Mines, Golden, CO 80401; Angelique N. Lasseigne-Jackson and Tom A. Siewert, National Institute of Standards and Technology, Boulder, CO 80305; Young-Do Park, Dept. of Advanced Materials Engineering, Dong-Eui University Busan 614-714, Republic of Korea

---The ability to assess microstructure through non-destructive techniques is possible through intelligent use of combinations of intrinsic property measurements. Numerous techniques to measure microstructure exist and are sensitive to microstructural changes and imminent phase transitions. Proper characterization of microstructure requires development of an advanced phase rule (degrees of freedom) to determine the minimum number of intrinsic property measurements required to characterize a specific microstructure. This microstructure rule must incorporate the need to identify both phases and microstructural topology. This paper will suggest rules and new methods to classify materials based on the material's electronic structure and their response to physical perturbations.

Kinetic Study of Aging in Uranium-Titanium Eutectoids Alloy, Using Thermoelectric Power Measurement

---**Benjamin Herrmann** and Alex Landau, Nuclear Research Center-Negev, Beer-Sheva, Israel; Yaniv Gelbstein and Giora Kimmel, Department of Materials Engineering, Ben-Gurion University, Beer-Sheva 84105, Israel

---Considerable attention has been given to the study of microstructure evolution and mechanical properties of dilute U-Ti alloys. The eutectoid alloy (0.85 wt% Ti) has a unique "maraging steel type" of strengthening mechanism, meaning; relatively soft martensitic quenched structure, that can be strengthened by precipitation hardening. The martensitic microstructure is produced by solution heat treating of the U-alloy in the γ phase region followed by quenching to room temperature with subsequent aging in the 300 to 500^{o}C range. It is known that rapid cooling suppresses diffusional decomposition of the γ BCC phase which transforms martensitically to a supersaturated Orthorhombic α' uranium. The subsequent aging causes GP Zone formation in the α' Martensite, results in precipitation reaction $\alpha' \rightarrow \alpha+\delta$ (δ phase is an Hexagonal U_2Ti structure). The aging process increases significantly the level of the micro-strain in the metastable α' matrix. Characterization methods of the microstructure and the mechanical properties evolution are usually monitored by destructive testing measurement, using tensile tests, metallographic techniques or hardness measurements. Thermoelectric power (TEP) measurements have recently gained a growing attention for the characterization of metallurgical properties in steels and alloys. These measurements, which are based on Seebeck effect, are sensitive to the changes in the electronic structure of the material as results of various metallurgical processes. In the current research, TEP measurement technique was applied as an NDT assessment technique to characterize the aging kinetics of the quenched Uranium-Titanium binary alloy. To support the TEP results the micro-strain evolution was measured during the aging using XRD and complimentary hardness measurements. Good correlation was determined. A model giving the correlation between the crystallography changes, micro-strain, TEP, and properties will be presented.

Advanced Non-Destructive Measurement Schemes to Actively Monitor Hydrogen Content in Steel Pipelines

---**Angelique N. Lasseigne-Jackson**, Jennifer M. Anton, and Thomas A. Siewert, National Institute of Standards and Technology, Materials Reliability Division, Boulder, CO 80305; David L. Olson, Brajendra Mishra, and Joshua E. Jackson, Colorado School of Mines, Department of Metallurgical and Material Engineering, Golden, CO

---With the introduction of new higher strength steels operating at higher pressure, the need for characterization of hydrogen content in high strength steel pipelines is timely for the pipeline industry. The higher strength steel pipelines have higher susceptibility to hydrogen damage. Through the use of low frequency induced current impedance measurements, a new non-contact sensor has been developed for real-time determination of diffusible hydrogen content in coated pipeline steel. A measurement scheme to separate additional variables associated with pipelines is discussed. This electromagnetic technique allows for a rapid, non-destructive assessment of hydrogen accumulation in coated steel line pipe and thus an evaluation of the pipeline integrity.

Monitoring Homogenization of Cerium-Lanthanum Alloys Using Thermoelectric Power and Electrical Resistivity

---**D. E. Dooley**, Los Alamos National Laboratory, Los Alamos, NM; D.L. Olson, Colorado School of Mines, Golden, CO; F.E. Gibbs, CH2M-HILL, Greenwood Village, CO

---Since nuclear underground testing ceased in 1992, reliance on scientific interpretation of aging properties of plutonium-gallium alloys has greatly increased in importance. Aging in plutonium-gallium alloys is due to both radioactive decay and metallurgical instabilities. The ability to determine signs of these aging effects in plutonium-gallium alloys nondestructively would be an extremely beneficial tool. The nondestructive techniques to be implemented in this work are measurements of electrical resistivity and thermopower. These techniques were selected because they are sensitive to electronic scattering mechanisms, electronic band structure and energies, electronic interactions, phase stability and transformations. To verify that these measurements can accurately monitor changes in plutonium-gallium alloys due to aging, measurements will first be performed on cerium-lanthanum alloys. Cerium-lanthanum alloys are considered to be a surrogate system for plutonium-gallium alloys because they are both f-electron systems and both alloy systems can undergo constitutional segregation. The experiment matrix consisted of measuring these two electronic properties as a function of homogenization, i.e., removal of lanthanum concentration gradient. Observed changes in these electronic properties will validate that electronic properties can nondestructively evaluate the physical changes in the material.

Quantitative Nondestructive Evaluation (QNDE) of the Elastic Moduli of Porous TiAl Alloys

---**Ori Yeheskel**, Nuclear Research Center-Negev, P. O. Box 9001 Beer Sheva, 84190, Israel

---Various techniques e.g. cold isostatic pressing (CIP), pressure-less sintering, or hot isostatic pressing (HIP) were studied to consolidate γ-TiAl samples. Porosity linearly affects the dynamic elastic moduli of samples. The results indicate that the sound wave velocities and the elastic moduli affected by the processing route and depend not only on the attained density but also on the consolidation temperature. Pressure-less sintering at low temperature <1100°C barely affects the density but substantially the sound velocity and the elastic moduli. In this paper we show that there is linear correlation between the shear and the longitudinal sound velocities in porous TiAl. This opens the way to use a single sound velocity as a tool for QNDE of porous TiAl alloys. We demonstrate the applicability of an equation derived from the elastic theory and used for porous cubic metallic metals, also in the present study.

Developing a Monitoring Tool to Assess the Fatigue Damage in Ni-Based Superalloys Using Thermoelectric Electric Power Measurements

---**Alex Landau** and Malki Pinkas, Nuclear Research Center-Negev, Beer Sheva, 84190, Israel; Angelique N. Lasseigne-Jackson and David L. Olson, Colorado School of Mines, Golden, CO 80401

---The demand for new non-destructive measurement techniques for materials characterization is rapidly increasing. Electronic non-destructive techniques can allow for a quick and accurate means to monitor material properties and thus integrity. There is a correlation between the electronic properties of a material and its microstructure. Thermo-electric (TEP) measurements are an electronic measurement tool that can be used to assess Microstructural modifications. In this investigation an attempt to correlates TEP values to changes occurring in the microstructure of a super-alloy caused by fatigue. The Seeback coefficient of a Ni-based superalloy specimens was measured in liquid nitrogen, after various fatigue cycles. A correlation was found between the number of cycles and the measured Seeback coefficient. Transmission electron microscopy (TEM) was used to investigate the microstructure of the fatigued specimens in an attempt to correlate between the changes in the TEP values to Microstructural modifications.

Hydrogenization of Intermetallic Compounds Characterized by Magnetic Susceptibility and Thermoelectric Power Measurement

---**Saisamorn Niyomosoan**, Preecha Termsuksawad, David L. Olson, and Branjedra Mishra, Colorado School of Mines, Golden, CO 80401; Ron B. Goldfarb, National Institute of Standards and Technology, Boulder, CO 80305; Gavra Zamir, Nuclear Research Center - Negev, Beer-Sheva 84190, Israel

---The magnetic susceptibility and thermoelectric power of Zr0.9Ti0.1CrxFe2-x intermetallic compounds were investigated as functions of hydrogen content. The alloys are all paramagnetic, with magnetic susceptibility and Seebeck coefficient increasing with the amount of stored hydrogen. The susceptibility is proportional the Seebeck coefficient and to d-electron concentration, consistent with a free-electron model. The paper demonstrates the use of two electronic and magnetic properties measurements to verify the correlation of hydrogen content to physical property measurement.

Applying TEP Measurements to Assess the Aging Stage of a Maraging 250 Steel

---Yoav Snir, **Malki Pinkas**, and Alex Landau, Nuclear Research Center-Negev, Beer Sheva, 84190, Israel; Yaniv Gelbstein, Department of Materials Engineering, Ben-Gurion University of the Negev, Beer-Sheva, Israel

---Maraging steels are age hardenable alloys distinguished by their combination of high strength, high toughness, good ductility and resistance to crack propagation. The microstructure of the as-quenched steel consists of low-carbon high-Nickel Martensite. Aging yields intense hardening due to precipitation of Ni3(Mo,Ti) and Fe2Mo phases. In the over-aged state the precipitate coarsening and the formation of reverted Austenite are responsible to the degradation of the steel properties. The optimal aging treatment depends on the alloy composition and on the thermo-mechanical history, which affects the local chemical and phase compositions. Due to the complexity of the aging process and its sensitivity to prior thermo-mechanical treatments it should be carefully monitored. Currently the identification of the aging state of Maraging steel is mostly based on destructive measurements. Thermoelectric power (TEP) measurements were proved as an effective method for evaluating thermal aging of various alloys including cast duplex stainless steel, Al alloys, Zr alloys and Cu-Al based shape memory alloys. The purpose of the current work was to prove the feasibility of applying TEP measurement as a non-destructive tool to asses the aging state of Maraging steel. Commercial Maraging 250 steel was heated to 510°C for 30-360 minutes. TEP and hardness (Rc) measurements were performed on the as-received and the annealed specimens. XRD measurements were conducted to identify the formation of reverted Austenite and to evaluate changes in the micro-strain caused by the formation and coarsening of the precipitates. A good correlation was found between the TEP, hardness and micro-strain values as a function of the aging time. Compared to hardness, the TEP values were found to be more sensitive to the aging state. Transmission electron microscopy was used to identify aging induced microstructural modifications which may explain the observed changes in the TEP values.

A PAL and Optical Transmission Study of Damage Evolution in Irradiated Sapphire (á-Al2O3)

---**Itamar Israelashvily**, Sharon May-Tal Beck, Oded Shahal, Zvi Berant, and Arie Beck, Physics Department, Nuclear Research Center Negev, P. O. Box 9001, Israel; Moshe Ganor, Material Engineering Department, Nuclear Research Center Negev, P. O. Box 9001, Israel; Amnon Moalem, Physics Department, Ben-Gurion University of the Negev, P. O. Box 653, Beer-Sheva, Israel

---Neutron irradiation damage in Sapphire and its evolution with heating temperature was studied by Positron Annihilation Lifetime (PAL) and Optical Transmission (OT) techniques. These methods are sensitive to point defects in the bulk material, specifically to aluminum and oxygen vacancies, respectively. Six Sapphire samples were neutron irradiated to doses of {1,2,3,4,5,6}*10^18n/cm^2. The sample irradiated to a dose of 5*10^18n/cm^2 was then annealed to temperatures between 543K and 1773K for 30 minutes. PAL measurements show existence of Al-vacancies within un-irradiated reference samples. The vacancy concentration increases significantly during irradiation, becoming high enough to trap all positrons already after irradiation to a dose of 1*10^18n/cm^2. After annealing to ~800K larger clusters of vacancies are detected, interpreted as voids. Their intensity increases as the annealing temperature rises. After annealing to 1773K the voids disappear but the concentration of vacancies remains high. OT measurements show complete optical absorption in single O-vacancies already at a dose of 1*10^18n/cm^2, and growth of di-vacancies concentration with the increasing dose. After annealing to 1773K the concentration of O-vacancies has reduced significantly. Both PAL and OT results demonstrate remaining of Al-vacancies after annealing to a high temperature (1773K), with larger concentration than in an un-irradiated material.

Study on In-Situ Diffusible Hydrogen Sensor for Welded HSLA Steel

---**Yeong-Do Park**, Dept. of Advanced Materials Engineering, Dong-Eui University Busan 614-714, Republic of Korea; Yang-Do Kim, School of Materials Science and Engineering, Pusan National University Busan 609-735, Republic of Korea; Young-Seok Kim, Korea Institute of Industrial Technology, Busan Research Center Advanced Manufacturing Technology Team, Busan, 609-735, Republic of Korea; David L. Olson, Colorado School of Mines, Golden, CO 80401

---Diffusible hydrogen contents of welds need to be measured to avoid hydrogen cracking in weldment of high strength steels. Unlike other elements in weld metal, hydrogen diffuses very quickly at normal room temperature, and hence, difficulties occur in accurate measurement. Several methods are currently being used, which are the Japanese method (JIS Z 313-1975), the International Institute of Welding (IIW) method (ISO 3690-1977), and the AWS standard (ANSI/AWS A4.3-93). However, these methods do not give identical results when applied to identical conditions. Therefore, this investigation was attempting to correlate the measured TEP coefficient values with diffusible hydrogen content measured by AWS standard method. TEP measurement was studied for application as in-situ diffusible hydrogen sensor for welded high strength low alloy (HSLA) steel. The results of TEP measurement are shown to be sensitive to the weld diffusible hydrogen content in low temperature (- 80°C) measurement and almost thirty times faster than standard diffusible hydrogen test.

Session 10

SESSION 10
NEW TECHNIQUES AND APPLICATIONS
R. Zoughi, Chairperson
Ballroom C

8:30 AM **A Noninvasive Pressure Measurement Technique and the Potential for Integrated Temperature Compensation**
---**M. J. Guers**, C. J. Fontana, and B. R. Tittmann, The Pennsylvania State University, Department of Engineering Science and Mechanics, University Park, PA 16802-6812

8:50 AM **Status of FAA Studies in Thermal Acoustics**
---**J. A. Lively**, Pratt & Whitney MPE/NDE, West Palm Beach, FL 33410

9:10 AM **Digital Audio Signal Processing and NDE: An Unlikely, but Valuable, Partnership**
---**P. Gaydecki**, School of Electrical and Electronic Engineering, University of Manchester, P. O. Box 88, Manchester M60 1QD, United Kingdom

9:30 AM **Prediction of the Propagation and Leakage of Torsional Waves in a Waveguide of Arbitrary Cross-Section Immersed in a Fluid**
---**Z. Fan** and M. J. S. Lowe, Imperial College, Mechanical Engineering, London, United Kingdom; M. Castaings and C. Bacon, Bordeaux University, Physical Mechanics Laboratory, Talence, France

9:50 AM **Ultrasonic Crack Monitoring Using SH Waves [at High Temperatures (>500°C)]**
---**F. Cegla** and P. Cawley, Imperial College, 682 Mechanical Engineering, Exhibition Road, London SW7 2AZ, United Kingdom

10:10 AM ***Break***

10:30 AM **Ultrasonic Method for Measuring Internal Temperature Profile in Heated Materials**
---**I. Ihara** and M. Takahashi, Nagaoka University of Technology, Department of Mechanical Engineering, Nagaoka, Niigata, Japan

10:50 AM **Investigation of Ultrasonic Methods for Measuring Burning Rate of Solid Propellants**
---**H.-T. Oh**, H.-J. Kim, S.-J. Song, S.-F. Ko, I.-C. Kim, J.-C. Yoo, and J.-Y. Jung, Sungkyunkwan University, School of Mechanical Engineering, Suwon, Kyunggi-do, Korea, Agency for Defense Development, Daejeon, Korea

11:10 AM **Development of a Nondestructive Evaluation Technique for Degraded Thermal Barrier Coatings Using Microwave**
---**M. Sayar**, K. Ogawa, and T. Shoji, Tohoku University, Department of Mechanical Engineering, Sendai, Miyagi, Japan

11:30 AM **Estimation of Low Concentration Magnetic Fluid Density with Giant Magnetoresistance Sensor**
---**S. Yamada**, C. P. Gooneratne, and M. Iwahara, Kanazawa University, Institute of Nature and Environmental Technology, Kanazawa, Ishikawa, Japan; K. Chomsuwan, King Mongkut's University of Technology Thonburi, Department of Electrical Technology Education, Thungkru, Bangkok, Thailand

11:50 PM ***Lunch***

A Noninvasive Pressure Measurement Technique and the Potential for Integrated Temperature Compensation

---**Manton J. Guers**, Christopher J. Fontana, and Bernhard R. Tittmann, The Pennsylvania State University, Dept. of Engineering Science and Mechanics, University Park, PA 16802-6812

---Pressure sensing devices are utilized in many industrial applications. Typically, the pressure sensor must be mounted in direct contact with the pressurized media. However, it is expensive and often difficult to manufacture the necessary access port in pressurized vessels and pipes. Additionally, corrosive environments may prevent the use of internally mounted sensors. Therefore, external clamp-on transducers are an attractive alternative. In this research, a pressure measurement based on ultrasonic waves reflected from a fluid-vessel interface had been investigated. Changing the operating pressure of the vessel leads to a change in the acoustic impedance of the material under pressure. Results have shown that the amplitude of the reflected ultrasonic signal can be related to the internal pressure of the vessel. The experimental measurements are consistent with calculated changes in the reflection coefficient. Experimental measurements have also indicated that this technique is sensitive to temperature variations. Therefore, strategies for an integrated temperature calibration have been investigated.

Status of FAA Studies in Thermal Acoustics

---**John A. Lively**, Pratt & Whitney MPE/NDE, West Palm Beach, FL 33410

---As with many aerospace applications, jet engine components are operated in demanding environments, often at extreme temperature and stress conditions. The predominant used surface inspection method used on these components is fluorescent penetrant inspection. Research has been ongoing for a number of years on a new technology using a short burst of low frequency (on the order of 20 KHz) ultrasound to “heat up” cracks and make them visible in the infrared range. The basic premise of the thermal acoustic method is to use an energy source with recent efforts using an ultrasonic horn originally intended for use in ultrasonic welding to excite the component. The energy source causes an increase in local heating, which is detectable with infrared cameras typically used in thermographic inspection. While considerable research is underway, additional information on the sensitivity and applicability of this technique to engine components and alloys is needed prior to widespread use in the aviation industry. The purpose of this program is to provide additional data to determine applicability of this method to engine components. The programs objectives are to: ·evaluate the applicability of thermal acoustic inspection methods for engine materials and components including studies of the process parameters and their relationship to inspection effectiveness; assess the potential of thermal acoustic methods to induce damage in the component and/or cause additional crack initiation/growth; develop preliminary process specifications and associated POD curves.

Digital Audio Signal Processing and NDE: An Unlikely, but Valuable, Partnership

---**Patrick Gaydecki**, School of Electrical and Electronic Engineering, University of Manchester, P. O. Box 88, Manchester M60 1QD, United Kingdom

---In the Digital Signal Processing (DSP) group, within the School of Electrical and Electronic Engineering at The University of Manchester, research is conducted into two seemingly distinct and disparate subjects: instrumentation for nondestructive evaluation, and DSP systems & algorithms for digital audio. We have often found that many of the hardware systems and algorithms employed to recover, extract or enhance audio signals may also be applied to signals provided by ultrasonic or magnetic NDE instruments. Furthermore, modern DSP hardware is so fast (typically performing hundreds of millions of operations per second), that much of the processing and signal reconstruction may be performed in real time. Here, we describe some of the hardware systems we have developed, together with algorithms that can be implemented both in real time and offline. A next generation system has now been designed, which incorporates a processor operating at 0.55 Giga MMACS, six input and eight output analogue channels, digital input/output in the form of S/PDIF, a JTAG and a USB interface. The software allows the user, with no knowledge of filter theory or programming, to design and run standard or arbitrary FIR, IIR and adaptive filters. Using audio as a vehicle, we can demonstrate the remarkable properties of modern reconstruction algorithms when used in conjunction with such hardware; applications in NDE include signal enhancement and recovery in acoustic, ultrasonic, magnetic and eddy current modalities.

Prediction of the Propagation and Leakage of Torsional Waves in a Waveguide of Arbitrary Cross-Section Immersed in a Fluid

---**Zheng Fan** and Michael J. S. Lowe, Imperial College, Mechanical Engineering, London, United Kingdom; Michel Castaings and Christophe Bacon, Bordeaux University, Physical Mechanics Laboratory, Talence, France

---Guided torsional waves in a bar with a non-circular cross section have been exploited by previous researchers to measure the density of fluids. When such a bar is immersed, the velocity of the wave is affected by the density of the fluid. The previous publications have presented thorough measurements of this velocity change in rectangular bars, but predictive models to simulate these effects have only been approximate, because of the complexity of the wave behavior in the non-circular cross-sectional shape. Thus the inversion accuracy has been compromised. We propose and demonstrate a Semi-Analytical Finite Element (SAFE) method to model accurately the propagation velocity and leakage of guided waves along an immersed waveguide with arbitrary non-circular cross section. The method can thus be used for accurate inversion of velocity measurements to find the fluid density. It can also predict the attenuation of the guided waves by leakage from the waveguide into the fluid. Predictions have been made for a variety of cross sections of waveguide, and compared with available experimental measurements and with the results of the earlier approximate models, and work is ongoing to optimize the sensitivity by selection of the waveguide material and cross-sectional shape.

Ultrasonic Crack Monitoring Using SH Waves [at High Temperatures (>500°C)]

---**Frederic Cegla** and Peter Cawley, Imperial College, 682 Mechanical Engineering, Exhibition Road, London SW7 2AZ, United Kingdom

---The development of SH wave probes that can work at high temperatures (>500°C) has opened up the possibility to carry out ultrasonic monitoring using SH waves at elevated temperatures on running plants. The deployment of such monitoring devices can results in substantial economic benefit by continuously supplying information about the state of a critical plant component rather than only at periods of shut down, which can be years apart. This paper presents two different crack size monitoring techniques using SH waves and highlights their advantages and disadvantages. The method of time of flight diffraction (TOFD) that uses the diffracted signal from the crack tip is analyzed for cracks on the near and far side of the specimen relative to the probes. In the other method used to estimate crack size the amplitude drop of the received wave between two receiving probes due to shielding of the incoming wave by the crack is used. Theoretical and experimental results are presented.

Ultrasonic Method for Measuring Internal Temperature Profile in Heated Materials

---**Ikuo Ihara** and Manabu Takahashi, Nagaoka University of Technology, Department of Mechanical Engineering, Nagaoka, Niigata, Japan

---In many materials processes, online monitoring of internal temperature distribution of materials being heated is often very important since the internal temperature is closely related to the productivity and quality of final products. Ultrasound, because of its capability to probe the interior of materials and its sensitivity to temperature, is expected to be a promising candidate for measuring internal temperature. In this paper, a new ultrasonic method for internal temperature measurement is presented. The principle of the method is based on temperature dependence of the velocity of the ultrasonic wave propagating through the material. An inverse analysis to determine the temperature profile in a heated plate is developed and experiments are carried out in order to verify the validity of the developed method. A single side of a steel plate of 30 mm thickness is heated up to about 600 K and ultrasonic pulse-echo measurements are then performed during heating. A change in the propagation time of ultrasonic wave in the heated steel is monitored and used to determine the temperature profile of the steel. The internal temperature profile determined ultrasonically agrees well with that obtained using commercial thermocouples installed in the steel.

Investigation of Ultrasonic Methods for Measuring Burning Rate of Solid Propellants

---**Hyun-Taek Oh**, Hak-Joon Kim, Sung-Jin Song, Sun-Feel Ko, In-Chul Kim, Ji-Chang Yoo, and Jung-Yong Jung, Sungkyunkwan University, School of Mechanical Engineering, Suwon, Kyunggi-do, Korea, Agency for Defense Development, Daejeon, Korea

---To measure burning rate of solid propellants, the strand burner method is widely adopted as a standard technique. But, the strand burner technique measures a burning rate under a constant pressure, so it requires a number of measurements to determine the burning rates at many different pressures. However, ultrasonic technique can measure burning rates as a function of pressure in a single test performed under a constant volume condition. So, in this study, to improve reliability of burning rate measurement using ultrasound, we fabricate an ultrasonic measurement system that can acquire ultrasonic signals and pressure values in a real time fashion, and develop a signal analysis technique. Also, we know that burning rates of solid propellants are varying according to their composition. Thus, burning rates of solid propellants may predicted by measuring sound velocity and attenuation. In this study, performance of new ultrasonic measurement system will be presented by comparing of burning rates using ultrasonic technique to strand burner method. Also, relationship between measured attenuation and sound velocity and burning rate will be presented.

Development of a Non-Destructive Evaluation Technique for Degraded Thermal Barrier Coatings Using Microwave

---**M. Sayar**, K. Ogawa, and T. Shoji, Tohoku University, Department of Mechanical Engineering, Sendai, Miyagi, Japan

---Thermal barrier coatings (TBCs) have been widely used in gas turbine engines in order to protect the substrate metal alloy against high temperature and to enhance turbine efficiency. After service at high temperature, delamination or micro-cracks will initiate in TBC, leading to TBC separation from substrate and ultimately in unexpected gas turbine destruction. TBC failure is primarily attributed to the growth of TGO and partly to TBC degradation. Crack propagation during cyclic oxidation appears to be related to TGO growth. Currently, there are no reliable nondestructive techniques available to monitor TBC integrity over lifetime of the coating. Thus, to detect TBC and TGO thicknesses, a microwave nondestructive technique that utilizes a rectangular waveguide was developed. The rectangular waveguide acts both as a source and receiver of microwave signals. The phase of the reflection coefficient at the interface of TBC and waveguide varies for different TGO and TBC thicknesses. Therefore, measuring the phase of the reflection coefficient enables us to accurately calculate TGO and TBC thicknesses. High sensitivity of this technique enhances the measurement accuracy and resolution. Finally, a theoretical analysis was used to evaluate the reliability of the experimental results.

Estimation of Low Concentration Magnetic Fluid Density With Giant Magnetoresistance Sensor

---**S. Yamada**, C. P. Gooneratne, and M. Iwahara, Kanazawa University, Institute of Nature and Environmental Technology, Kanazawa, Ishikawa, Japan; K. Chomsuwan, King Mongkut's University of Technology Thonburi, Department of Electrical Technology Education, Thungkru, Bangkok, Thailand

---This article describes the measuring methodology of ferrite density of low concentration magnetic fluid injected into live body for therapeutic purposes. The density of magnetic fluid can be estimated by the difference between the magnetic flux density inside and outside magnetic fluid mass under uniform magnetic fields. In order to apply a uniform magnetic flux density to the magnetic fluid model a Helmholtz tri-coil was used. Because of minute differences in the magnetic flux density measurement a high performance magnetic sensor, taking into account its high sensitivity and spatial resolution, is needed. Giant magnetoresistance device with a sensitive area 250 um x 250 um was connected as a bridge circuit and fabricated on the tip of a 2 cm needle. The needle sensor is useful for using in narrow region or inside human body. Experiments were conducted on the magnetic fluid model to verify the estimation capability. The results show that the proposed technique can estimate the magnetic fluid density lower than 10 mgFe/cc. Therefore this technique can be applied to biomedical engineering such as in the confirmation of magnetic fluid density injected to human body for cancer treatment by means of hyperthermia therapy, based on induction heating technique.

Session 11

Tuesday, July 24, 2007

SESSION 11

STUDENT POSTER COMPETITION

Green Center

NOTE: Student posters are to be mounted Monday, July 23rd from 3:00 to 6:00 p.m. for Monday evening judging only-*not public display*. During this period, no identification (author names, institutional names etc.) will be shown on the posters in order to preserve anonymity during judging. They will be open for public viewing with author and institutional titles during the regular Poster Session 11 on Tuesday, July 24th from 1:30-3:00 p.m. For more details on the student poster competition, please see the "Conference Information" document (pages 11-12) on the QNDE web site at: http://www2.cnde.iastate.edu/QNDE/2007/Conference2007.html

- Characterization of Fatigue Damage with Nonlinear Lamb Waves
- Ultrasonic Characterization of Effective Elastic Constants and Texture in Aluminium Correlated with EBSD
- A 3D Semi-Analytical Model for Eddy Current Inspection in Aeronautics: Application to Riveted Structures with Flaw
- Ultrasonic Characterization of Thermal Gradients in a Homogeneous Plate
- Characterization of Dispersive Ultrasonic Rayleigh Surface Waves in Asphalt Concrete
- An Ultrasonic Angle Beam Method for Determining Third Order Elastic Constants Via Acoustoelasticity Measurements
- Discriminating Damage from Surface Variations Via Feature Analysis for Ultrasonic Structural Health Monitoring Systems
- Characterization of Air Voids in Fresh Cement Paste Through Ultrasonic Nondestructive Testing
- Infrared Monitoring of the Powder-Metallurgy Process
- Finite Element Modeling of Elastic Wave Propagation and Defect Interaction in Large, Complex Components
- Fermation Space Mapping for the Improved Inspection of Austenitic Steel Welds
- Continuous, Noninvasive Level Measurement with a Piezoelectric Strip
- On the Solution to the Lamb Problem in an Elastic Half-Space with Quadratic Nonlinearity
- Evaluation of the Temperature Stability of a Low-Frequency A0 Mode Transducer Developed for SHM Applications
- Signal Processing for Sparse Sensor Arrays in Structural Health Monitoring
- Guided Wave Tomography to Evaluate Maximum Depth of Corrosion Patches
- Quantitative Analysis of Surface Barkhausen Effect Measurements
- Lift-Off Performance of Ferrite Enhanced Generation EMATs
- FE and Experimental Investigations of Ultrasonic Guided Waves Diffracted by Adhesive Lap Joints
- The Sensitivity of Guided Waves to the Properties of an Adhesive Layer Between a Metallic Plate and a Viscoelastic Patch
- The Feasibility of Strain Mapping in Engineering Materials by Correlation of Ultrasonic Array Images

3:10 PM ***Break***

Characterization of Fatigue Damage With Nonlinear Lamb Waves

---The goal of this research is to apply the nonlinear Lamb wave technique for evaluating accumulated fatigue damage in relatively thin structural components. To this end, developing a more robust and reliable procedure to accurately measure the second order harmonic amplitude of a Lamb wave is investigated. This is achieved by improving both the generation and detection of the Lamb waves, as well the signal processing, and also by selecting a best mode of propagation. Ultrasonic Lamb waves generated using a Plexiglas wedge transducer are detected with a laser heterodyne interferometer. The experimentally measured Lamb wave signals are then processed with a short-time Fourier transformation (STFT), which yields the amplitudes of the frequency spectrum as a function of time. The ratio of the fundamental to the second harmonic amplitude taken as a relative nonlinearity parameter is calculated. This research then characterizes the change in the nonliterary (parameter) of the material (measured with Lamb waves) caused by monotonic load above the yield stress and fatigue damage under cyclic load of the metallic plates.

Ultrasonic Characterization of Effective Elastic Constants and Texture in Aluminium Correlated With EBSD

---Electron Backscatter Diffraction (EBSD) is a microscopic technique that provides detailed crystallographic orientation information for given samples. It enables the qualitative calculation and visualization of important microstructural properties such as grain size, aspect ratio and the average grain orientation of the aggregate of grains, commonly known as the Orientation Distribution Function (ODF). In order to validate an ultrasonic technique to quantitatively describe texture we are correlating ultrasonic velocity measurements with results from EBSD. The velocity variations as a function of angle from the Rolling Direction in sheet samples are dependent on such qualities measurable from the EBSD technique. We describe a modified technique to extrapolate the three independent Orientation Distribution Coefficients (ODCs) W400, W420 and W440 for cubic structures from the Bunge-Euler angle data determined through EBSD scans as a description of texture within the sample. EBSD results, taken from through-thickness scans to eliminate the errors that arise with surface-to-bulk inhomogeneity, for rolled Aluminium sheets are discussed and compared to the ODCs obtained using an ultrasonic EMAT-EMAT S0 Lamb wave velocity measurement system.

A 3D Semi-Analytical Model for Eddy Current Inspection in Aeronautics: Application to Riveted Structures With Flaw

---Eddy current is currently the operational technique used for fastener inspection which is an important issue for the maintenance of aircraft structures. The industry calls for faster, more sensitive and reliable non-destructive testing techniques for fastener inspection. In order to reduce the development time and to optimize the design and the performances assessment of an inspection procedure, the CEA and EADS have started a collaborative work aiming at extending the modeling features of the CIVA non destructive simulation platform to the case of flaw detection in a fastened assembly. In this framework, an approach based on the Volume Integral Method using the Green dyadic formalism has been developed and optimized in order to increase computation efficiency. The configuration under consideration consists in a layered planar structure with a flaw nearby a fastener. In a previous communication, we presented a model enable to handle a fastener in a multilayer structure and validated with experimental data. Since, we worked on the addition of a flaw nearby a rivet in the same structure. The model overcomes a scale issue between the size of the rivet and the one of the flaw, the latter being much smaller in a direction than the former.

Ultrasonic Characterization of Thermal Gradients in a Homogeneous Plate

---The effectiveness of structural health monitoring via ultrasonic methods is seriously compromised by changing environmental conditions such as temperature. Variations in temperature can be spuriously identified as damage owing to thermal expansion or contraction of the material as well as changing of the wave propagation speed. This problem becomes even more serious when temperature changes are inhomogeneous such as when the structure is in unevenly sunlit conditions. The focus of this paper is the detection and characterization of thermal gradients in a homogeneous plate, which is a necessary first step before considering the effect of thermal gradients on monitoring of damage. Experiments were performed by permanently mounting two piezoelectric disc transducers on a homogeneous aluminum plate. Long-time, reverberating signals were recorded from the plate under ambient conditions, homogeneous temperature changes, and thermal gradients. The gradients were generated by local heating of a small area on the plate, and signals were recorded during cooling until steady state conditions were reached. Signals from both homogeneous temperature changes and thermal gradients were compared with the baselines using various metrics such as squared error, drop in correlation coefficient, loss of local temporal coherence, and time-dependent time-shift. These metrics were evaluated in terms of their ability to detect and characterize thermal gradients as compared to homogeneous temperature changes.

Characterization of Dispersive Ultrasonic Rayleigh Surface Waves in Asphalt Concrete

---This research focuses on the application of ultrasonic Rayleigh surface waves to nondestructively characterize the mechanical properties and structural defects (segregation of aggregates) in asphalt concrete. An efficient wedge technique is developed in this study to generate Rayleigh surface waves that is shown to be effective in characterizing Rayleigh waves in this highly viscoelastic (attenuating) and heterogeneous medium. Experiments are performed on an asphalt-concrete beam produced with and without segregation. Ultrasonic techniques using both a tone burst and a pulse are examined and their results are compared to each other and to that of a reference material. Ultrasonic attenuation coefficients and wave speeds are measured in the frequency range of 20 kHz to 100 kHz. Experimental results also show the relative dominance of material absorption over aggregate scattering in the total attenuation coefficient. This quantitative knowledge of scattering will serve as useful information to determine segregation volume and to ensure performance of asphalt concrete.

An Ultrasonic Angle Beam Method for Determining Third Order Elastic Constants Via Acoustoelasticity Measurements

---Ultrasonic measurements of acoustoelastic constants, which relate wave speed changes to applied loads, are one of the few methods for experimentally determining third order elastic constants. A typical set of measurements involves multiple experimental setups using both longitudinal and shear transducers with directions of propagation both parallel and perpendicular to the direction of applied uni-axial stress. Experiments are generally tedious, time-consuming, and require access to both sides of a specimen, and can be problematic when the direction of propagation is parallel to the loading direction. Here we consider an angle beam technique where two transducers are mounted on the same side of a specimen. Due to beam spread, multiple echoes can be recorded from a single test setup, providing more information than is possible from a normal incidence configuration. The general theory of acoustoelasticity is specifically considered for longitudinal and shear wave propagation at an angle to the principal stress directions for homogeneous and isotropic materials, and third order elastic constants are derived from the various acoustoelastic constants. The number of required measurements is compared to the number required for normal incidence measurements. Experimental results are shown for several materials and are compared to previously published third order elastic constants.

Discriminating Damage From Surface Variations Via Feature Analysis for Ultrasonic Structural Health Monitoring Systems

---Benign environmental effects, including temperature and surface condition changes, can adversely affect the performance of ultrasonic structural health monitoring systems because ultrasonic waves propagating over long distances are sensitive to these changes as well as to damage. Compared to temperature, the problem of surface condition changes is more difficult to formalize because of their variability in terms of type, location and extent. In this paper, we systematically investigate the effects of benign surface variations with two simplified experiments where well controlled and typical disturbances are applied to exposed surfaces in conjunction with damage. The specimens are two aluminum plates of different sizes, and surface variations considered include water, oil droplets, and oil-coupled brass bars. The approach is to find selective features which are sensitive to damage but insensitive to the applied surface conditions. Features considered are derived from the time and time-frequency domains, and also from the matching pursuit decomposition of ultrasonic signals. Experimental results show good performance in detecting damage in the presence of the applied surface variations, and illustrate a strategy for dealing with the problem of surface condition changes for ultrasonic structural health monitoring systems.

Characterization of Air Voids in Fresh Cement Paste Through Ultrasonic Nondestructive Testing

---It is understood that the performance of entrained air voids in cement paste is dependent on their size and distribution, or spacing factor. However, conventional methods for qualifying air content, such as the Pressure Method, Volume Method, and Gravimetric Method, measure total (i.e., entrained and entrapped) air volume and cannot assess spacing; spacing is measured through petrographic methods, which can be time-consuming and costly to perform. The objective of the research thus being undertaken is to seek a means to characterize the air voids in fresh cement-based materials - particularly air-entrained voids - through the use of ultrasonics. Current efforts focus on developing a suitable and reliable means to contain and test fresh cement paste specimens over the first several hours of hydration. Ultrasonic readings - through transmission and pulse echo - are taken every 15 minutes over the first 20-24 hours of hydration. With proper consideration of shrinkage effects, it is believed that the ultrasonic test data can provide a proper means to distinguish and characterize non-air-entrained and air-entrained pastes in the fresh state.

Infrared Monitoring of the Powder-Metallurgy Process

---Quality-control for powder metallurgy components proves to be a major challenge since standard non-destructive evaluation techniques are not applicable for the pre-sintered state. Due to high production speeds, low strength and delicate material compositions the testing approach of powder metallurgy compacts should ideally be one hundred percent contact-less, real time, and reliable. This paper describes an inspection approach for the detection of surface cracks and subsurface defects in the important, early-stage manufacturing process of powder metallic compacts. Our thermographic detection system is configurable to be passive for online testing where we have to rely on residual heating emanating from the parts when they exit the high pressure compaction machine. A second configuration is active thermography that utilizes induction heating as an external heat source for more comprehensive evaluation. This second approach proves to be very useful and practical for the detection of subsurface defects and small surface cracks. We will discuss the theoretical basis for the detection system, including the analytically predicted, transient temperature behavior in the part with simulated subsurface defects to assess the defect /energy interaction. We will then present results from practical tests carried out in a production environment.

Finite Element Modelling of Elastic Wave Propagation and Defect Interaction in Large, Complex Components

---An Inspection Qualification (IQ) must be completed before the inspection of a safety critical component can take place. Modelling can be used to support the IQ process and demonstrate inspection capability in a cost and time efficient manner. One appropriate modelling technique to simulate elastic wave propagation and the interaction between the wave and a defect is Finite Element (FE) modelling. In practical NDE applications, large welded components with complex geometries are often inspected. Due to its size and complexity it is typically not possible to use an FE modelling approach to model the entire component. Original work by Castaings et al has been further developed by Drozdz et al to generate the Absorbing Layers using Increasing Damping (ALID) technique to facilitate the modelling of acoustic waves in unbounded elastic media. ALID is used to model the inspection of a large welded component containing a range of known defects. The simulated results are compared to experimental data and demonstrate the validity of the modelling approach.

Fermation Space Mapping for the Improved Inspection of Austenitic Steel Welds

---Inspection of austenitic welds is particularly difficult because the materials tend to form anisotropic grains resulting in an inhomogeneous structure whose properties are specifically unknown. These grains, which are of a dimension comparable to the applied ultrasonic wavelength, are responsible for both scattering and beam-steering. A reliable method of ultrasonic NDE would remove the need for radiography, reducing inspection time and cost. The poster will present a novel approach to inspection of austenitic steel welds. The geometry of the real space is mapped to a Fermatian space such that the material becomes uniformly isotropic and homogeneous, unique to a specified point source or receiver. This approach will enable the exploitation of the large body of knowledge available in conventional imaging to tackle this complex application. Illustrations of maps of example welds with defects will also be discussed.

Continuous, Noninvasive Level Measurement With a Piezoelectric Strip

---Continuous level measurements are vital for process control in many industrial applications. Frequently, continuous measurements employ sensors which are mounted on the inside of the containment vessel. However, an internal sensor may not be acceptable in certain applications. For example, internally mounted equipment may be an obstruction or the contents of the vessel may be corrosive. An alternative approach is to use external, clamp-on sensors which can interrogate through the vessel wall. Typically, external sensors measure in a point-wise fashion. Thus, a network of multiple sensors and special electronics is required to obtain a reasonably continuous level measurement. However, the complex wiring and electronics requirements may not be desirable. In this research, a single transducer consisting of a long strip of piezoelectric material has been investigated for a non-invasive level measurement. The relatively large surface area of the piezoelectric strip transducer provides a beamwidth which spans the tested length of vessel wall. Results indicate that a single piezoelectric strip transducer can provide a continuous, noninvasive level measurement on a single data collection channel. Both theoretical calculations and experimental tests showed that the transducer's response is directly proportional to how much of the ultrasonic beam is incident on air-versus-water. The experimental results demonstrated excellent agreement with theoretical predictions.

On the Solution to the Lamb Problem in an Elastic Half-Space With Quadratic Nonlinearity

---The consideration of a half-space subjected to a line load on the surface is one of the well-known Lamb problems. Even since Lamb's original solution, numerous investigators have obtained solutions to many different variants of the Lamb problem. However, most of the solutions existing in the current literature are limited to wave propagation in a linear elastic half-space. In this work, we consider the Lamb problem in an elastic half-space with quadratic nonlinearity. For this, the problem is first formulated as a hyperbolic system of conservation laws, which is then solved numerically using different numerical approaches such as Flux Limiter as well as Central Schemes. The numerical methods are implemented using the packages CLAWPACK and CentPack. The accuracy of the various numerical methods is in a first step studied by comparing the numerical solution with the analytical solution for a half-space with linear response (the original Lamb's problem). Furthermore, the adherence of the free surface condition is evaluated in both the linear and nonlinear cases. For the latter scenario, numerical results for the half-space with quadratic nonlinearity are studied using signal-processing tools such as the Fast Fourier Transformation in order to analyze and interpret any nonlinear effects.

Evaluation of the Temperature Stability of a Low-Frequency A0 Mode Transducer Developed for SHM Applications

---A piezoelectric-based transducer generating high purity A0 mode guided waves at low frequencies (around 20kHz) was developed. The through-thickness resonance of a piezoelectric element was lowered to the frequency region of interest by use of backing masses and low-stiffness front layers. Soft front layers also reduced significantly the transmission of in-plane displacements caused by Poisson ratio effects in the piezoelectric element to the structure. Parametric studies were undertaken by varying the backing mass length, the transducer diameter and the thickness of the front layer. The thickness of the plates on which the transducers were operated was found to be a critical issue and these effects were evaluated. Results obtained by FEM were validated by experimental measurements and showed that signals with A0/S0 energy ratios substantially above 40dB can be obtained. The amplitude, phase and frequency stability of signals produced by these transducers and the general robustness of an experimental pitch-catch system were evaluated in a temperature controlled environment. This led to optimal choice of materials and assembly techniques.

Signal Processing for Sparse Sensor Arrays in Structural Health Monitoring

---Ultrasonic guided waves offer the possibility of inspecting large areas from a small number of sensor positions. However, inspection of complex structures is difficult as the reflections from different features overlap. Estimating the number and amplitude of the wave packets contained in ultrasonic time traces is therefore crucial for the development of a successful guided wave inspection system, in order to enable damage to be detected and located by identifying changes in the measured signal over time. This paper investigates the use of deconvolution methods to address this problem. A suitable deconvolution approach for Structural Health Monitoring must be able to resolve closely spaced events and to distinguish reflections due to the presence of a defect from reflections caused by structural features. We have considered two very well established approaches which have been extensively used in the past in different applications:(i) Wiener filter (ii) Maximum-likelihood deconvolution (MLD). The first approach represents the most commonly used method in geophysics and oil exploration; both its non optimal and optimal formulations have been evaluated. In the field of maximum likelihood deconvolution, we have studied the possibility of using one of this family of techniques, the Single Most Likely Replacement (SMLR). To assess the capability of these methods, numerical tests have been carried out in order to simulate typical configurations that could be of interest for SHM applications.

Guided Wave Tomography to Evaluate Maximum Depth of Corrosion Patches

---The evaluation of the maximum depth of corrosion patches is a major issue in the oil and aerospace industries. In this context, Lamb wave tomography is a potentially attractive technique. This approach is not new and it has been used in the past to detect and size defects in a range of applications. The aim of tomography is to reconstruct the spatial distribution of the material properties of an unknown object with projection data. In our case, a projection corresponds to a set of line integrals of the time-of-flight of a specific Lamb wave mode through a corrosion patch (the object) at a given angle and the property to be reconstructed is the depth profile. The accuracy of the reconstruction depends on the guided modes and frequencies employed. The higher the dispersion of a mode the more sensitive it is to depth changes. The choice of the frequency is based on a trade-off between resolution and number of propagating modes. It is also essential to select a point of operation which facilitates the evaluation of the time-of-flight. Mode conversion at the defect makes the estimation of the time-of-flight more complicated. Hence for a short propagation distance multiple modes are superimposed in the time domain and the estimation of the time-of-flight is not straightforward. This paper discusses optimal testing conditions initially based on finite element simulations and investigates various methods to achieve a robust estimation of the time-of-flight.

Quantitative Analysis of Surface Barkhausen Effect Measurements

---The Barkhausen effect, sometimes described as Barkhausen noise, is the result of domain wall motion past pinning sites inside ferromagnetic materials. Our recent work has investigated permeability-independent measurements of the Barkhausen effect, made possible by directly controlling the magnet circuit flux and its derivative. This approach, as opposed to control of the excitation coil current, improves on Barkhausen effect measurement repeatability and also our ability to analyze the resulting waveforms. In this paper, quantitative measurement and analysis techniques that can be applied to the measured waveforms are demonstrated. These start with single Barkhausen events, and expand to all the measured events for a full sweep around the hysteresis loop. A set of non-redundant parameters, useful for the characterization and analysis of the Barkhausen effect, is presented. The relationship between these parameters and materials properties such as the pinning site distribution, texture and residual stress is discussed.

Lift-Off Performance of Ferrite Enhanced Generation EMATs

---Electromagnetic Acoustic Transducers (EMATs) are non-contact ultrasonic transducers capable of generating wide-band ultrasonic waves on electrically conductive and magnetostrictive samples. The lack of physical contact makes EMATs particularly suitable for online inspection applications, or situations where samples may be moving or hot. The generation efficiency of a given EMAT on a given sample is dependent on the "lift-off", which is the distance between the EMAT and the sample surface, efficiency dramatically reducing with increased lift-off. This requirement to be in close proximity imposes a practical limit of operation and changes in lift-off due to phenomena such as sample vibration can have practical implications in certain NDE applications. This paper describes some results from experiments comparing the performance of a ferrite enhanced EMAT design to one of our 'standard' EMATs, where we have substituted the permanent magnet from the standard EMAT with a suitable ferrite material. When the EMAT coil is placed in proximity to the ferrite, but not wrapped around the ferrite, the increase in the generated eddy current amplitude is significant whilst the inductance or bandwidth of the EMAT is not significantly effected. Using a ferrite material eliminated the eddy current loss in the permanent magnet, and also amplifies the self-field generation mechanism, which generates a repulsive normal force on the sample surface. Direct experimental results show that the generation efficiency of the standard EMAT is higher than the ferrite enhanced EMAT when lift-off is small. However, the ferrite enhanced EMAT generation efficiency can be higher at large lift-offs and is also less sensitive to lift-off variations. Although the example we describe here only applies to EMAT generation, there are situations where ferrite could be used to enhance detector efficiencies.

FE and Experimental Investigations of Ultrasonic Guided Waves Diffracted by Adhesive Lap Joints

---Despite considerable efforts in the last decades to find reliable NDT methods for the control of adhesive joints, the correlation between the bond strength and the ultrasonic measurements is not yet well established. Moreover, the durability of adhesive bonding remains unable to be determined by non-destructive methods. In this paper, the adhesive lap joints between two aluminum plates are first investigated by a finite element approach to compute the transmission and reflection coefficients of Lamb modes and their conversion through the joint. The joint is simulated with the classical “springs model” for which the normal and tangential stiffnesses can be adjusted to represent the quality of the joint. This model is confronted to experimental measurements performed on adhesive lap joints for which the quality of the glue is such that the ultimate stress is known to have very different values. In order to get reproducible measurements and to satisfy the non-contact and the unilateral access requested for the industrial applications, the excitation and detection of the fundamental ultrasonic guided modes are performed with air-coupled transducers.

The Sensitivity of Guided Waves to the Properties of an Adhesive Layer Between a Metallic Plate and a Viscoelastic Patch

---The Centre Essais Aeronautique of Toulouse is concerned by the repair of metallic structures using carbon-epoxy patches bonded with an adhesive layer. In order to guarantee the quality of this bond, the sensitivity of ultrasonic guided waves is investigated. The results presented here concern a preliminary study the purpose of which is to apprehend the best mode-frequency configurations to evaluate the cohesive and/or adhesive properties of the bond layer. In this study, the patch is made of Plexiglas and the metallic structure is an aluminium plate, in order to avoid difficulties due to the anisotropy of carbon-epoxy patches or to metallic structures of complex geometries. Two FE models are used to predict the effects of the bond properties on wave modes propagating along the aluminium plate, and transmitted past the patch: one spring model and one layer model, this latest being shown to be more suitable. This model takes into account the viscoelasticity of both the adhesive layer and patch, and this is shown to be of significant importance. A parametric study, which consists in varying the frequency and the properties of the bond, is presented as a contribution to the establishment of possible strategies for testing bonds.

The Feasibility of Strain Mapping In Engineering Materials by Correlation of Ultrasonic Array Images

---The non-destructive measurement of stress and strain is of interest in many engineering applications. It is known that surface displacement, and hence strain, can be measured using the correlation of optical speckle patterns. In this paper a similar approach is adopted, except that correlation is performed on the speckle in high frequency ultrasonic array images. This has the key potential advantage that the internal strains are measured. This paper describes and investigation into this concept and compares and contrasts the results on metallic structures with those obtained using elastography in the medical field. Experiments are described in which an ultrasonic array was used to generate high resolution speckle images of the scattering from the microstructure within various materials including grains in steel and the fibre bundles within a carbon composite laminate. The full matrix of transmit-receive signals from the array was post processed to synthetically focus the array on every point within the field of view. Cross-correlation was then used to find the displacement of the speckle images and the result compared to the known displacement. A mathematical model is also described that allows the performance limits of this technique to be quantified, the aim being to obtain high accuracy displacement measurement map with a fine spatial resolution.

SESSION 11 – POSTERS
ACOUSTIC EMISSION AND GUIDED WAVES AND DEMONSTRATIONS
Green Center

1:30 PM

Acoustic Emission and Guided Waves

Plate Wave Transmission in Integrally Stiffened Plates
---**R. A. Roberts**, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

Array-Based Acoustic Leak Location in Spacecraft Structures
---**D. E. Chimenti**, R. Reusser, R. Roberts, and S. Holland, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

Ultrasonic Guided Waves for Health Monitoring of High Pressure Composite Tanks
---**M. Castaings** and B. Hosten, Laboratoire de Mécanique Physique, UMR CNRS 5469, 351 cours de la Libération, Université Bordeaux 1, 33400 Talence, France

Visualization of Guided Wave Propagation with Laser Doppler Vibrometer Scanning on Curved Surfaces
---**T. Hayashi** and Y. Kojika, Nagoya Institute of Technology, Faculty of Engineering, Nagoya, Japan; K. Kataoka and M. Takikawa, East Japan Railway Company, Technical Center, Saitama, Japan

Demonstrations

Homodyne Multi-Channel Laser-Ultrasonic Receiver
---**B. F. Pouet**, S. Breugnot, and P. Clemenceau, Bossa Nova Technologies, Venice, CA 90291

Demonstration Display of Prototype Scanning NIR Imaging Device
---**G. Diamond**, P. Pallav, and D. A. Hutchins, University of Warwick, School of Engineering, Coventry, W. Mids., CV47AL, United Kingdom

Determination of Porosity Content in Composites by Micrograph Image Processing
---**A. H. Kite**, D. K. Hsu, and D. J. Barnard, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

Nondestructive Optical Metrology of Thin Film Tape Head Structures Using Scanning Laser Confocal Microscopy
---J. A. Schwenn[1] and **D. B. Quinn**[2], [1]SUN Microsystems, Quality Management Systems, Louisville, CO 80027, [2]Olympus Industrial America, Micro-Imaging Division, Orangeburg, NY 10962

3:10 PM ***Break***

Plate Wave Transmission In Integrally Stiffened Plates

---R. A. Roberts, Center for NDE, Iowa State University, Ames, IA 50011

---An improved array-based method of acoustic emission leak location is being pursued at CNDE for application to spacecraft, under NASA funding. A factor impacting the effectiveness of the method is the signal lost in transmission across stiffening ribs which are integrally machined into the spacecraft outer skins. This paper presents results of an examination of plate wave signal transmission characteristics in these integrally stiffened plates, using a combination of computational tools and experimental observations. Work presented last year examined the transmission characteristics of the individual stiffeners, and specifically the dependence on stiffener geometry. That work demonstrated the potential existence of frequency pass bands for which the stiffener has minimal impact on signal transmission. Work this year extends the study to consider the cumulative effect of transmission/reflection involving numerous stiffeners over an extended area. Work is examining the correspondence between the stiffener bandpass characteristics and the coherence of signal transmission over extended distances. The impact on the ability of source location algorithms to determine source direction is examined.

Array-Based Acoustic Leak Location In Spacecraft Structures

---**D. E. Chimenti**, R. Reusser, R. Roberts, and S. Holland, Center for NDE, Iowa State University, 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. 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 has historically performed less-than-robustly due to signal complications introduced by the multi-mode dispersive propagation characteristics of the plate structures. Our work has pursued the use of spatial array detection to rigorously accommodate the complexity multimode signals. Past work has developed integrated array sensors appropriate for in-flight application. The ongoing work summarized in this paper is examining the performance of these sensors when functioning in the presence of non-ideal structural features, such as an integral stiffening pattern machined into the skin of spacecraft structures.

Ultrasonic Guided Waves for Health Monitoring of High Pressure Composite Tanks

---**M. Castaings** and B. Hosten, Laboratoire de Mécanique Physique, UMR CNRS 5469, 351 cours de la Libération, Université Bordeaux 1, 33400 Talence, France

---Ultrasonic guided wave modes are proposed to control the integrity of high-pressure composite tanks produced by EADS - ASTRIUM, France. The purpose is to demonstrate the potentiality of air-coupled transducers to set-up a contact-less, single-sided technique for testing the moisture content and/or the micro-cracking of carbon epoxy composite wound around a Titanium liner, as well as to detect local disbonds between the composite and the liner. First of all, a laboratory experimental system and numerical tools are used to quantify the sensitivity of specific parameters (wave numbers or attenuations) of some modes to the moisture content and to the micro-cracking in composite plate samples. These results are then used to set an experimental strategy for testing the carbon epoxy component of a high pressure composite tank, and the use of air-coupled transducers for generating-detecting sensitive wave modes is demonstrated. Secondly, the air-coupled system is employed for detecting a local disbond in the tank, simulated by a Teflon insert.---This work was supported by EADS-ASTRIUM and Conseil Regional Aquitain, France.

Visualization of Guided Wave Propagation with Laser Doppler Vibrometer Scanning on Curved Surfaces

---**Takahiro Hayashi** and Yusuke Kojika, Nagoya Institute of Technology, Faculty of Engineering, Nagoya, Japan; Keita Kataoka and Mitsunobu Takikawa, East Japan Railway Company, Technical Center, Saitama, Japan

---Guided waves propagate in pipes and rails with very complex characteristics, which are described as superposition of many modes with different wave velocities and wave structures. Recently, computer simulations for such guided wave propagation have been performed, and their visualization results revealed such complex propagation. However, when we consider obtaining visualization results experimentally, we need to measure waveforms at many points on the surface of such objects as pipes and rails. It is very difficult to measure waveforms at many points on the curved surface using a scanning system with linear motions, which is widely used to obtain C scan images. In this study, therefore, scanning on a curved surface was performed with Laser Doppler vibrometer installed on a robot arm. In order to measure waveforms, a focal point and direction of a Laser beam must be controlled, and therefore techniques for controlling the position and posture of Laser vibrometer with the robot arm was developed. Using this technique, guided wave propagating in a pipe were measured at 1700 points, and some non-axisymmetric modes as well as an axisymmetric mode were able to be visualized.

Homodyne Multi-Channel Laser-Ultrasonic Receiver

---**Bruno F. Pouet**, Sebastien Breugnot, and Philippe Clemenceau, Bossa Nova Technologies, Venice, CA 90291

---Recently, we demonstrated that a robust interferometer for remote detection of ultrasound could be achieved based on multi-channel random-quadrature detection. This interferometer is very well suited for industrial measurements where single-shot detection of ultrasounds at frequency below 20MHz is of interest. Here, we propose a new demodulation scheme that is better suited for detection of small ultrasonic signals buried in background noise. For this new demodulation scheme, we use the same architecture based on multi-channel detection. Homodyne interference signals are expressed as sine or cosine functions of the phase difference and the knowledge of this phase is required in order to know the sign of the transfer function for the very small, high-frequency, phase variations caused by ultrasound. We will demonstrate that a simple and robust demodulation that removes the sign ambiguity of the transfer function can be achieved, leading to an output signal that is proportional to the small ultrasonic surface displacement. This linear detection scheme exhibits very high sensitivity, with a theoretical signal-to-noise ratio identical to an ideal homodyne Michelson interferometer. A breadboard prototype will be displayed and demonstration will be carried out with the measurement of ultrasound on unprepared, rough sample surfaces.

Demonstration Display of Prototype Scanning NIR Imaging Device

---**G. Diamond**, P. Pallav, and D. A. Hutchins, University of Warwick, School of Engineering, Coventry, W.Mids, CV4 7AL United Kingdom

---A demonstration of a novel application of near infrared (NIR) imaging will be displayed that can be used to provide images of many different materials and objects. It is effectively a very low cost non-ionizing alternative to many applications currently being investigated using electromagnetic waves at other frequencies, such as THz and X-ray imaging. This alternative technique can be realized by very simple and inexpensive electronics and is inherently far more portable and easy to use. Applications are expected to encompass general purpose NDE tasks, medical applications and security screening The acquisition of real-time transmission imaging results from this technique will demonstrated operating in situ on suitable examples appropriate to industrial quality control, food inspection and various security applications. The display will be consist of small bench-top device, with a footprint no more that 2’ square., weighing about 10 lbs and real-time imaging results will be displayed on an accompanying laptop computer. It is possible that a miniature model conveyer belt (4 inches wide and 3 feet long) would be used too for certain demonstrations. Power requirements would be minimal - ordinary domestic power sockets - and a bench-top display area of 8’ by 4’ would be ideal, though smaller sized tables are also acceptable.

Determination of Porosity Content in Composites by Micrograph Image Processing

---**Adam H. Kite**, David K. Hsu, and Dan J. Barnard, Iowa State University, Center for NDE, 1915 Scholl Road, 162 ASC II, Ames, IA 50010

---A method to determine the porosity content of a composite lay-up by processing the micrograph images of the laminate is discussed. The porosity content of a composite structure is critical to the overall strength and performance of the structure. The determination of the porosity content is often done by the acid digestion method. The acid digestion method requires the use of chemicals and costly equipment that may not be available. The image processing method developed utilizes a free software package to process micrograph images of the test sample. The process can be automated with simple scripts within the free software. The results from the image processing method are shown to correlate well with the acid digestion results.

Nondestructive Optical Metrology of Thin Film Tape Head Structures Using Scanning Laser Confocal Microscopy

---J. A. Schwenn[1] and **D.B. Quinn**[2], [1]SUN Microsystems, Quality Management Systems, Louisville, CO 80027; [2]Olympus Industrial America, Micro-Imaging Division, Orangeburg, NY 10962

---Critical dimension measurements of thin film tape head structures has typically been performed using methods such as scanning electron microscopy (SEM) for lateral (X and Y) dimensional analysis and atomic force microscopy (AFM) for height (Z) measurements. These traditional methods however have some drawback in that they are time consuming, generally destructive, and require large capital investment. This paper describes an alternative method using an Olympus LEXT OLS3000 scanning laser confocal microscope for typical constructional analysis of thin film tape heads.

Session 12

SESSION 12

THERMOGRAPHIC AND THERMOSONIC NDE II

X. Han, Chairperson

Ballroom A

3:30 PM **Reliable Crack Detection in Thermosonics NDT**
---**M. Morbidini** and P. Cawley, Imperial College London, RCNDE (Research Centre for NDE), Mechanical Engineering, London, SW7 2AZ, United Kingdom

3:50 PM **Multi-Mode Excitation System for Thermosonic Testing of Turbine Blades**
---**B. Kang** and P. Cawley, Imperial College London, Mechanical Engineering, London, United Kingdom

4:10 PM **Automated Processing of Flash Thermography Data Using Logarithmic Derivatives**
---**S. M. Shepard**, Y. Hou, and J. R. Lhota, Thermal Wave Imaging, Inc., Ferndale, MI 48220

4:30 PM **Tone Burst Eddy Current Thermography (TBET)**
---**K. Balasubramaniam**, Centre for Non-Destructive Evaluation and Department of Mechanical Engineering, Indian Institute of Technology Madras, Chennai 600036, India

4:50 PM **Experimental and Theoretical Study of a Multi-Point Pump Method for Characterizing Thermal Properties of Materials**
---**S. Y. Zhang**, D. Ma, P. K. Kuo, X. D. Xu, and X. J. Shui, Lab of Modern Acoustics, Institute of Acoustics, Nanjing University, Nanjing, China

Reliable Crack Detection in Thermosonics NDT

---**Marco Morbidini** and Peter Cawley, Imperial College London, RCNDE (Research Centre for NDE) Mechanical Engineering, London, SW7 2AZ, United Kingdom

---Thermosonics (also known as Sonic-IR) has potential for detecting small fatigue cracks in metals. A high-power fixed-frequency acoustic horn excites a high-amplitude multiple-frequency cyclic strain in the test-piece which causes heating of the defect by friction. The resulting local increase in temperature can be detected by an IR camera. In this study we prescribe the threshold vibration level that must be achieved at the crack in order to be able to measure a satisfactory temperature rise. Given the non-reproducible and non-stationary nature of the excitation, it was necessary to introduce a unified measure of excitation (which we call Heating Index and is essentially a combination of vibration amplitude and frequency) and to calculate it from the strain recorded during each excitation pulse using the Short Time Fourier Transform method. We calibrated the Heating Index against the measured temperature rise in multiple tests on each of 14 cracked beams with cracks measuring from around 3% to 40% of the total cross section. Then we plotted the thermosonic efficiency of each crack (the ratio of temperature rise to Heating Index) versus crack size to obtain a curve which represents the sensitivity of our implementation of Thermosonics testing. The threshold Heating Index required to reliably detect any crack of predetermined target size can be estimated from this curve and is a function of crack size, camera sensitivity and spatial averaging used to obtain the images.

Multi-Mode Excitation System for Thermosonic Testing of Turbine Blades

---**Bubyoung Kang** and Peter Cawley, Imperial College London, Mechanical Engineering, London, United Kingdom

---Several studies have shown that a rich spectrum of vibration greatly improves the sensitivity and reliability of thermosonic testing. The excitation is usually provided by an ultrasonic horn that is pressed against the structure via a thin layer of compliant material that reduces the chance of surface damage at the contact point. This paper investigates the influence of the clamping method and the excitation signal that is input to the horn. In some cases it is possible to secure the component to be tested in a clamp and to attach the horn to the clamp via a stud. This method significantly increased the vibration amplitude obtained and the degree of excitation of the higher harmonics, and so may be attractive in some applications. With either coupling method, if the horn is excited by a pure sine wave at the horn resonance frequency via a high fidelity power amplifier, the dominant frequencies in the response are the input frequency and its harmonics and sub-harmonics that are generated by non-linearity in the coupling. However, a higher response can be obtained if the excitation frequency coincides with the resonances of the system comprising the component and the excitation system. This has been achieved by employing a chirp input over about 1 kHz centered on the system resonance frequency. Significant vibration amplitudes are then seen at the system resonances in the frequency range of the chirp, and at resonances in the corresponding bands around the harmonics and sub-harmonics of the centre frequency. This multi-mode excitation potentially increases the reliability of the test in cases where damage can be located anywhere in the component, and so may be at a node of some modes of vibration.

Automated Processing of Flash Thermography Data Using Logarithmic Derivatives

---**Steven M. Shepard**, Yulin Hou, and James R. Lhota, Thermal Wave Imaging, Inc., Ferndale, MI 48220

---Early efforts in thermographic NDE were primarily qualitative, based on visual interpretation of image results by a trained inspector. In modern practice, a significant amount of mathematical processing is often performed on the time history of each pixel before an image is presented to the inspector. In general, these though-the-pixel signal processing methods improve overall detection capability, compared to the unprocessed data, or to 2-dimensional image processing methods. However, some methods still rely on detection of contrast in the processed image so that a human inspector must still evaluate each result. Contrast-based methods are only effective where the defect is smaller than the field of view, i.e. the difference between defect-free and entirely defective samples may not be detectable. The logarithmic derivatives of flash thermography time histories can be quantitatively evaluated without comparison to neighboring pixels, thus providing an excellent basis for automated detection. Information about the thermophysical characteristics of a sample can be ascertained from a single pixel. A unique model, based on the well-known Green's function solution for a plate, provides a template for identifying pixels that deviate from uninterrupted diffusion that is characteristic of a defect-free sample. Experimental results on various sample types are presented.

Tone Burst Eddy Current Thermography (TBET)

---**Krishnan Balasubramaniam**, Centre for Non-Destructive Evaluation and Department of Mechanical Engineering, Indian Institute of Technology Madras, Chennai-600036, India

---The so-called Eddytherm technique has been previously reported where continuous induction heating using eddy currents is employed, along with thermal imaging, for NDT applications of defect detection during manufacturing 1. Our paper reports on a Tone Burst Eddy Current Thermography (TBET) technique that uses short (typically up to a few seconds) tone-burst pulses of eddy-currents induced in a conducting media to generate heating inside the material. Transient diffusion of the heat (thermal energy) inside the material, induced by this pulsed, short-time induction heating, is imaged by measuring the transient temperature profiles on the surface of the material. The presence and characteristics of defects in the material alters the transient surface temperature behavior and thus TBET can be applied to the NDE of conducting materials. Axisymmetric numerical models of conventional transient thermography are taken to benchmark with this new TBET technique. From temperature profile data, temperature contrast information is obtained for a variety of defects at different depths beneath the heated surface. Temperature contrast data obtained using TBET was compared with that obtained from conventional transient thermography data. It was found that the eddy current frequency and, consequently, the skin-depth of the induced field, plays an important role in the effective utilization of this technique. Simulation details and experimental results are presented in the paper. Possible advantages of TBET over conventional flash thermography are also discussed and supported by experimental data.

Experimental and Theoretical Study of a Multi-Point Pump Method for Characterizing Thermal Properties of Materials

---**S. Y. Zhang**, D. Ma, P. K. Kuo, X. D. Xu, X. J. Shui, Lab of Modern Acoustics, Institute of Acoustics, Nanjing University, Nanjing, China

---A multi-point pump method is developed and used to characterize the thermal properties of materials. In the experiment, a multi-mode fiber is as an optical waveguide to make a modulated Ar+ ion laser beam as a multi-point source irradiated on materials. The absorbed optical energy induces a two-dimensional thermal grating in the material. A He-Ne laser beam is grazing incident on the thermal grating, then a diffraction effect is generated. Based on the photo-diffraction theory of thermal gratings, the intensity dependences of the 0th order diffraction beams on the thermal gratings can be obtained, by which the thermal diffusivities of the materials can also be determined due to the thermal grating configurations are closely correlated to the thermal properties of the materials. The thermal diffusivities of silicon crystal and different diamond films deposited on the silicon substrates are studied and determined, which demonstrate that the multi-point pump method is effective for evaluating the thermal properties of films deposited on substrates, even the films are transparent.---
This work is supported by National Natural Sciences Foundation of China, No. 10574073.

Session 13

SESSION 13

BENCHMARKS

L. W. Schmerr, Jr., Chairperson

Ballroom C

3:30 PM **Eddy Current Benchmark Problem**

---T. Chady, **R. Sikora**, and P. Lopato, Szczecin University of Technology, Department of Electrical Engineering, Szczecin, Poland

3:50 PM **Results of the 2007 UT Modeling Benchmark Using Various Semi-Analytical Beam Propagation and Flaw Scattering Codes**

---R. Raillon, S. Chatillon, and **S. Mahaut**, CEA LIST, CEA Saclay, 91191 Gif-sur-Yvette Cedex, France; M. Spies, Fraunhofer-Institute for Nondestructive Testing (IZFP), University of Saarland, Bldg. 37, 66123 Saarbrucken, Germany

4:10 PM **Results of 2007 ECT Benchmark Obtained with CIVA at CEA: Prediction of ECT Inspection Over Tubes with 2D or 3D Flaws**

---G. Pichenot, C. Reboud, R. Raillon, and **S. Mahaut**, CEA LIST, CEA Saclay, 91191 Gif-sur-Yvette, Cedex, France

4:30 PM **Modeling the 2007 Ultrasonic Benchmark Problems**

---**Lester W. Schmerr Jr.**[1,2] and Ruiju Huang[1], [1]Center for NDE and the [2]Dept. of Aerospace Engineering, Iowa State University, Ames, IA 50011

4:50 PM **Model Prediction Results for 2007 Ultrasonic Benchmark Problems**

---**H.-J. Kim** and S.-J. Song, Sungkyunkwan University, School of Mechanical Engineering, 300 Chunchun-dong, Janang-gu, Suwon, Kyunggi-do, 440-746, Korea

Eddy Current Benchmark Problem
---Tomasz Chady, **Ryszard Sikora**, and Przemyslaw Lopato, Szczecin University of Technology, Department of Electrical Engineering, Szczecin, Poland

---This paper describes the proposal of a benchmark activity. The objective of the proposed eddy current benchmark problem is to evaluate accuracy of various numerical or semi-analytical methods in predicting an eddy current probe multi-frequency response. The probe has a complicated structure and it consists of a cylindrical ferrite core with five symmetrically placed columns. A pickup coil is wounded on the central column and four excitation coils are placed on remaining columns in pairs on two perpendicular axes. The resulting flux in the pickup coil in equilibrium state is about zero. The probe was used to test plates made from nickel-base superalloy INCONEL 600. In the plate a set of electrical-discharge-machined flaws having rectangular as well as complicated profiles were introduced. An AC currents consist of 15 harmonic components are applied to the excitation coils. The probe was moved using the X-Y stage over the flaw. In all cases the specimens were examined by placing the probe on the reverse side of the flaws. The acquired data will be send by email to all participants of the benchmark's activity. Additional technical information can be achieved by sending email to tchady@ps.pl.---This work was supported in part by the State Committee for Scientific Research, Poland, under the Grant no: 3T10A 017 30 (2006-2009).

Results of The 2007 UT Modeling Benchmark Using Various Semi-Analytical Beam Propagation and Flaw Scattering Codes
---R. Raillon, S. Chatillon, and **S. Mahaut**, CEA LIST, CEA Saclay, 91191 Gif-sur-Yvette Cedex, France; M. Spies, Fraunhofer-Institute for Nondestructive Testing (IZFP), University of Saarland, Bldg 37, 66123 Saarbrücken, Germany

---This paper presents some applications of ultrasonic (UT) simulation codes developed at IZFP, Germany and CEA, France, those latter being integrated into the CIVA software platform. Those UT simulation codes are dedicated to the prediction of echographic responses of flaws. Results given and discussed are those obtained for the various problems of the 2007 UT benchmark modelling session. These results concern the responses of flat bottomed holes inside curved blocks (concave or convex) inspected with immersed focused probes. The simulation codes are used to investigate the influence of the curvature upon the amplitude response of the flaw with respect to a flat specimen, used as a reference. Comparison with experimental results is also discussed.

Results of 2007 ECT Benchmark Obtained With CIVA at CEA : Prediction of ECT Inspection Over Tubes With 2D or 3D Flaws

---G. Pichenot, C. Reboud, R. Raillon, and **S. Mahaut**, CEA LIST, CEA Saclay, 91191 Gif-sur-Yvette Cedex, France

---The CIVA software developed at the French Atomic Energy Commission for processing and simulating NDT data includes tools for modelling the whole eddy current inspection of a component in which virtual defects are positioned. In this paper, the semi-analytical codes developed within CIVA were used to simulate the eddy current response of flaws inside tubes. These codes are based on Volume Integral Method using the Green's dyad formalism. Primary fields are obtained using different approaches depending on the symmetry of the configuration (for centered axial probes in tubes, for instance, one may use Dodds & Deeds solutions, while off-centered probes are modelled using additional developments). Finally, the sensitivity at reception is predicted using reciprocity argument. Results given and discussed are those obtained for the various problems of the 2007 ECT benchmark modelling session. These results concern the responses of one external groove, one transverse and one longitudinal notch inspected using an axial probe in differential mode scanning along the axis of the tube. Comparison with experimental results is also discussed.

Modeling the 2007 Ultrasonic Benchmark Problems

---**Lester W. Schmerr Jr.**[1,2] and Ruiju Huang[1], [1]Center for NDE and the [2]Dept. of Aerospace Engineering, Iowa State University, Ames, IA 50011

---A set of reference experiments using side-drilled holes forms the first part of the 2007 ultrasonic benchmark study. We will model the measured A-scan responses of these reference experiments using a combination of beam and flaw scattering models coupled to an overall ultrasonic measurement model. The beam model will be a multi-Gaussian model. The flaw scattering models will be based on either the Kirchhoff approximation or more exact numerical methods. We will compare the capabilities of these various models for predicting the measured responses and the underlying incident and scattered wave fields. The second part of the 2007 benchmark is a study of the influence of surface curvature on the response of a flat-bottom hole. We will use similar beam, flaw scattering, and measurement models to simulate the curvature effects.---This work was supported by the NSF Industry/University Cooperative Research Center at Iowa State University.

Model Prediction Results for 2007 Ultrasonic Benchmark Problems

---**Hak-Joon Kim** and Sung-Jin Song, Sungkyunkwan University, School of Mechanical Engineering, 300 Chunchun-dong, Janang-gu, Suwon, Kyunggi-do, 440-746, Korea

---The World Federation of NDE Centers (WFNDEC) has addressed two types of problems for the 2007 ultrasonic benchmark: 1) pulse-echo responses of side-drilled holes with 45¢ªand 60¢ªrefracted shear waves for further investigation of 2004 ultrasonic benchmark problems, and 2) effects of surface curvature on the ultrasonic responses of flat-bottomed hole for model based surface curvature corrections. For solving this year ultrasonic benchmark problems, multi-Gaussian beam models for calculation of ultrasonic beam fields in the side-drilled hole specimens and the curved specimens generated from a planar and a focused transducers, and Kirchhoff approximation and separation of variables method for prediction of far-field scattering amplitudes from the side-drilled holes and the flat-bottomed hole, respectively, will be adopted. Also, system transfer functions will be applied for comparison of model predicted responses to the experimental signals of the side-drilled holes. By integration of the models, we will predict the responses of the side-drilled holes with planar interface and flat-bottomed holes with planar and curved interfaces. For model based surface curvature corrections, the predicted responses of flat-bottomed holes are normalized by predicted signals of a #4 flat-bottomed hole with planar interface. In this presentation, comparison results to the experiments and model based curvature effects on the ultrasonic responses will be presented.

Session 14

SESSION 14
TERAHERTZ IMAGING
H. Ringermacher, Chairperson
Ballroom B

3:30 PM **Modeling of Terahertz Ray Signals for NDE Applications**
---**C.-P. Chiou**[1], R. B. Thompson[1], and J. L. Blackshire[2], [1]Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011; [2]AFRL/MLLP Wright Patterson AFB, OH 45433

3:50 PM **Time Domain Terahertz Detection of Concealed Corrosion Beneath Insulation and Water Intrusion in Composites**
---**D. A. Zimdars** and J. S. White, Picometrix, LLC., Ann Arbor, MI 48104

4:10 PM **The Application of Terahertz Radiation to the Detection of Corrosion Under the Shuttle's Thermal Protection System**
---**Eric I. Madaras**[1], Robert F. Anastasi[2], Jeffrey P. Seebo[3], Stephen W. Smith[4], James L Walker[5], Janice K. Lomness[6], Paul E. Hintze[6], Catherine C. Kammerer[7], William P. Winfree[1], and Richard W. Russell[8], [1]NASA Langley Research Center, Nondestructive Evaluation Sciences Branch, MS 231 Hampton, VA 23681; [2]U.S. Army Research Laboratory, Vehicle Technology Directorate, AMSRD-ARL-VT-SM, Nondestructive Evaluation Sciences Branch, NASA Langley Research Center, MS 231, Hampton, VA 23681; [3]Lockheed Martin, NASA Langley Research Center, MS 231, Hampton, VA 23681; [4]NASA Langley Research Center, Metals & Thermal Structures Branch, MS 188, Hampton, VA 23681; [5]NASA Marshall Flight Center, Damage Tolerance Assessment Branch, EM20 Huntsville, AL, 35801; [6]NASA Kennedy Space Center, Corrosion Technology Laboratory, KT-E, Kennedy Space Center, FL, 32899; [7]United Space Alliance, NASA Kennedy Space Center, Specialty Engineering and Technical Services, USK-507, Cape Canaveral, FL, 32920-4304; [8]NASA Kennedy Space Center, NASA Orbiter Project Office, MV7, Kennedy Space Center, FL, 32899

4:30 PM **Simultaneous Non-Contact Precision Measurement of Microstructural and Thickness Variation in Dielectric Materials Using Terahertz Energy**
---**D. J. Roth**, NASA Glenn Research Center, MS 6-1, 21000 Brookpark Road, Brookpark, OH 44135; J. P. Seebo and W. P. Winfree, Lockheed Martin, NASA Langley Research Center, MS 231, Hampton, VA 23681-2199

4:50 PM **The Potential for Insitu Damage Imaging of Inflatable Space Structures**
---**Eric I. Madaras**[1], Robert F. Anastasi[2], Jeffrey P. Seebo[3], George Studor[4], Douglas L. McMakin[5], Robert Nellums[6], and William P. Winfree[1], [1]NASA Langley Research Center, Nondestructive Evaluation Sciences Branch, MS 231 Hampton, VA 23681; [2]U.S. Army Research Laboratory, Vehicle Technology Directorate, AMSRD-ARL-VT-SM, Nondestructive Evaluation Sciences Branch, NASA Langley Research Center, MS 231, Hampton, VA 23681; [3]Lockheed Martin, NASA Langley Research Center, MS 231, Hampton, VA 23681; [4]NASA Johnson Space Center, Structures Branch, ES2, Houston, TX; [5]Pacific Northwest National Laboratory, Applied Physics, P.O. Box 999 MSIN:K2-31, Richland, WA, 99354; [6]Sandia National Laboratory, P.O. Box 5800, Albuquerque, NM 87185

Modeling of Terahertz Ray Signals for NDE Applications

---**Chien-Ping Chiou**[1], R. Bruce Thompson[1], and James L. Blackshire[2], [1]Center for NDE, Iowa State University, Ames, Iowa 50011; [2]AFRL/MLLP Wright Patterson AFB, OH 45433

---Recently, terahertz ray (T-ray) imaging has emerged as one of the most promising new techniques for NDE applications. This technique, however, is still in its early development, and requires further study. This work explores the use of state-of-the-art computer modeling technologies to study T-ray radiation in media. A series of point source synthesis (PSS) models have been developed, using both the classic Fresnel-Kirchhoff and the refined Rayleigh-Sommerfeld formulations. The flexibility of these models enables us to investigate T-ray propagation through interfaces of various geometry and morphology. That in turn allows us to simulate T-ray interaction with flaws and hence to predict the flaw responses. In this paper, we present preliminary results of T-ray propagation, including the beam field mapping through lens systems within the T-ray emitter. Also presented is comparison between the new PSS model and a modified Gauss-hermite beam model.---This material is based upon work supported by the Air Force Research Laboratory under Contract #FA8650-04-C-5228 at Iowa State University's Center for NDE.

Time Domain Terahertz Detecton of Concealed Corrosion Beneath Insulation and Water Intrusion in Composites

---**David A. Zimdars** and Jeffrey S. White, Picometrix, LLC., Ann Arbor, MI 48104

---We report on the detection of corrosion concealed beneath insulation on metal pipes using time domain terahertz (TD-THz) non destructive evaluation (NDE) imaging. Corrosion can be differentiated due to increased surface roughness and differential reflectivity, altering the returned TD-THz waveform. We demonstrate the location and identification of delaminations and water intrusion in advanced composite materials used in ground based radome panels, shelters and towers using TD-THz imaging. Water has a very high absorption in the THz spectral region in comparison to polymer foam and fiberglass, so the method is very sensitive to water intrusion. The sub-picosecond near single cycle electromagnetic images enabled identification of delaminations of the fiberglass shell and foam. We report a novel TD-THz NDE control system, which is suitably portable for applications such as field examination of radome composites.

The Application of Terahertz Radiation to the Detection of Corrosion Under the Shuttle's Thermal Protection System

---**Eric I. Madaras**[1], Robert F. Anastasi[2], Jeffrey P. Seebo[3], Stephen W. Smith[4], James L Walker[5], Janice K. Lomness[6], Paul E. Hintze[6], Catherine C. Kammerer[7], William P. Winfree[1], and Richard W. Russell[8], [1]NASA Langley Research Center, Nondestructive Evaluation Sciences Branch, MS 231 Hampton, VA 23681; [2]U.S. Army Research Laboratory, Vehicle Technology Directorate, AMSRD-ARL-VT-SM, Nondestructive Evaluation Sciences Branch, NASA Langley Research Center, MS 231, Hampton, VA 23681; [3]Lockheed Martin, NASA Langley Research Center, MS 231, Hampton, VA 23681; [4]NASA Langley Research Center, Metals & Thermal Structures Branch, MS 188, Hampton, VA 23681; [5]NASA Marshall Flight Center, Damage Tolerance Assessment Branch, EM20 Huntsville, AL, 35801; [6]NASA Kennedy Space Center, Corrosion Technology Laboratory, KT-E, Kennedy Space Center, FL, 32899; [7]United Space Alliance, NASA Kennedy Space Center, Specialty Engineering and Technical Services, USK-507, Cape Canaveral, FL, 32920-4304; [8]NASA Kennedy Space Center, NASA Orbiter Project Office, MV7, Kennedy Space Center, FL, 32899

---The Space Shuttle Orbiters are maintained in carefully controlled environments, except during final preparations for launch, flight, and post landing processing. During these times they are exposed to the Florida subtropical environment where formation of corrosion is a concern. Conventional NDE methods are unsuccessful in reliably detecting corrosion on the Orbiters metallic surfaces when the surfaces are covered with various thermal protection systems that mitigate the abilities of those NDE methods. Pulsed Terahertz NDE is being studied as a method for detecting corrosion under the Orbiter's thermal tiles and blankets. The ability to detect corrosion under thermal tiles and thermal felt blankets is demonstrated in a laboratory setting and on a large test article at the Kennedy Space Center (KSC). The laboratory samples consist of induced corrosion spots that range in diameters from 2.54 to 15.2mm and depths from 0.036 to 0.787mm in aluminum substrate materials covered with High Temperature Reusable Surface Insulation tiles or Felt Reusable Surface Insulation blankets. The large test article at KSC has a high fidelity to the Orbiters' structure and its corrosion condition is unknown. Results of those measurements demonstrate the ability to detect artificially manufactured corrosion regions with a depth deeper than 0.13 mm under Shuttle thermal 1" tiles and single layer thermal felt blankets. The large test article results demonstrate measurement flexibility and detection of underlying structural geometry.

Simultaneous Non-Contact Precision Measurement of Microstructural and Thickness Variation in Dielectric Materials Using Terahertz Energy

---**Don J. Roth**, NASA Glenn Research Center, MS 6-1, 21000 Brookpark Road, Brookpark, OH 44135; Jeffrey P. Seebo and William P. Winfree, Lockheed Martin, NASA Langley Research Center, MS 231, Hampton, VA 23681-2199

---This presentation describes a non-contact single-sided terahertz electromagnetic measurement and imaging method that simultaneously characterizes microstructural (egs. spatially-lateral density) and thickness variation in dielectric (insulating) materials. As demonstrated in the article, its use can be especially significant at NASA for evaluating thermal protection system materials such as foams that are currently nondestructively evaluated for flaws using terahertz energy. It is hoped that this method can help as an inspection method for current and future NASA thermal protection system and other dielectric material inspection applications.

The Potential for Insitu Damage Imaging of Inflatable Space Structures

---**Eric I. Madaras**[1], Robert F. Anastasi[2], Jeffrey P. Seebo[3], George Studor[4], Douglas L. McMakin[5], Robert Nellums[6], and William P. Winfree[1], [1]NASA Langley Research Center, Nondestructive Evaluation Sciences Branch, MS 231 Hampton, VA 23681; [2]U.S. Army Research Laboratory, Vehicle Technology Directorate, AMSRD-ARL-VT-SM, Nondestructive Evaluation Sciences Branch, NASA Langley Research Center, MS 231, Hampton, VA 23681; [3]Lockheed Martin, NASA Langley Research Center, MS 231, Hampton, VA 23681; [4]NASA Johnson Space Center, Structures Branch, ES2, Houston, TX; [5]Pacific Northwest National Laboratory, Applied Physics, P.O. Box 999 MSIN:K2-31, Richland, WA, 99354; [6]Sandia National Laboratory, P.O. Box 5800, Albuquerque, N.M. 87185

---NASA is investigating the potential for using inflatable habitat structures for orbital, transfer, and planetary applications. These types of structures are vulnerable to damage from micro-meteoroid and orbital debris. The ability to monitor and assess structural health is an important factor in determining the feasibility of using inflatable technologies for habitat requirements. Performing effective non-destructive evaluation (NDE) of the inflatable habitat layers from the interior during a mission is an essential capability that needs to be developed. This inspection could be used on a routine basis or as needed in a quick-response situation. Potential NDE methods of radar and pulsed terahertz that can measure damage through multiple habitat layers and potentially be developed into hand-held imaging systems are examined. A sample habitat structure with multi-layer construction is impacted with hypervelocity projectiles of different sizes and energy causing a range of damage. A comparison of the strengths and weaknesses of the various techniques is presented.

Session 15

SESSION 15
RELIABILITY AND POD
B. Hosten, Chairperson
Ballroom D

3:30 PM **Reliability of Radiographic Inspection of Girth Weld in Steel Pipelines**
---R. M. Almeida, **J. A. Rebello**, and A. A. Carvalho, Federal University of Rio de Janeiro, Metallurgy and Materials Department, Rio de Janeiro, RJ, Brazil; J. Smid, Oceaneering Inspection Brasil, Rio de Janeiro, RJ, Brazil

3:50 PM **Model Based Ultrasonic Inspection Technique Design and Evaluation**
---**J. G. P. Bloom** and A. W. F. Volker, TNO Science and Industry, Monitoring Systems-Acoustics, Delft, The Netherlands

4:10 PM **Directed Design of Experiments (DOE) for Determining Probability of Detection (POD) Capability of NDE Systems (DOE POD)**
---**E. Generazio**, Agency NDE Specialist, Research and Technology Directorate, National Aeronautics and Space Administration, Langley Research Center, Hampton, VA, NDE Program Manager, Safety and Mission Assurance Office, National Aeronautics and Space Administration Headquarters, Washington, DC

4:30 PM **POD Generator – A Quantitative Assessment of the Performance of an Inspection System Under Specific Conditions Based on Models**
---**A. Mast**, TNO Science & Industry, Monitoring Systems, Delft, The Netherlands

4:50 PM **A Unified Approach to the Model-Assisted Determination of Probability of Detection**
---R. B. Thompson, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

Reliability of Radiographic Inspection of Girth Weld in Steel Pipelines

---Romulo M. Almeida, **Joao A. Rebello**, and Antonio A. Carvalho, Federal University of Rio de Janeiro, Metallurgy and Materials Department, Rio de Janeiro, RJ, Brazil; Jan Smid, Oceaneering Inspection Brasil, Rio de Janeiro, RJ, Brazil

---In this work, radiography was employed as the NDT technique for detection of flaws in circumferential girth welds of steel pipelines used in offshore installations in the petroleum industry. The method of installation involves what is called reeling operation; the pipeline is welded onshore and after is wounded over a rigid circular surface which introduces high level of plastic deformation. For this reason, the weld acceptance criteria for defects must be very strict and the NDT method of inspection must be consequently very reliable and able to detect even very small defects. In a previous paper ("Reliability of the Ultrasonic Technique Applied to Detection of Pipe Weld Defects", QNDE 2006, Portland, OR, USA), results of the UT technique were presented for the manual and automatic inspections for a range of defect sizes that could be considered almost at the lower limit for detection. In a complementary research, the present work aims to optimize the radiographic parameters, which could offer the best detectability conditions for two kinds of weld defects: lack of fusion and lack of root penetration. Two paths of research were followed. In the first one, XRSIM, an x-ray radiographic simulation tool was used. It was so possible to establish the optimal radiographic parameters to reach the lower limit for detection for these two kinds of defects. The second path was essentially experimental: these weld defects were introduced in real girth welds by a strictly controlled welding procedure. The presence and size of these inserted defects after welding completion were checked by a carefully conducted UT inspection, and finally confirmed by cutting the welds. Finally, these defective welds were x-ray inspected using the radiographic parameters previously established by simulation.

Model Based Ultrasonic Inspection Technique Design and Evaluation

---**Joost G. P. Bloom** and Arno W.F. Volker, TNO Science and Industry, Monitoring Systems - Acoustics, Delft, The Netherlands

---Traditionally, new ultrasonic inspection methods are developed using extensive lab measurements on synthetic defects (i.e. side drilled holes or notches). The objective is to establish the reliability of the NDT (determined by the falls call rate and POD) by laboratory experiments. This approach provides limited insight in the interaction of ultrasonic waves with artificial and realistic defects. However, for a thorough insight in the factors that determine the reliability it is necessary to understand the wave field inside the object of inspection. This wave field can be very complex, even in relatively simple geometries. Therefore, we propose the usage of numerical simulation tools. Advanced simulation tools can visualize the full-elastic wave field (including for example wave conversion). This way a connection can be made between the recorded signal and the wave field inside the test object. Moreover, numerical simulations allow easy variation of transducer properties and artificial/realistic defect geometries. These insights will improve the performance of an inspection method and reduce time spent on experimental validation. In this paper we will illustrate this approach on a number of real-life examples.

Directed Design of Experiments (DOE) for Determining Probability of Detection (POD) Capability of NDE Systems (DOE POD)
---**Ed Generazio**, Agency NDE Specialist, Research and Technology Directorate, National Aeronautics and Space Administration, Langley Research Center, Hampton, VA, NDE Program Manager, Safety and Mission Assurance Office, National Aeronautics and Space Administration Headquarters, Washington, DC

---The inspection of failure critical components requires demonstration that the inspection system actually meets the inspection requirements. The capability of an inspection system is established by applications of various methodologies to determine the probability of detection (POD). Directed DOE POD has been developed to provide real-time guidance and an efficient test methodology that accurately yields *observed* POD and *observed* confidence bounds for both hit-miss or signal amplitude testing. Methodology may be applied to demonstrate that inspection systems actually meets the inspection requirements or to determine the capability of inspection systems, and at anytime to serve as a diagnostic tool providing DOE guidance before, during, and after testing. Directed DOE POD has been applied to over 450 data sets including the Space Shuttle thrusters, and external tank sprayed on foam insulation. Directed DOE POD methodology, processes, driving parameters, optimization options, data set classifications, minimization of data set requirements, validation requirements, diagnostic directed recommendations, multiple alternate 90/95 POD options, 90/95 POD flaw size, false call rates, false call confidence bounds, and applications to selected existing new test plan data sets will be presented.

POD Generator – A Quantitative Assessment of the Performance of an Inspection System Under Specific Conditions Based on Models
---**Arjan Mast**, TNO Science & Industry, Monitoring Systems, Delft, the Netherlands

---Process installations and pipelines suffer from degradation, like corrosion and cracking, and therefore have a finite lifetime. The condition of the installation or pipeline is often determined by off-line inspections, employing non-destructive testing techniques. These inspection techniques have their limitations, thus having an uncertainty in terms of detection probability and false call rates. Quantitative knowledge about the performance and uncertainties of inspections can help operators to reduce maintenance cost and to rationalize their maintenance strategy. In the POD generator project, numerical models are being developed and validated, simulating the physics of the degradation mechanisms and the inspections techniques. Also the human factor is taken into account. These validated numerical models can be used to generate so-called Probability Of Detection (POD) curves. This quantitative assessment based on models can then be used to more accurately assess the performance of an inspection system under specific conditions. We will illustrate this project on a number of examples. Within this innovative project all participating companies (N.V. Nederlandse Gasunie, GEP, Sabic, Shell/NAM, YARA, Tronox, Huntsman Polyurethanes, KEMA, AIB Vinçotte, RTD, SGS, Sonovation, Lloyds) are greatly acknowledged for their financial support and fruitful discussions during the project.

A Unified Approach to the Model-Assisted Determination of Probability of Detection

---**R. Bruce Thompson**, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---Two approaches have traditionally been used for determining Model Assisted Probability of Detection (MAPOD). These have been called the transfer function and full model assisted approaches. This paper shows that these can be viewed as a part of a single, unified MAPOD approach in which either experiment or physics-based theoretical models (previously validated by experiment) are used to extend the information gained in empirical measurements to new situations. Included are a discussion of the MAPOD philosophy, a unified protocol which includes the previous approaches, and the interpretation of three previously conducted examples in the context of this unified protocol.

WEDNESDAY

Session 16

SESSION 16
POD
E. Lindgren, Chairperson
Ballroom D

8:30 AM **Eddy Current BEM Model Validation Toward Airframe Inspection Application**
---**N. Nakagawa** and B. F. Larson, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011; J. M. Amos and V. Pendse, Cessna Aircraft, Wichita, KS 67212

8:50 AM **Practical Estimation of Inspection Performance (or How to Do POD Without Data)**
---**D. S. Forsyth**, Texas Research Institute Austin, NDE Division, Austin, TX 78738

9:10 AM **Determination of Sonic IR Experimental Conditions and Estimation of POD for Cracks in Fan Blades**
---C. Gao and **W. Q. Meeker**, Iowa State University, Center for NDE, Ames, IA 50011; D. Mayton, SAIC, 16701 West Bernardo Drive, San Diego, CA 87185-0825

9:30 AM **The Use of Inspection Results in Planning Future Maintenance Schedules**
---**P. W. Hovey**, University of Dayton, Department of Mathematics, 300 College Park Drive, Dayton, OH 45469-2316; J. Knopp, U.S. Air Force Research Laboratory, NDE Branch, Wright Patterson Air Force Base, OH

9:50 AM **Model-Based Approach to Refinement of Eddy Current Inspection of Condenser Tubes**
---**N. Trepal**, J. Liu, and K. Lipetzky, Naval Surface Warfare Center Carderock Division, Welding, Processing and Nondestructive Evaluation Branch, Code 611, 9500 MacArthur Boulevard, West Bethesda, Maryland 20817

10:10 AM ***Break***

Panelists:

- *C. Annis*
- *S. Cargill*
- *D. S. Forsyth*
- *W. Winfree*

The panel discussion will address emerging issues in POD determination, application, and overall reliability related issues. This includes advanced topics in POD, such as POD for Structural Health Monitoring Methods, confidence-bound determination for model-based data, POD for image-based data, and other items brought forward by both the panelists and the audience.

11:50 AM ***Lunch***

Eddy Current BEM Model Validation Toward Airframe Inspection Application

---**Norio Nakagawa** and B. F. Larson, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011; J. M. Amos and V. Pendse, Cessna Aircraft, Wichita, KS 67212

---This paper reports on an on-going project having to do with eddy current (EC) models and their validation. The project aims toward EC model applications to airframe inspections. The project scope includes, in addition to model development and validation, development of a validation protocol that provides guidelines for a validation procedure. A draft version of the protocol has been developed based on prior experience in industrial inspections and laboratory measurements. In essence, the project attempts to exercise the protocol as a case study, and to refine the procedure through this exercise. To be explicit, we selected a BEM-based model and several prototypical airframe inspections as test examples. The paper describes the project status including, specifically, the model development, sample preparation (selection, fabrication, and characterization), validation measurements, and model calculations. Ultimately, the model validation procedure should be integrated into model-assisted POD methodologies. An example will be given to show how to combine measured and computed data to yield POD estimation.---This material is based upon work supported by the Federal Aviation Administration under Contract #DTFA03-98-D-00008, Delivery Order #0039 and performed at Iowa State University's Center for NDE as part of the Center for Aviation Systems Reliability program.

Practical Estimation of Inspection Performance (Or How to do POD Without Data)

---**David S. Forsyth**, Texas Research Institute Austin, NDE Division, Austin, TX 78738

---Modern life cycle management of assets such as aircraft, power plants, pipelines, and pressure vessels requires that nondestructive testing (NDT) be performed at intervals that are determined by the occurrence and/or growth rates of discontinuities of interest, and the reliability of the NDT performed to detect these. The United States Air Force has promoted MIL-HDBK-1823 to determine the probability of detection (POD) of NDT as a function of the size of the discontinuity of interest. This approach is widely accepted as providing excellent estimates of POD, if well executed, but it requires significant experimental data. The European Network of Inspection Qualification (ENIQ) has published EUR 17299EN, which is less stringent in the requirements for experimental data. However, in both cases, the effort to produce a reliability estimate will require a significant burden of time and cost. In situations when a problem arises in the operation of an asset such as an aircraft or power plant, the engineer is confronted with the problem of how to make an estimate of inspection capability in short time and with little data. This paper examines how this process can be best performed.

Determination of Sonic IR Experimental Conditions and Estimation of POD for Cracks in Fan Blades

---Chunwang Gao and **William Q. Meeker**, Iowa State University, Center for NDE, Ames, IA 50011; Donna Mayton, SAIC, 16701 West Bernardo Drive, San Diego, CA 87185-0825

---This talk will describe the analysis of data from sonic IR inspections on turbine blades. Separate analyses were done for two different purposes. In both analyses, we fit statistical models with random effects to describe the crack-to-crack variability and the effect the experimental variables on the responses. In the first analysis, the purpose of the study was to find Sonic IR equipment settings that will provide good crack detection capability over the population of similar cracks in the particular kind of jet engine turbine blades that were inspected. Then, the fitted model was used to determine the test conditions where the probability of detection is expected to be high and probability of alarm is expected to be low. In of second analysis, crack size information was added, a similar model was fit. This model provides an estimate of POD as a function of crack size for specified test conditions.---This material is based upon work supported by the Air Force Research Laboratory under Contract # FA8650-04-C-5228 at Iowa State University's Center for NDE.

The Use of Inspection Results in Planning Future Maintenance Schedules

---**Peter W. Hovey**, University of Dayton, Department of Mathematics, 300 College Park Drive, Dayton, OH 45469-2316; Jeremy Knopp, US Air Force Research Laboratory, Nondestructive Evaluation Branch, WPAFB, OH

---The U.S. Air Force plans for maintenance and retirement of aircraft based in part on fatigue crack growth models. Periodic inspections are used to help assess airworthiness and plan for future inspections. Nondestructive inspections are not perfect so some cracks are missed and the probability that an individual crack is detected is a function of the size of the crack when inspected. The Air Force currently uses an estimate of the probability of detecting (POD) cracks based on data collected under nearly ideal conditions. A better estimate of POD could be achieved using results recorded for real in-service inspections; however there is no information about the sizes of cracks that were missed. At the same time, the Air Force is considering a change in the definition of the reset crack size used to schedule inspections from a number completely determined by the POD function for the inspection system used to a risk based definition that takes into account the sizes of missed cracks and potential damage in repaired structure. This paper describes ongoing research on how to effectively use inspection results to properly estimate both the distribution of crack sizes that were present at the time of the inspection and the probability of detecting cracks as a function of crack size and potential methods for estimating the reset size directly from sizes of the cracks that are found.

Model-Based Approach to Refinement of Eddy Current Inspection of Condenser Tubes

---**Nathan Trepal**, John Liu, and Kirsten Lipetzky, Naval Surface Warfare Center Carderock Division, Welding, Processing and Nondestructive Evaluation Branch, Code 611, 9500 MacArthur Boulevard, West Bethesda, MD 20817

---The Navy has been interested in moving from a time-based approach to nondestructive inspection of condenser tubes to a condition based approach in order to support the increased availability of our military assets. Trending studies were initiated in FY03 to determine if existing eddy current data could predict tube condition and degradation rates. Although historically the eddy current data was never developed for trending purposes, but rather for go / no go decisions, the study of the eddy current data from three different ships pointed to the fact that while certain trends were noted there were also inconsistencies between inspections that at times brought into question the validity of the trends. The inconsistencies that were noted seemed to be largely dependent upon the mode of degradation attributed to the wall loss within a condenser tube. The age of the ship also appeared to have an impact on the type of degradation modes that were noted. A major outcome of the trending study was the determination that non-uniform thinning conditions were assessed quite differently depending upon the shipyard responsible for the inspection; this inconsistency was later attributed to differences in calibration standards that were permitted for use at the shipyards. As a result of the work performed in FY03 and FY04, changes were implemented to provide for greater consistency of inspections between shipyards, including standardization of the means by which non-uniform thinning is to be assessed. Furthermore, a recommendation was made to perform ultrasonic inspection on condenser tubes when eddy current analysis indicated significant wall loss. Results from subsequent ultrasonic inspections have pointed to the fact that eddy current inspection analysis was overly conservative for wall loss calculations in non-uniform thinning conditions. This in turn has led to additional questions as to the overall accuracy of eddy current inspection process for other types of discontinuities. The accuracy and precision with which discontinuities can be identified by NDE methods is a critical issue for the successful application of condition-based maintenance to aging military platforms. Probability of detection (POD) studies are one means by which to determine the reliability of a given nondestructive inspection method for a specific application, however, there are underlying costs associated with performing POD studies that often become prohibitive. Modeling is seen as a potential means by which variables can be studied within the eddy current inspection process, without the expense associated with extensive experimental work. Engineers at Carderock have made use of VIC-3D, a commercial-off-the-shelf software package developed by Victor Technologies, to model calibration standards used in eddy current condenser tube inspection. Once validated, the models have been used to predict eddy current probe response to a variety of discontinuities. Ongoing work in this area will attempt to determine the cause for the overly conservative analyses of non-uniform thinning conditions, as well as to provide a predictive assessment of the accuracy of eddy currents to detect other types of discontinuities commonly found in condenser tubes.

Session 17

SESSION 17
INVERSION, RECONSTRUCTION, IMAGING
S. Hirose, Chairperson
Ballroom C

8:30 AM **Potential Drop Data Inversion for Crack Depth Profiling**
---**G. Sposito** and P. Cawley, Imperial College London, Mechanical Engineering, London, United Kingdom; P. B. Nagy, University of Cincinnati, Aerospace Engineering and Engineering Mechanics, Cincinnati, OH

8:50 AM **Online Bayesian Estimation for Solving Electromagnetic NDE Inverse Problems**
---**P. Ramuhalli** and T. M. Khan, Nondestructive Evaluation Laboratory, Department of Electrical and Computer Engineering, Michigan State University, East Lansing, MI 48824

9:10 AM **MFL Signal Inversion Using the Finite Element Network**
---**P. Ramuhalli**, Michigan State University, Department of Electrical and Computer Engineering, 2120 Engineering Building, East Lansing, MI 48824

9:30 AM **3D Image Reconstruction from Low Energy Fuzzy and Noisy 2D X-Ray Projective Data**
---**V. Vengrinovich**, S. Zolotarev, and Y. Reshetovski, Institute of Applied Physics, Belarus National Academy of Sciences, Minsk, Belarus

9:50 AM **Flaw Shape Reconstruction Using Topological Gradient for 2D Scalar Wave Equation**
---**K. Kimoto** and S. Hirose, Tokyo Institute of Technology, Department of Mechanical and Environmental Informatics, Meguro-ku, Tokyo, Japan

10:10 AM ***Break***

10:30 AM **3D Reconstruction from Narrow-Angle Radiographs**
---**L. Fournier**, L. Chatellier, and P. Peureux, Electricite de France, Research and Development, Chatou, 78401, France; A. Mohammad-Djafari, UMR 8506 (CNRS-Supelec, UPS), Laboratoire des Signaux et Systèmes, Gif-sur-Yvette, 91192, France

10:50 AM **Defect Detection Using Capacitive Imaging**
---**G. G. Diamond** and D. A. Hutchins, University of Warwick, School of Engineering, Coventry, W. Mids., CV4 7AL United Kingdom; T. H. Gan, TWI Ltd. Granta Park, Great Abington, Cambridge, CB21 6AL, United Kingdom

11:10 AM **Near Infrared (NIR) Imaging for NDE**
---**G. G. Diamond**, D. A. Hutchins, and P. Pallav, University of Warwick, School of Engineering, Coventry, W. Mids., CV4 7AL, United Kingdom

11:30 AM **Short Range Scattering of the Fundamental Shear Horizontal Guided Wave Mode by Part-Through Surface Breaking Cracks in an Isotropic Plate**
---**P. Rajagopal** and M. J. S. Lowe, Imperial College London, Mechanical Engineering, Exhibition Road, London SW7 2AZ, United Kingdom

11:50 AM **GPR Scanning Methods for Enhanced Data Imaging in Wooden Logs**
---S. Pyakurel and **U. B. Halabe**, West Virginia University, Department of Civil and Environmental Engineering, Morgantown, WV 26506-6102; B. Gopalakrishnan, West Virginia University, Department of Industrial and Management Systems Engineering, Morgantown, WV 26506-6107

12:10 PM ***Lunch***

Potential Drop Data Inversion for Crack Depth Profiling

---**Giuseppe Sposito** and Peter Cawley, Imperial College London, Mechanical Engineering, London, United Kingdom; Peter B. Nagy, University of Cincinnati, Aerospace Engineering and Engineering Mechanics, Cincinnati, OH

---Estimating the shape and size of a defect is a problem of major interest in many industrial applications, since the depth of a crack is often a key parameter in calculations of structural integrity. Previous studies have shown that the potential field created on the surface of a testpiece by the injection of direct or alternating currents for PD measurements can be calculated with a simple three-dimensional Finite Element (FE) model; this model is therefore able to give an accurate solution to the direct problem of predicting the response of a probe to a surface-breaking defect of known geometry. Most previous work on the inverse problem of using values of transfer resistance measured at a number of different locations to calculate the depth profile of an unknown defect have assumed a priori knowledge of the defect shape; crack gauges are commercially available that assume the defect has a semi-circular form. However, this assumption is not always correct. The aim of the present study is to develop an inversion technique of more general validity. The results of both FE analyses and experimental tests on specimens with EDM notches of various shapes and sizes were used to develop an inversion algorithm, which was subsequently applied to experimental data obtained with an array probe on samples with laboratory-grown stress corrosion cracks (SCC), in order to reconstruct the depth profile of the cracks.

Online Bayesian Estimation for Solving Electromagnetic NDE Inverse Problems

---**Pradeep Ramuhalli** and Tariq Mairaj Khan, Nondestructive Evaluation Laboratory, Department of Electrical and Computer Engineering, Michigan State University, East Lansing, MI 48824

---Flaw profile estimation from measurements is a typical inverse problem in electromagnetic nondestructive evaluation (NDE). This paper proposes a novel state-space approach to combat the ill-posedness in the solution to the inverse problem, particularly in the presence of measurement noise. The inversion approach formulates the inverse problem as a tracking problem with state and measurement equations. The state-space model thus formed, resembles the classical discrete-time tracking problem, and enables the application of Bayesian non-linear filters based on sequential Monte Carlo methods in conjunction with numerical models that represent the measurement process (i.e. solution of forward problem). The proposed approach is applied to simulated NDE measurements from known flaw shapes. Numerical models derived from the physics of the NDE inspection process are used as the measurement model and a probabilistic state transition model is defined for proposed technique. Initial results of applying the proposed approach to eddy current NDE inverse problems indicate the feasibility of proposed method.

MFL Signal Inversion Using the Finite Element Network

---**Pradeep Ramuhalli**, Michigan State University, Department of Electrical and Computer Engineering, 2120 Engineering Building, East Lansing, MI 48824

---Iterative algorithms that incorporate a numerical forward model have been typically used to solve the problem of flaw profile estimation from measured magnetic flux leakage (MFL) data. In these approaches, the forward model is used to determine the measurement signal for a given defect profile, and the desired defect profile is found by iteratively minimizing a cost function. The use of numerical models is computationally expensive, and therefore, alternative forward models need to be explored. This paper presents a finite element neural network (FEN) obtained by embedding a finite element model in a parallel neural network architecture that enables fast and accurate solution of the forward problem. Previous results have indicated that the FEN performance as a forward model is comparable to that of the conventional finite element method. The parallel nature of the FEN also makes it an attractive solution for parallel implementation in hardware and software. In this paper, we investigate the applicability of the FEN to determining flaw profiles from MFL data in pipeline inspection and present results on synthetic MFL data.

3D Image Reconstruction From Low Energy Fuzzy and Noisy 2D X-Ray Projective Data

---**V. Vengrinovich**, S. Zolotarev, and Y. Reshetovski, Institute of Applied Physics, Belarus National Academy of Sciences, Minsk, Belarus

---The tomographic imaging of clumpy and polythickness objects, namely made with steel and cast iron, need x-ray sources with extremely high energy, sometimes appearing out of the energetic capabilities of x-ray tubes. Practically this makes very problematic of using x-ray data and classical tomographic algorithms for 3D imaging of those objects. In this report we consider some iterative approaches to 3D image reconstruction from fuzzy and noisy x-ray data described in our recent works. The main ideas are: a priory knowledge, both quantitative and qualitative, integration in the fast iterative reconstruction algorithms like a) image registration with image deformation and b) preliminary x-ray penetration model generation using results with known phantoms. In both cases the Bayesian statistics is applied. We demonstrate here the theory and application of this new approach using both simulated and real experimental data. In some cases the necessary energy of x-ray source can be reduced several times having as a result high quality 3D image. The investigation of different reconstruction parameters values is presented.

Flaw Shape Reconstruction Using Topological Gradient for 2D Scalar Wave Equation

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

---Topological gradient (TG) for 2D scalar wave equation is used in this study for ultrasonic flaw shape reconstruction. A time domain representation of the TG is derived from the frequency domain representation as done for elastic wave equation by Dominguez et al.(Wave Motion 42,31-52, 2005). Using simulated and measured waveforms, performance of the TG-based reconstruction technique is investigated numerically and experimentally. A cylindrical cavity embedded in an isotropic, homogeneous elastic plate is reconstructed for the investigations. For the simulation study, waveforms are synthesized by a time domain finite difference technique. In the experimental study, ultrasonic measurements are taken with a linear SH-wave array transducer and a steel block specimen with a side-drilled hole. Results of the shape reconstruction are shown firstly for the simulated waveforms, and then for the measured ones. The simulation study demonstrates several attractive features of the TG technique, while remarkable accuracy of the technique is in part confirmed by the experimental study. It is concluded that the TG technique has some great advantages over linearized inverse scattering methods. However, great deal of modeling efforts have to be taken to use the TG technique with measured data. This issue is also discussed in this study.

3-D Reconstruction From Narrow-Angle Radiographs

---**Louis Fournier**, Laurence Chatellier, and Pierre Peureux, Electricite de France, Research and Development, Chatou, 78401, France; Ali Mohammad-Djafari, UMR 8506 (CNRS-Supelec,UPS), Laboratoire des Signaux et Systèmes, Gif-sur-Yvette, 91192, France

---So as to detect and to characterize potential casting defects in some components of the primary circuits of PWRs, inspections are carried out with non-destructive examination techniques (NDE) including g radiography. Should a defect be detected, one can be asked to demonstrate that the component still stands the service mechanical stresses. In these cases of expertise, the use of a 3-D reconstruction processing technique can be very useful. One characteristic of such applications is that, in general the number and angles of projections are very limited and the data are very noisy, so the reconstruction problem is highly ill posed and classical tomography algorithms can’t solve the problem. In this work, we propose a particular reconstruction technique based on an a priori model (Markov-Potts) which takes into account the specificity of the Non Destructive Technique (NDT) Computed Tomography (CT). This paper focuses on the first results we obtain on a mock-up with several electro-sparking machined cylindrical defects.

Defect Detection Using Capacitive Imaging

---**G. G. Diamond** and D. A. Hutchins, University of Warwick, School of Engineering, Coventry, W. Mids, CV4 7AL United Kingdom; T. H. Gan, TWI Ltd, Granta Park, Great Abington, Cambridge, CB21 6AL, United Kingdom

---Further details of a novel capacitance sensing technique are presented, which is capable of imaging defects within a range of materials, including insulators, conductors and fibre reinforced composites. Images can also be obtained underwater. Representative results from each of these separate classes of material are presented here. A specific advantage of this technique is that, by suitable design of the electrode geometry, the spatial distribution of the electric field, and hence the image resolution, can be adjusted for a particular situation. The skin depth into a specimen can be increased by reducing the frequency in the normal fashion. Secondly, images can be taken of objects and defects that lie behind a metallic barrier that would normally completely screen against conventional electromagnetic NDE techniques. Examples will be presented of experiments on real-life aerospace specimens, and the in-situ inspection of large civil structures.

Near Infrared (NIR) Imaging for NDE

---**G. G. Diamond**, D. A. Hutchins, and P. Palav, University of Warwick, School of Engineering, Coventry, W. Mids, CV4 7AL United Kingdom

---A novel application of near infrared (NIR) signals is presented, which can be used to provide images of many different materials and objects. It is effectively a very low cost non-ionising alternative to many applications currently being investigated using electromagnetic waves at other frequencies, such as THz and X-ray imaging. This alternative technique can be realised by very simple and inexpensive electronics and is inherently far more portable and easy to use. Transmission imaging results from this technique are presented from examples industrial quality control, food inspection and various security applications, and the results compared to existing techniques. In addition, this technique can be used in through-transmission mode on biological and medical samples, and images are presented that differentiate between not only flesh and bone, but also various types of soft tissue.

Short Range Scattering of the Fundamental Shear Horizontal Guided Wave Mode by Part-Through Surface Breaking Cracks in an Isotropic Plate

---**Prabhu Rajagopal** and Michael J. S. Lowe, Imperial College London, Mechanical Engineering, Exhibition Road, London, SW7 2AZ, United Kingdom

---Array based imaging to improve the resolution of guided Ultrasonic wave inspection is of continued interest in our research group at Imperial College London. In this context, it is important to understand the interaction of guided waves with defects, some key questions being how the transducer, defect location and defect extent impact the accuracy of such methods. The attractiveness of the fundamental Shear Horizontal (SH0) mode for this purpose and its interaction with through-thickness cracks were presented by the authors in QNDE 2006. Here we extend this line of investigation and consider part-through instead of through-thickness cracks. Both specular reflection and crack edge diffraction are studied. 3D FE simulations are used to obtain trends which are then confirmed by experiments and analysis. We first take up the case of normal incidence at the crack face and examine the influence of the crack length and the distance of source and measurement positions relative to the crack on the reflection behaviour. The insight obtained into the physics of the scattering is then used to explore the more complex case of oblique incidence. Finally the relation between the 2-D (through-thickness cracks) and the 3-D (part-through cracks) case is explored and some conclusions are drawn for guided wave imaging.

GPR Scanning Methods for Enhanced Data Imaging in Wooden Logs

---Sandeep Pyakurel and **Udaya B. Halabe**, West Virginia University, Department of Civil and Environmental Engineering, Morgantown, WV 26506-6102; Bhaskaran Gopalakrishnan, West Virginia University, Department of Industrial and Management Systems Engineering, Morgantown, WV 26506-6107

---A major problem facing wooden saw mills is the presence of hidden or subsurface defects in logs (such as embedded nails and metallic objects, knots and decays) that become visible only after the log is sawed and processed into lumber or veneer. If these defects are detected earlier, that is, before the log is sawn into lumber or sliced into veneer, significant increases in productivity can result by avoiding these defects through optimization of the sawing process. Recently, Ground Penetrating Radar (GPR) has been used to identify subsurface defects in wooden logs. Past study conducted by the authors showed that GPR has the potential to be successfully implemented as a nondestructive method to identify these defects. Therefore, this research is focused on exploring different ways to enhance the GPR data acquisition in order to obtain maximum information from the GPR radargrams on the internal condition of wooden logs. Data acquisition involved methods such as canting the logs, using higher frequency antenna and scanning the log from multiple orientations. This paper discusses GPR imaging and mapping of the internal defects using data enhancements in a manner suitable for future online implementation.

Session 18

SESSION 18

STRUCTURAL HEALTH MONITORING I

K. Jata, Chairperson

Ballroom A

8:30 AM **Quantification and Validation of SHM**
---**J. Markmiller** and F.-K. Chang, Stanford University, Palo Alto, CA

8:50 AM **Opportunities and Challenges in NDE and Health Monitoring of Turbine Engine Components**
---**S. Mazdiyasni**, Metals, Ceramics & NDE Division, Materials and Manufacturing Technology Directorate, Wright Patterson AFB, OH 45433; V. K. Jain, Department of Mechanical and Aerospace Engineering, University of Dayton, Dayton, OH 45469-0238

9:10 AM **Minimizing Uncertainty in Metals Damage Prognosis**
---**R. John** and J. Larsen, AFRL/MLLM, Wright Patterson AFB, OH 45433

9:30 AM **Point of Impact Prediction in Anisotropic Plates from the Acoustic Emission Data**
---**T. Kundu** and S. Das, University of Arizona, Department of Civil Engineering and Engineering Mechanics, Tucson, AZ 85721; K. V. Jata, Air Force Research Laboratory, MLLP, NDE Branch, Wright Patterson AFB, OH 45433

9:50 AM **Identifying Impacts Using Adaptive Fiber Bragg Grating Demodulator for Structural Health Monitoring Applications**
---**G. R. Kirikera** and S. Krishnaswamy, Northwestern University, Center for Quality Engineering and Failure Prevention, CAT 327, 2137 N. Sheridan Road, Evanston, IL 60208

10:10 AM ***Break***

10:30 AM **SHM of Orthotropic Plates Through an Ultrasonic Guided Wave STMR Array Patch**
---**J. Vishnuvardhan**, A. Muralidharan, C. V. Krishnamurthy, and K. Balasubramaniam, Indian Institute of Technology, Centre for Nondestructive Evaluation (CNDE), Department of Mechanical Engineering, Chennai-600 036, India

10:50 AM **Damage Characterization Using PWAS and Time-Frequency Signal Analysis**
---R. Gangadharan, S. Gopalakrishnan, D. R. Mahapatra, **C. R. L. Murthy**, M. R. Bhat, Indian Institute of Science, Department of Aerospace Engineering, Bangalore, Karnataka, India

11:10 AM **In-Situ Monitoring of Fatigue Crack Growth at Fastener Holes Using Rayleigh-Like Waves**
---**B. Masserey** and P. Fromme, Department of Mechanical Engineering, University College London, Torrington Place, London WC1E 7JE, United Kingdom

11:30 AM **A Bayesian Approach for Estimating Sizes of Fatigue Cracks Near Fastener Holes**
---**A. C. Cobb** and J. E. Michaels, Georgia Institute of Technology, School of Electrical and Computer Engineering, Atlanta, GA 30332

11:50 AM **Corrosion-Induced Pitting Damage Detection Using Remote Actuation and Sensing of Vibration and Wave Propagation Response**
---**N. C. Yoder** and D. E. Adams, Purdue University, Mechanical Engineering, West Lafayette, IN 47907-2031

12:10 PM ***Lunch***

Quantification and Validation of SHM
---**Johannes F.C. Markmiller** and Fu-Kuo Chang, Dept. of Aeronautics and Astronautics, Stanford University

---Despite the advancement in structural health monitoring (SHM) technologies, appropriate quantification and validation methodologies are still missing which are crucial for the practical implementation and the certification of these systems. While there are established procedures for quantifying traditional NDE systems, these techniques can not be used directly to quantify SHM systems. In this study, a new method for performance quantification of a SHM system for impact detection in composite structures will be presented: The probability of detection (POD) will be introduced as a quantification measurement of the built-in SHM system considering the sensor layout (number of sensors and sensor locations) as well as the geometry, material properties and the boundary conditions of the structures. Statistical techniques based on test data or numerical simulations will be proposed to verify the accuracy of the SHM system. Examples will be shown to demonstrate the new techniques.

Opportunities and Challenges in NDE and Health Monitoring of Turbine Engine Components
---**S. Mazdiyasni**, Metals, Ceramics & NDE Division, Materials and Manufacturing Technology Directorate, Wright Patterson AFB, OH 45433; V. K. Jain, Department of Mechanical and Aerospace Engineering, University of Dayton, Dayton, OH 45469-0238

---The application of nondestructive evaluation of turbine engine components is expanding to include not just the traditional methods of damage detection and materials characterization at the Air Force Depots, but to include on-board damage sensing data also. The assessment of micro- and macro-structural properties is conducted using advanced eddy current, ultrasonic, and other sensors that yield information on the health of the components or state of the material through noninvasive means. Currently, new techniques are being developed to correlate the on-board sensor information with the traditional NDE damage detection and materials characterization data to determine the health and prognosis of turbine engine components. This paper presents the technical issues and challenges that lie ahead in realizing this objective.

Minimizing Uncertainty in Metals Damage Prognosis

---**R. John**[1], J. M. Larsen[1], M. J. Caton[1], and S. Jha[2], [1]U. S. Air Force, Air Force Research Laboratory, Materials and Manufacturing Directorate (AFRL/MLLMN), Wright Patterson AFB, OH 45433, [2]Universal Technology Corporation, Dayton, OH

---Mechanism-based life prediction models and material state awareness are key elements of improved turbine engine component life management practices under consideration by the Air Force. Lifetime limits of these components are typically based on extensive data generated under simulated operating conditions. Minimizing uncertainty in prediction of remaining useful life and future capability requires accurate knowledge of life-limiting damage initiation and accumulation mechanisms. Recent investigations on advanced propulsion alloys demonstrated that the life-limiting mechanisms are typically dominated by the growth of damage emanating from microstructural features. This presentation discusses recent advances in understanding sources of uncertainty in establishing fatigue life-limit of advanced turbine engine materials in fracture-critical applications.

Point of Impact Prediction in Anisotropic Plates from the Acoustic Emission Data

---**Tribikram Kundu** and Samik Das, University of Arizona, Department of Civil Engineering and Engineering Mechanics, Tucson, AZ 85721; Kumar V. Jata, Air Force Research Laboratory, MLLP, NDE Branch, Wright Patterson Air Force Base, OH 45433

---The conventional triangulation technique cannot predict the point of impact in an anisotropic plate from the time history signals received by the passive sensors attached to the plate because the triangulation technique assumes that the wave speed is independent of the direction of propagation which is not true for anisotropic plates. In this paper an alternative method based on the optimization scheme is proposed to locate the point of impact in anisotropic plates by analyzing the ultrasonic signals received by the passive sensors attached to the plate. The objective function that is minimized during the optimization process considers the wave velocity as a function of the direction of propagation of the wave. Thus the formulation presented here is quite general and should work for any type of anisotropic plate - transversely isotropic, orthotropic, monoclinic or triclinic as well as for isotropic plates. Experiments are carried out by dropping balls on a plate and picking up acoustic signals by passive transducers adhesively bonded to the plate at different locations. The impact point is predicted by the proposed method and compared with the actual location of impact.

Identifying Impacts Using Adaptive Fiber Bragg Grating Demodulator for Structural Health Monitoring Applications

---**Goutham R. Kirikera** and Sridhar Krishnaswamy, Northwestern University, Center for Quality Engineering and Failure Prevention, CAT 327, 2137 N. Sheridan Road, Evanston, IL 60208

---A network of Fiber-Bragg Grating (FBG) sensors is developed as part of a Structural Health Monitoring system to identify impact damage on safety-critical structures such as aircraft, naval and civil structures. The FBG network is used in conjunction with a set of "shaped" piezoelectric transducers for comparison. The FBG sensor signals are adaptively demodulated using two-wave mixing (TWM) technology. The system uses the InP:Fe photorefractive crystal to demodulate the spectral shifts from the FBG sensor. Strains applied on the FBG sensors are encoded as wavelength shifts of the light reflected by the FBG sensor which are then converted into phase shifts and then demodulated by the TWM interferometer. The demodulator automatically filters the low frequency strain signals, such as signals caused by large quasi-static strain and allows only high frequency signals to pass through. The FBG sensor network is mounted on a plate, and the structure is subjected to impacts generated by dropping small ball bearings. The impact signals from multiple FBG sensors are simultaneously acquired and their time-frequency signatures are used to identify the impact location.

SHM of Orthotropic Plates Through an Ultrasonic Guided Wave STMR Array Patch

---**J. Vishnuvardhan**, Ajith Muralidharan, C. V. Krishnamurthy, and Krishnan Balasubramaniam, Indian Institute of Technology, Centre for Nondestructive Evaluation (CNDE), Department of Mechanical Engineering, Chennai-600 036, India

---The Single Transmitter Multiple Receiver (STMR) array based Structural health monitoring (SHM) technique has been introduced for evaluation of isotropic and anisotropic plate like structures. SHM is carried out by utilizing a phased addition reconstruction algorithm for imaging damage in large plate-like structures. A flexible Printed Circuit Board (PCB) based patch was developed for SHM of aluminum and composite plates. Additionally, an elastic moduli reconstruction algorithm is described here, using the PCB array patch, which can be applied in at least two cases; (a) for SHM applications, the leave-in-place compact array can provide a means for the in-situ measurement of changes in the elastic moduli during the life time monitoring of structures, thereby providing velocity data for the phased addition reconstruction algorithm, and (b) for materials characterization, where the compact array can be developed as a portable sensor for the measurement of elastic moduli of in-service and as-fabricated structures. This elastic moduli reconstruction method uses the velocity measurement of the fundamental guided Lamb wave modes (S0 and A0), generated from a central transmitter, and received by a sparse array of receivers that encircle the transmitter. Sensitivity analysis of orthotropic elastic moduli to the Lamb wave velocity of S0 and A0 modes has been carried out. Experiments were conducted on 3.15 mm graphite-epoxy composite plate using PCB based STMR array and compared to Laser vibrometer based experiments.

Damage Characterization Using PWAS and Time-Frequency Signal Analysis

---R. Gangadharan, S. Gopalakrishnan, D. Roy Mahapatra, **C. R. L. Murthy**, M.R. Bhat, Indian Institute of Science, Department of Aerospace Engineering, Bangalore, Karnataka, India

---Use of advanced engineering materials like composites has increased the need for a robust Structural health monitoring system (SHM). The development of PZT wafer active sensors (PWAS) which can be embedded or surface mounted is used especially for actuation and sensing in ultrasonic modes for SHM of aerospace structures. Use of smart sensor technology (PWAS) along with intelligent signal processing plays a crucial role in the implementation and working of any damage detection system. In the present work, experiments were conducted in aluminum and composite plates to study the various damages using PWAS. Numerical simulations were carried out using spectral finite element method (SFEM) to study the wave propagation in thin plate structures. SFEM was used to simulate wave propagation in composites with different damages like delamination, material degradation and transverse cracks. Time-frequency analysis of the experimental and the simulated signals were performed using Wavelet Transform (WT) and Hilbert Huang transform (HHT) and was compared. Quantitative measures were derived with rigorous mathematical analysis for different types of damages using both the methods. This study has given us significant insight into the problem of (1) identifying localized damages and (2) dispersion of multi-frequency signal after they interact with different types of damage.

In-Situ Monitoring of Fatigue Crack Growth at Fastener Holes Using Rayleigh-Like Waves

---**Bernard Masserey** and Paul Fromme, Department of Mechanical Engineering, University College London, Torrington Place, London WC1E 7JE, United Kingdom

---The development of fatigue cracks at fastener holes due to stress concentration is a common problem in aircraft maintenance. This contribution investigates the use of Rayleigh-like waves for the in-situ monitoring of fatigue crack growth in tensile, aluminum specimens. Rayleigh-like waves have a good sensitivity for defect detection and can propagate along the structure, thus having the potential for the inspection of difficult to access parts from a stand-off distance. Experimentally the Rayleigh-like waves are excited using standard wedge transducers and measured using either standard pulse-echo equipment or laser interferometry. The growth of fatigue cracks during cyclic loading is monitored optically and the resulting changes in the ultrasonic signal caused by crack growth are quantified. Full three-dimensional simulation of the scattering of the Rayleigh wave at the fastener hole and crack has been implemented using Finite Difference (FD) method. The comparison of the results shows a good correlation of the observed signal changes. The sensitivity and repeatability are ascertained, and the robustness of the methodology for practical in-situ ultrasonic monitoring of fatigue crack growth is discussed.

A Bayesian Approach for Estimating Sizes of Fatigue Cracks Near Fastener Holes

---**Adam C. Cobb** and Jennifer E. Michaels, Georgia Institute of Technology, School of Electrical and Computer Engineering, Atlanta, GA 30332

---Ultrasonic methods have been developed for in situ monitoring of metallic alloys to estimate the presence and size of fatigue damage within a structure. These ultrasonic techniques, however, only provide an estimate of the current state of the structure and cannot predict the remaining life without making additional assumptions concerning both the fatigue process and the resulting crack initiation and growth. On the other hand, a statistical crack propagation approach can estimate the expected remaining life based upon an assumed initial flaw size distribution and future loads. The problem with this approach is that it assumes a worst case initial flaw size to ensure the safety of the structure, which results in an overly conservative estimate of remaining life. Presented here is a Bayesian approach for incorporating both methodologies. As is typical for these types of problems, a Kalman Filter is implemented to combine ultrasonic measurements of fatigue damage with a crack propagation model for fatigue crack growth. Previous work by the authors has employed a shear wave, angle-beam method for detecting and sizing fatigue cracks originating from fastener holes using an energy ratio feature. For the work presented here, this feature, in conjunction with an ultrasonic interaction model for correlating it with crack size, functions as the measurement model for the state estimation approach, and a version of Paris's law is used as the system model for crack propagation. This state estimation approach effectively merges the ultrasonic crack size estimate with the predicted crack size from the crack propagation law to obtain both a better crack size estimate and a prediction of remaining life. Experimental results are shown to assess the performance of the framework, where the resulting crack size estimates are more accurate than those obtained individually from either the ultrasonic measurements or the crack propagation approach.

Corrosion-Induced Pitting Damage Detection Using Remote Actuation and Sensing of Vibration and Wave Propagation Response

---**Nathanael C. Yoder** and Douglas E. Adams, Purdue University, Mechanical Engineering, West Lafayette, IN 47907-2031

---Pressurized air tanks installed in the front-driver side of a military ground vehicle can experience corrosion-induced pitting, which reduces the sidewall thickness in localized areas and results in lower burst strengths. Due to how the tank is mounted, corrosion consistently occurs on the bottom of the tanks at the end furthest from the driver seat making in situ visual inspection ineffective. A simple finite element model was created in order to facilitate the creation of methods that can provide an indication of which tanks must be replaced immediately and which tanks can continue to operate. The model was used to investigate the sensitivity of the tank's resonant frequencies and frequency response functions to changes in cross-sectional properties. As a result of this analysis, a modal impact based method was created for detecting the corrosion from the opposite end of the tank. Because of the remote damage location and the localized nature of the damage, a wave propagation method using a piezoelectric actuator was also investigated. These methods were then applied to a number of different specimens with varying levels of corrosion to determine the effectiveness of each method in detecting and quantifying the damage despite variability among the specimens.

Session 19

SESSION 19
GUIDED WAVES II
J. L. Rose, Chairperson
Ballroom B

8:30 AM **Detection of Defects in Composite Structures Using Guided Waves**
---**A. Mal**, University of California, Mechanical and Aerospace Engineering Department, Los Angeles, CA 90095-1597; I. Saxena, Intelligent Optical Systems, Inc., Torrance, CA; D. Keene, Flight/Mechanical Systems Division, Engineering Directorate, Robins Air Force Base, GA

8:50 AM **Ultrasonic Guided Waves for Health Monitoring of High Pressure Composite Tanks**
---**M. Castaings** and B. Hosten, Laboratoire de Mécanique Physique, UMR CNRS 5469, 351 cours de la Libération, Université Bordeaux 1, 33400 Talence, France

9:10 AM **Ultrasonic Guided Waves for the Inspection of Adhesively Bonded Joints**
---**P. K. Puthillath**, F. Yan, C. J. Lissenden, and J. L. Rose, Pennsylvania State University, Engineering Science and Mechanics Department, University Park, PA 16802

9:30 AM **The Application of Synthetic Focusing for High Resolution Guided Wave Pipe Inspection**
---**J. Davies** and P. Cawley, Imperial College London, Mechanical Engineering, London, United Kingdom

9:50 AM **Quantification of Defect Size from Long Range Guided Wave Ultrasonic Tests on Pipes**
---**P. J. Mudge**, TWI Ltd, NDT Technology Group, Cambridge, CB21 6AL, United Kingdom; P. P. Catton, Brunel University, School of Engineering & Design, Uxbridge, United Kingdom

10:10 AM ***Break***

10:30 AM **Feasibility Assessment of Sludge and Blockage Detection Inside Pipes Using Guided Ultrasonic Waves**
---**J. Ma**, M. J. S. Lowe, and F. Simonetti, Imperial College London, Department of Mechanical Engineering, Exhibition Road, London, SW7 2AZ, United Kingdom

10:50 AM **A Comparison of Temperature Compensation Methods for Guided Wave Structural Health Monitoring**
---A. J. Croxford, P. D. Wilcox, and B. W. Drinkwater, University of Bristol, Department of Mechanical Engineering, Queens Building, University Walk, Bristol BS8 1TR, United Kingdom, Y. Lu and **J. E. Michaels**, Georgia Institute of Technology, School of Electrical and Computer Engineering, Atlanta, GA 30332-0250

11:10 AM **Lamb Wave Tuning for Piezoelectric Wafer Active Sensor Applications in In-Situ Structural Health Monitoring**
---V. Giurgiutiu, **L. Yu**, G. Santoni, and B. Xu, University of South Carolina, Department of Mechanical Engineering, 300 S. Main Street, Columbia, SC 29208

11:30 AM **Numerical Simulation of Lamb Wave Signals Generated and Detected by Laser Ultrasonic Techniques**
---**K. Luangvilai** and L. J. Jacobs, School of Civil and Environmental Engineering, Georgia Institute of Technology, Atlanta, GA 30332; L. J. Jacobs and J. Qu, G. W. Woodruff School of Mechanical Engineering, Georgia Institute of Technology, Atlanta, GA 30332

11:50 AM **Time Reversal Method for Pipe Inspection with Guided Waves**
---**F. Deng**, C. He, and B. Wu, Beijing University of Technology, College of Mechanical Engineering and Applied Electronic Technology, Ping Le Yuan 100#, Chaoyang District Beijing 100022 P. R. China

12:10 PM ***Lunch***

Detection of Defects in Composite Structures Using Guided Waves

---**Ajit Mal**, University of California, Mechanical and Aerospace Engineering Department, Los Angeles, CA; Indu Saxena, Intelligent Optical Systems, Inc., Torrance, CA; Dennis Keene, Flight/Mechanical Systems Division, Engineering Directorate, Robins Air Force Base, GA

---Advanced composites are being used increasingly in state-of-the-art aircraft and aerospace structures due to their high strength and low weight. In spite of their many advantages, composite materials are highly susceptible to hidden flaws that may occur at any time during the life cycle of a structure and if undetected, may cause its sudden and catastrophic failure. Examples of defects critical structural components are laminated composites and honeycomb composites in which thin composite skins are bonded with adhesives on the two faces of extremely lightweight and relatively thick metallic honeycombs. These components are often used in aircraft and aerospace structures due to their light weight and high strength. The bond between the laminas and between the honeycomb and the skins may degrade with age and service loads leading to separation of the laminas (delaminations) and between the load-bearing skin from the honeycomb (disbonds) compromising the safety of the entire structure. This paper is concerned with the noninvasive detection of defects in the two types of composites using ultrasonic guided waves. Laboratory experiments have been carried out on a variety of composite specimens containing localized defects regions. Ultrasonic waves are launched into the specimen using a broadband PZT transducer and are detected by a distributed array of identical transducers located on the surface of the specimen. The guided wave components of the signals are shown to be very strongly influenced by the presence of both types of defects. The experimentally observed results have been used to develop an autonomous scheme to locate and to estimate the size of the defects. A practical detection system using a dense array of Fiber Bragg grating (FBG) sensors is being developed for field applications.

Ultrasonic Guided Waves for Health Monitoring of High Pressure Composite Tanks

---**M. Castaings** and B. Hosten, Laboratoire de Mécanique Physique, UMR CNRS 5469, 351 cours de la Libération, Université Bordeaux 1, 33400 Talence, France

---Ultrasonic guided wave modes are proposed to control the integrity of high-pressure composite tanks produced by EADS - ASTRIUM, France. The purpose is to demonstrate the potentiality of air-coupled transducers to set-up a contact-less, single-sided technique for testing the moisture content and/or the micro-cracking of carbon epoxy composite wound around a Titanium liner, as well as to detect local disbonds between the composite and the liner. First of all, a laboratory experimental system and numerical tools are used to quantify the sensitivity of specific parameters (wave numbers or attenuations) of some modes to the moisture content and to the micro-cracking in composite plate samples. These results are then used to set an experimental strategy for testing the carbon epoxy component of a high pressure composite tank, and the use of air-coupled transducers for generating-detecting sensitive wave modes is demonstrated. Secondly, the air-coupled system is employed for detecting a local disbond in the tank, simulated by a Teflon insert.---This work was supported by EADS - ASTRIUM and Conseil Regional Aquitain, France.

Ultrasonic Guided Waves for the Inspection of Adhesively Bonded Joints

---**Padma Kumar Puthillath**, Fei Yan, Clifford J. Lissenden, and Joseph L. Rose, Pennsylvania State University, Engineering Science and Mechanics Department, University Park, PA 16802

---Adhesive bonds in safety critical structures like aircraft fuselage components must be reliably inspected to ensure their performance over time. Ultrasonic guided waves serve as a potential solution to the inspection issue because of their multi-mode nature and capability of performing inspections over large areas. The understanding of wave mechanics can help us select correct wave modes and physical features to extract information about the nature of bonding qualitatively or quantitatively. In this paper, we consider a problem of guided wave propagation in structures with lap joints. A hybrid analytical and numerical method is used to study the guided wave reflection and transmission at the region of transition from the skin to the lap joint itself. The influence of bonding quality on the energy reflection and transmission of guided waves is also investigated. It is shown that this wave mechanics study provides a useful guideline for guided wave nondestructive evaluation (NDE) and structural health monitoring (SHM) for adhesively bonded structures in terms of wave mode and frequency selection as well as feature extraction. Both isotropic and anisotropic structures are considered.

The Application of Synthetic Focusing for High Resolution Guided Wave Pipe Inspection

---**Jacob Davies** and Peter Cawley, Imperial College London, Mechanical Engineering, London, United Kingdom

---We have employed synthetic focusing of guided waves for imaging defects in pipes using an array of piezoelectric shear transducers clamped around the pipe circumference. The performance of the focused system is tested and compared to an unfocused system using data from finite element simulations of an 8 inch pipe with circumferentially orientated cracks and laboratory experiments with circumferential slots. Both finite element simulations and experiments were excited at 50 kHz. The amplitude of the reflection from smaller features is increased by around 16dB with the focused system and the circumferential location of non-symmetric reflecting features can be found. It is also possible to estimate the circumferential extent of the feature if it is larger than two wavelengths of the interrogating signal, in this case, the shear horizontal wavelength. The robustness of the focused system to possible setup errors, such as coupling or phase errors is then thoroughly investigated by corrupting finite element data with both random and systematic errors. The system is shown to be very robust against realistic levels of setup errors.

Quantification of Defect Size from Long Range Guided Wave Ultrasonic Tests on Pipes

---**Peter J. Mudge**, TWI Ltd., NDT Technology Group, Cambridge, CB21 6AL, United Kingdom; Philip P. Catton, Brunel University, School of Engineering & Design, Uxbridge, United Kingdom

---The application of long range guided wave ultrasonic tests for pipes and pipelines has gained considerable support in recent years as a rapid screening tool for detection of corrosion and other degradation, particularly for inaccessible sections. However, its usefulness has been limited by the lack of detailed information about the dimensions of defects detected, which prevents an assessment of likely severity without additional testing or direct examination. This paper presents recent developments in determination of the size of defects arising from the use of focused ultrasonic energy from phased array transducers. The additional information obtained allows the pipeline operator to make at least initial assessments of defect severity without additional testing.

Feasibility Assessment of Sludge and Blockage Detection Inside Pipes Using Guided Ultrasonic Waves

---**Jian Ma**, Michael J. S. Lowe, and Francesco Simonetti, Imperial College London, Department of Mechanical Engineering, Exhibition Road, London, SW7 2AZ, United Kingdom

---The accumulation of sludge and blockages in pipes is a problem which affects many industries. Guided ultrasonic waves are an attractive idea for the detection and even characterization of the sludge because they can travel long distances and have been proven, in inspection applications, to be sensitive to discontinuities. It has been previously reported that in principle sludge and blockages can be detected and even characterized by using guided ultrasonic torsional waves, based on a model study in which the sludge layer was simplified in terms of geometry and material properties. The work revealed that the presence of a layer inside a pipe scatters the guided wave propagating in the pipe and both the reflection and transmission of the guided wave can be used to effectively detect and characterize the layer. Accordingly, two guided wave measurement techniques, namely the reflection measurement and the transmission measurement, have been proposed. This paper proceeds the work by taking into account more realistic sludge characteristics, including irregular axial and circumferential profiles of the sludge layer, imperfect bonding state between the sludge and the pipe and the material damping of the sludge. The study included Finite Element simulations, laboratory experiments, and a realistic test in which the proposed measurements were implemented by commercial guided wave equipment to demonstrate the practical capability. The study shows that both reflection and transmission measurements can be exploited usefully and non-intrusively to detect realistic accumulations of sludge and blockages and a combination of the two measurements will lead to a reliable detection. However, the quantification of such materials will be difficult due to their arbitrary shape and properties.

A Comparison of Temperature Compensation Methods for Guided Wave Structural Health Monitoring

---Anthony J. Croxford, Paul D. Wilcox, and Bruce W. Drinkwater, University of Bristol, Department of Mechanical Engineering, Queens Building, University Walk, Bristol BS8 1TR, United Kingdom; Yinghui Lu and **Jennifer E. Michaels**, Georgia Institute of Technology, School of Electrical and Computer Engineering, Atlanta, GA 30332-0250

---Effective utilization of spatially distributed ultrasonic transducer arrays for structural health monitoring requires analysis of long range guided wave signals containing multiple reflections from geometric features in the structure. The analysis typically entails comparing signals to those captured while the structure was known to be undamaged, which is problematic if the environmental conditions have changed. Temperature changes are of particular interest because small temperature changes are generally unavoidable, and their effect on received signals is directly related to the distance of propagation. Several time and frequency domain methods have been proposed to compensate signals for temperature changes prior to waveform comparison. One method is to simply find the baseline signal which best matches the current signal, a second method is to stretch or contract one of the baseline signals in the time domain to best match the current signal, and the third method is to apply a frequency-compensated time dilation in the frequency domain to effect a time-dependent time shift of an echo train. Here we examine the assumptions inherent in each method and compare performance on data recorded under varying temperatures. Results are reported from several aluminum specimens.

Lamb Wave Tuning for Piezoelectric Wafer Active Sensor Applications in In-Situ Structural Health Monitoring

---Victor Giurgiutiu, **Lingyu Yu**, Giola Santoni, and Buli Xu, University of South Carolina, Department of Mechanical Engineering, 300 S. Main Street, Columbia, SC 29208

---An analytical and experimental investigation of the Lamb wave mode tuning with piezoelectric wafer active sensors (PWAS) is presented. The analytical investigation assumes shear lag transfer of tractions and strains. Analytical solution using the space-wise Fourier transform is reviewed and closed form solutions are presented for the case of ideal bonding (i.e., load transfer mechanism localized at the PWAS boundary). The analytical solutions are used to derive Lamb-wave mode tuning curves which indicate that frequencies exist at which the A0 mode or the S0 mode can be either suppressed or enhanced. Experimental tests are run to verify the predicted tuning curves. The concept of “effective PWAS dimension” is introduced to account for the discrepancies between the ideal bonding hypothesis and the actual shear-lag load transfer mechanism. Two applications of PWAS transducers are presented to illustrate that the capability to excite only one desired Lamb wave mode is critical for practical structural health monitoring applications, including PWAS phased array technique (e.g., the embedded ultrasonics structural radar, EUSR) and the baseline-free time reversal process (TRP). In PWAS phased array EUSR applications, the basic assumption of the presence of a single low-dispersion Lamb wave mode (S0) is invoked. Since several Lamb wave modes traveling at different speeds would disturb the damage imaging results. Examples are given of correctly tuned EUSR images vs. detuned cases, which illustrate the paramount importance of Lamb wave mode tuning for the success of the EUSR method. In the TRP study, an input wave packet is reconstructed at a transmission PWAS when the signal recorded at the receiving PWAS is reversed in the time domain and transmitted back to the original PWAS. Ideally, TRP could be used for damage detection without a prior baseline. However, the application of TRP to Lamb-waves SHM is impended by the dispersive and multimodal nature of the Lamb waves. The presence of more then one mode usually produces additional wave packets on both sides of the original wave packet due to the coupling of the Lamb-wave modes. The PWAS Lamb-wave tuning technique described in this paper is used to resolve the side packets problem. Several tuning cases are illustrated. It is found that the 30 kHz tuning of the A0 Lamb-wave mode with a 16-count smoothed tone burst leads to the complete elimination of the side wave packets. However, the elimination was less perfect for the 290 kHz tuning of the S0 mode due to the frequency sidebands present in the tone-burst wave packet.

Numerical Simulation of Lamb Wave Signals Generated and Detected by Laser Ultrasonic Techniques

---**Kritsakorn Luangvilai** and Laurence J. Jacobs, School of Civil and Environmental Engineering, Georgia Institute of Technology, Atlanta, GA, 30332; Laurence J. Jacobs and Jianmin Qu, G. W. Woodruff School of Mechanical Engineering, Georgia Institute of Technology, Atlanta, GA, 30332

---This research develops a numerical simulation to generate the surface responses to Lamb waves that are measured in an experiment using point source/receiver laser ultrasonic techniques. This model is of axisymmetric Lamb waves propagating in a homogeneous, isotropic linearly-elastic plate. The laser ablation source is modeled as a transient normal surface source, while the laser detection measures the out-of-plane component of the plate's surface motion. The simulation uses the eigen-expansion technique to solve the governing wave equations so that the computations are efficient. Also, since Lamb wave modes are related to free-vibration modes, this simulation can generate both single-mode responses and multi-mode responses. Lastly, verification with experimental measurements is conducted. A laser source characteristic, called a laser source function, is measured from a reference system, which is a solid half-space. Then, the plate response is predicted by the convolution between the measured laser source function and the unit-impulse response generated by the simulation.

Time Reversal Method for Pipe Inspection with Guided Waves

---**Fei Deng**, Cunfu He, and Bin Wu, Beijing University of Technology, College of Mechanical Engineering and Applied Electronic Technology, Ping Le Yuan 100#, Chaoyang District Beijing 100022 P. R. China

---The temporal-spatial focusing effect of the time reversal method on the guided wave inspection in pipes is investigated theoretically with a transfer function. The amplitude of the time reversed wave propagating along the pipe is determined not only by the characters of the defect and the location of the observation point, but also the location of the time reversal transducer. Especially, the number of transducers distributed around the pipe in circumferential direction is the key for realizing the time reversal method. A steel pipe model with external diameter 70mm, and wall thickness 3.5mm is used to analyze the reflection coefficient of L(0,2) mode when time reversal method is used. The simulated results show that a synthetic time reversal array method is an effective means of improving the signal-to-noise ratio of guided wave inspection system. As the interception window is widened, more energy have been included in re-emitted signals, which leads to a large reflection coefficient of L(0,2) mode, that is, the inspection sensitivity of this method is improved greatly. In parallel, the results demonstrated that the time reversal method can be used to locate the defects in circumferential direction. When the time reversed signals getting from the guided wave inspection are applied on a numerical model, the defects can be recognized by the motion of the time reversed wave propagating along the pipe model. Finally, experiment results are given to show that the identify method is valid.

Session 20

SESSION 20
LASER US AND APPLICATIONS
M. Dubois, Chairperson
Ballroom B

1:30 PM **Keynote: Laser-Ultrasonic Testing and Its Application to Nuclear Reactor Internals**
---**M. Ochiai** and T. Miura, Power and Industrial Systems R&D Center, Toshiba Corporation, 8, Shinsugita-cho, Isogo-ku, Kokohama, 235-8523 Kanagawa, Japan; S. Yamamoto, Isogo Nuclear Engineering Center, Toshiba Corporation

2:10 PM **Non-Destructive Testing Using Multi-Channel Random-Quadrature Interferometer**
---**B. F. Pouet**, S. Breugnot, P. Clemenceau, and T. Blum, Bossa Nova Technologies, Venice, CA 90291

2:30 PM **Displacement and Deflection of an Optical Beam by Airborne Ultrasound**
---**J. N. Caron**, Research Support Instruments, Lanham, MD 20706

2:50 PM **Measurement and Analysis of Narrow-Band Surface Acoustic Waves in Cereamic Environmental Barrier Coatings**
---**T. L. Steen**[1], S. N. Basu[2], V. K. Sarin[2], and T. W. Murray[1], [1]Department of Aerospace and Mechanical Engineering, Boston University, [2]Department of Manufacturing Engineering, Boston University, Boston, MA 02215

3:10 PM ***Break***

3:30 PM **LaserUT®Technology Development Programs for the Laser-Ultrasonic Inspection of Composites in the Aerospace Industry**
---**T. Drake**, M. Dubois, M. Osterkamp, K. Yawn, D. Kaiser, T. Do, J. Maestas, and M. Thomas, Lockheed Martin Aeronautics, Laser UT Technology Center, P. O. Box 748, Fort Worth, TX 76101

3:50 PM **Laser Picosecond Ultrasonic Measurement of Longitudinal Sound Velocity in Nanometer Thin Films**
---**N.-W. Pu** and W.-I. Kuo, Chung Cheng Institute of Technology, National Defense University, Department of Applied Chemistry and Materials Science, Tahsi, Taoyuan 335, Taiwan, China (ROC)

4:10 PM **Detection of Kissing Bond in Extruded Aluminum by Laser-Ultrasound**
---**S. E. Kruger**, M. Lord, and D. Lévesque, National Research Council Canada, Industrial Materials Institute, Boucheville, Québec, Canada; A. J. den Bakker, Nedal Aluminium B. V. Utrecht, The Netherlands

4:30 PM **Theory and Applications of Laser Generated Zero-Group Velocity Lamb Mode Resonance**
---**T. W. Murray** and O. Balogun, Boston University, Department of Aerosapce and Mechanical Engineering, Boston, MA 02215; C. Prada, D. Clorennec, and D. Royer, Laboratoire Ondes et Acoustique, ESPCI-Université Paris 7 – CNRS UMR 7587, 10 rue Vauquelin, 75231 Paris Cedex 05, France

4:50 PM **Synthetic Aperture Focusing Technique for the Ultrasonic Evaluation of Friction Stir Welds**
---**D. Lévesque**, S. E. Kruger, M. Lord, and J.-P. Monchalin, Industrial Materials Institute, National Research Council Canada, Boucherville, Quebec, Canada; L. Dubourg, and M. Jahazi, Aerospace Manufacturing Technology Centre, Institute for Aerospace Research, National Research Council Canada, Montreal, Quebec, Canada; C. Mandache, Structures and Materials Performance Laboratory, Institute for Aerospace Research, National Research Council Canada, Ottawa, Ontario, Canada

Keynote: Laser-Ultrasonic Testing and Its Application to Nuclear Reactor Internals
---**Makoto Ochiai** and Takahiro Miura, Power and Industrial Systems R&D Center, Toshiba Corporation, 8, Shinsugita-cho, Isogo-ku, Kokohama, 235-8523 Kanagawa, Japan; Satoshi Yamamoto, Isogo Nuclear Engineering Center, Toshiba Corporation

---A new nondestructive testing technique for surface-breaking microcracks in nuclear reactor internals based on laser-ultrasonics is developed. Surface acoustic wave generated by Q-switched Nd:YAG laser and detected by frequency-stabilized long pulse laser coupled with confocal Fabry-Perot interferometer is used to detect and size the cracks. A frequency-domain signal processing is developed to realize accurate sizing capability. The laser-ultrasonic testing allows the detection of surface-breaking microcrack having a depth of 0.1 mm, and the measurement of their depth with an accuracy of 0.2 mm when the depth exceeds 0.5 mm including stress corrosion cracking. A laser-ultrasonic testing system combined with laser peening system, which is another laser-based maintenance technology to improve surface stress, for inner surface of small diameter tube is developed. The generation laser in the laser-ultrasonic testing system can be identical to the laser source of the laser peening. As an example operation of the system, the system firstly works as the laser-ultrasonic testing mode and tests the inner surface of the tube. If no cracks are detected, the system then changes its work mode to the laser peening and improves surface stress to prevent crack initiation. The performance of this system is verified through full-scale mock-up experiments.

Non-Destructive Testing Using Multi-Channel Random-Quadrature Interferometer
---**Bruno F. Pouet**, Sebastien Breugnot, Philippe Clemenceau, and Thomas Blum, Bossa Nova Technologies, Venice, CA 90291

---A new laser interferometric scheme was recently introduced in order to fully take advantage of possibilities offered by laser-based ultrasonic (LBU) inspection and to broaden their integration into industrial inspection systems. This interferometer exhibits high sensitivity to ultrasound on optically rough surfaces without requiring accurate positioning, path stabilization, high power laser or special environmental protections. The novel architecture combines a classic Michelson interferometer design with a multi-speckle processing technique based on random-quadrature detection. The ability to process the speckled light is achieved with the use of detector arrays and parallel processing. The random distribution of the speckled light is taken advantage of for reducing the system complexity and cost, leading to a very user-friendly interferometer. We will present the recent advances toward the development of this robust and sensitive interferometer for industrial LBU system. Results demonstrating the system performance for non-destructive testing applications will be presented. We will show a variety of LBU measurements that will illustrate the system performance and versatility: on moving target, at high temperature and on unprepared black polyurethane and carbon fiber composite samples.

Displacement and Deflection of an Optical Beam by Airborne Ultrasound

---**James N. Caron**, Research Support Instruments, Lanham, MD 20706

---Gas-Coupled Laser Acoustic Detection (GCLAD) enables laser-based sensing of ultrasound from a solid without contact of the surface, and independent of the optical properties of the solid surface. A probe laser beam, directed parallel to the surface, intercepts the ultrasound wave after transmission to air. A position-sensitive photodetector senses changes in the optical beam path created by the disturbance. The interaction between the probe beam and acoustic field has typically been modeled creating a deflection. To first order, sensitivity improves by increasing the distance from the interaction point to the photodetector. Well-resolved waveforms in a variety of materials have been recorded with this approach. This paper describes sensing displacement of the optical beam, as opposed to deflection. Displacement occurs when the beam is deflected twice by the acoustic field such that the probe beam is translated perpendicular to the optical axis. Although the displacement is small compared to the sensitivity of the photodetector, the translation can be magnified using a convex lens. Experiments show that the sensitivity of the displacement setup is comparable to the deflection setup, with the great advantage that a much smaller length is needed. This enables the miniaturization of the GCLAD technique.

Measurement and Analysis of Narrow-Band Surface Acoustic Waves in Ceramic Environmental Barrier Coatings

---**T. L. Steen**[1], S. N. Basu[2], V. K. Sarin[2], and T. W. Murray[1], [1]Department of Aerospace and Mechanical Engineering, Boston University, [2]Department of Manufacturing Engineering, Boston University, Boston, MA 02215

---A laser-based ultrasonic system is used to measure the mechanical properties and thickness of mullite environmental barrier coatings deposited on SiC substrates. Narrow-band surface acoustic waves (SAWs) are generated with an amplitude modulated laser source, and a photorefractive crystal based interferometer coupled to a lock-in amplifier is used to detect the resulting surface displacement. The complex displacement field is mapped over a source-to-receiver distance of approximately 500μm in order to extract the wavelength of the SAW at a given excitation frequency, from which the phase velocity is determined. Dispersion curves measured over a frequency range of 50-200 MHz are used to extract the elastic modulus and thickness of the coating. These values are compared to elastic modulus and thickness measurements made using nanoindentation and optical microscopy, respectively. It is shown that porosity in the substrate can have a significant impact on the experimental results, particularly over short measurement distances. Experiments on SiC with 1-4% porosity show a linear decrease of the mean SAW velocity with increasing porosity. Additionally, measurements made on a sample with a given bulk porosity indicate that the SAW velocity varies locally, leading to additional error in the measurement of coating properties. It is shown that this error can be reduced through spatially averaging the velocity measurements. Finally, the effects of reflections from sample boundaries on the measurement of SAW velocity using this narrow-bandwidth approach are considered, and the total uncertainty in SAW velocity measurements evaluated.

LaserUT® Technology Development Programs for the Laser-Ultrasonic Inspection of Composites in the Aerospace Industry

---**Thomas Drake**, Marc Dubois, Mark Osterkamp, Ken Yawn, David Kaiser, Tho Do, Jeff Maestas, and Michael Thomas, Lockheed Martin Aeronautics, LaserUT Technology Center, P. O. Box 748, Fort Worth, TX 76101

---As the worldwide production of composite parts for the aerospace industry is exploding, the requirement for a cost effective inspection technique during manufacturing is emerging as critical. At Lockheed Martin Aeronautics, a laser-ultrasonic technique named LaserUT® was developed for the F-22 and F-35 programs. LaserUT has demonstrated reduction in inspection labor while the production of composite parts increased ten fold. Nearly 20,000 parts have been inspected with LaserUT so far. Despite its early successes, additional technological improvements to the LaserUT technology will further benefit the F-35 program when production rate reaches its peak. Several technological development programs were therefore undertaken: new detection laser, structured-light mapping, improved CO2 laser, mid-infrared generation laser, and new robotic approach. All these technologies will reduce labor and capital expenditures of the F-35 program by increasing scanning speeds and reliability, and by facilitating data analysis and inspection setup. In this presentation, each technology will be reviewed and its status relatively to production integration will be discussed. The impact of those different technologies on the potential for LaserUT to enter the commercial market will also be discussed.

Laser Picosecond Ultrasonic Measurement of Longitudinal Sound Velocity in Nanometer Thin Films

---**Nen-Wen Pu** and Wei-I Kuo, Chung Cheng Institute of Technology, National Defense University, Department of Applied Chemistry and Materials Science, Tahsi, Taoyuan 335, Taiwan, China (ROC)

---We demonstrate applications of ultrafast-laser-based picosecond ultrasonic techniques to sound velocity measurement in nanometer thin films. The longitudinal sound velocities in various thin films (100 ~ 300 nm thick) were directly determined by pulse-echo technique. Many of the measured velocities deviate from the bulk values significantly and show strong dependence on the growth conditions. To overcome the problems such as echo overlapping and reduced accuracy in much thinner films, we further propose a method capable of measuring the sound velocity in films thinner than 10 nm. By measuring the effective sound velocities of periodic multilayer stacks with different thickness ratios, the velocities of individual constituents can be extracted using the superlattice phonon dispersion relation. The longitudinal sound velocities in ion-beam sputtered Mo and amorphous Si films of 2 ~ 5 nm thickness have been determined using this method. We have also performed theoretical calculations on the laser generation and detection of acoustic pulses in multilayers. The pulse shapes and spectra of acoustic waves were analyzed, and the results agree well with the experimental results. We believe this technique has general applicability to sound velocity measurement in ultra-thin films.

Detection of Kissing Bond in Extruded Aluminum by Laser-Ultrasound

---**Silvio E. Kruger**, Martin Lord, and Daniel Lévesque, National Research Council Canada, Industrial Materials Institute, Boucheville, Québec, Canada; Andrew J. den Bakker, Nedal Aluminium B.V. Utrecht, The Netherlands

---Kissing bond like other defects can occur in solid state joined metals, like friction stir welded aluminum or hollow aluminum extrusions produced by means of prothole dies, and its nondestructive detection is crucial for many structural applications. It is a zero volume joint line defect consisting of a discontinuous metal structure, with possibly entrapped oxide layers. The kissing bond defect causes a reduction of mechanical properties, specifically regarding the ductile characteristics. The nondestructive detection of this type of defect is very challenging due to the very tiny weld interface and partial bonding. In this paper, high frequency ultrasound generated and detected by lasers is applied to detect kissing bonds in extruded aluminum parts. It is found that an echo from the kissing bond discontinuity could be detected when the system has a signal-to-noise ratio (based on the backwall echo) of at least 40 dB in the frequency range of a few hundred MHz.

Theory and Applications of Laser Generated Zero-Group Velocity Lamb Mode Resonance

---**Todd W. Murray** and Oluwaseyi Balogun, Boston University, Department of Aerospace and Mechanical Engineering, Boston, MA 02215; Claire Prada, Dominique Clorennec, and Daniel Royer, Laboratoire Ondes et Acoustique, ESPCI- Université Paris 7- CNRS UMR 7587, 10 rue Vauquelin, 75231 Paris Cedex 05, France

---Lamb modes exhibit a resonant behavior at frequencies where the group velocity vanishes while the phase velocity remains finite. This type of zero group velocity (ZGV) point exists in most isotropic materials at the minimum frequency-thickness product of the first order symmetric (S1) Lamb mode. Laser sources couple efficiently into this resonance and a sharp peak is observed with source and receiver on epicenter. A model for the laser generation of ultrasound in thin plates using an amplitude modulated laser source is presented. The effects of the laser source parameters on the generation of the S1-ZGV resonance are explored, and the spatial distribution of the displacement produced at the resonant frequency determined. Lamb wave displacement spectra are measured using an amplitude modulated laser source for excitation and a Michelson interferometer coupled to an RF lock-in amplifier for detection. The displacement spectra of Lamb waves generated in micron scale plates show good agreement with theoretical predictions. Experimental results are presented demonstrating excitation of the S1-ZGV resonance in a 4um thick membrane using a high frequency (700 MHz) amplitude modulated laser source. Subsurface features below the membrane are detected by tracking the S1-ZGV resonance peak as the sample is scanned.

Synthetic Aperture Focusing Technique for the Ultrasonic Evaluation of Friction Stir Welds

---**Daniel Lévesque**, Silvio E. Kruger, Martin Lord, and Jean-Pierre Monchalin, Industrial Materials Institute, National Research Council Canada, Boucherville, Quebec, Canada; Laurent Dubourg, and Mohammad Jahazi, Aerospace Manufacturing Technology Centre, Institute for Aerospace Research, National Research Council Canada, Montreal, Quebec, Canada; Catalin Mandache, Structures and Materials Performance Laboratory, Institute for Aerospace Research, National Research Council Canada, Ottawa, Ontario, Canada

---Friction stir welding (FSW) is a recently developed solid-state joining process that uses a specially shaped rotating tool to produce the weld. The motion of the welding tool on the metal sheet generates frictional heat that creates a plasticized region around the immersed portion of the tool to produce lap or butt joints. However, with changes in material conditions or welding parameters, discontinuities such as worm holes, lack of penetration, hooking or voids can be formed. A more difficult situation is the presence of joint line remnants or ”kissing bonds” due to entrapped oxide layers also resulting in a reduction of the weld mechanical properties. An ultrasonic technique is presented in this paper that uses numerical focusing and processing for the detection of different types of flaws in FSW. The data is acquired using an immersion technique or laser ultrasonics. For the numerical focusing, a Synthetic Aperture Focusing Technique (SAFT) is used while taking into account surface variations induced by the FSW tool. Both immersion and laser-ultrasonic results with SAFT are presented. Measurements on far and near sides of the welding tool for both lap and butt joints of 1 to 3 mm thick aluminum sheets are investigated.

Session 21

SESSION 21

NDE COMPOSITES AND BONDED STRUCTURES

D. Fei, Chairperson
Ballroom C

1:30 PM **Damage Modeling in Composite Materials for NDE**
---**V. Dayal**, D. Hsu, and A. Kite, Center for NDE, Iowa State University, 1915 Scholl Road, Ames, IA 50011

1:50 PM **Approaches to Porosity Assessment in Composite Structures**
---**J. R. Kollgaard**, C. A. Decker, and T. L. Aljundi, Boeing Commercial Airplanes, In-Service NDT R&D Ground, P. O. Box 3707, Mail Code 2T-42, Seattle, WA 98124-2207

2:10 PM **Thermal Nondestructive Testing of CFRP Impact Damage and Metal Porous Filters**
---**L. Feng**, N. Tao, W. Xu, and Y. Li, Capital Normal University, Department of Physics, Beijing, 100037, China

2:30 PM **Pulsed Thermography Applied to Components with Complex Shape**
---**G. Hendorfer**, G. Mayr, and E. Schlotthauer, University of Applied Science, Stelzhamerstraße 23, A-4600 Wels, Austria

2:50 PM **Evaluation of Delamination in CFRP Composite by Laser Generated Ultrasound**
---**Y.-J. Ha**, S.-J. Lee, J.-H. Lee, and J.-H. Byun, Pusan National University, Department of Mechanical Design Engineering, Busan, Korea

3:10 PM ***Break***

3:30 PM **Millimeter Wave Holographical Inspection of Honeycomb Composites**
---J. T. Case, S. Kharkovsky, and **R. Zoughi**, University of Missouri-Rolla, Electrical and Computer Engineering Department, Applied Microwave Nondestructive Testing Laboratory (amntl), 1870 Miner Circle, Rolla, MO 65409-0040; G. Steffes, Wright-Patterson Air Force Base, Air Force Research Laboratory, Wright-Patterson, OH 45433; F. L. Hepburn, NASA George C. Marshall Space Flight Center, Marshall Space Flight Center, AL 35812

3:50 PM **Microwave and Millimeter Wave Near-Field Methods for Evaluation of Randome Composites**
---M. M. Ravuri, M. A. Abou-Khousa, **S. Kharkovsky**, and R. Zoughi, University of Missouri-Rolla, Electrical and Computer Engineering Department, Applied Microwave Nondestructive Testing Laboratory (amntl), 1870 Miner Circle, Rolla, MO 65409-0040; R. Austin, Texas Research Institute at Austin (TRI Austin), Austin, TX 78733

4:10 PM **NDE for Water Ingression Composite Radomes on Aircraft**
---**D. K. Hsu**, D. J. Barnard, and A. H. Kite, Center for NDE, Iowa State University, Ames, IA 50011; K.-B. Kim, Korea Research Institute of Standards and Science, Daejeon, Korea

4:30 PM **Sources of and Remedies for Removing Unwanted Reflections in Millimeter Wave Images of Complex SOFI-covered Structures**
---S. Kharkovsky, J. T. Case, and R. Zoughi, University of Missouri-Rolla, Electrical and Computer Engineering Department, Applied Microwave Nondestructive Testing Laboratory (amntl), Rolla, MO 65409-0040; F. L. Hepburn, NASA George C. Marshall Space Flight Center, Marshall Space Flight Center, AL 35812

4:50 PM **NDE of Bonded Aluminum Components on Aircraft Structures**
---**G. J. Steffes**, USAF AFRL/MLLP, 2230 Tenth Street, Suite 1, Building 655, WPAFB, OH 45433; D. K. Hsu, D. J. Barnard, C. Foreman, S. Wendt, and N. A. Kreitinger, Center for NDE, Iowa State University, Ames, IA 50011

Damage Modeling in Composite Materials for NDE

---**V. Dayal**, David Hsu, and Adam Kite, Center for NDE, Iowa State University, 1915 Scholl Road, Ames, IA 50011

---Damage in layered composites is directional and generally is oriented in the fiber directions. The failure mode can be modeled in three ways. First, the damage can be in the form of reduction of the lamina stiffness; second, the damage can be a result of the inter-ply delamination, and finally, a combination of the two. The first two types of damages have been modeled in this work. In NDE the damage interacts with the stress waves propagating in the medium and the resulting damage signature is recorded to determine the extent of damage. The effect of the damage on the low frequency ultrasound (120 kHz -240 kHz) is the objective of this work. Proliferation of air-coupled ultrasound in recent past adds significance and importance to the numerical damage modeling. The ultrasonic NDE of composite structures is frequency dependent and more so at lower frequencies. We present here our experience with the NDE of laminated composites. Also, presented are the various models and their theoretical resonant responses.

Approaches to Porosity Assessment in Composite Structures

---**Jeffrey R. Kollgaard**, Carrie A. Decker, Boeing Commercial Airplanes, In-Service NDT R&D Ground, P. O. Box 3707, Mail Code 2T-42, Seattle, WA 98124-2207

---As solid laminate structure becomes an increasingly common in primary aircraft structure, the need for accurate assessment of porosity has increased. Porosity is a known detrimental condition that affects the performance of these materials under load. This paper will summarize a number of novel approaches evaluated by Boeing Commercial Airplanes with the intent of simplifying porosity assessment. Not all approaches were successful but each led to an improved understanding of the porosity assessment problem. Some promising methods are identified that may result in future improvements.

Thermal Nondestructive Testing of CFRP Impact Damage and Metal Porous Filters

---**Lichun Feng**, Ning Tao, Weichao Xu, and Yanhong Li, Department of Physics, Capital Normal University, Beijing, 100037, China

---Pulse thermography and pulse phase thermography methods were applied for nondestructive testing of carbon fiber reinforced plate after low velocity impact and metal porous filters. Ten pieces of CFRP were used in the experimental study by QMW test method. Results from PT and PPT methods both show the validity of active thermography for CFRP impact damage inspection. Metal porous filters which are used for gas-liquid separation are difficult to test by traditional nondestructive testing methods due to its instinctive porosity and requirement for noncontact test. Thermal nondestructive method shows its superiority after adequate surface treating.

Pulsed Thermography Applied to Components with Complex Shape

---**Guenther Hendorfer**, Guenther Mayr, and E. Schlotthauer, University of Applied Science, Stelzhamerstraße 23, A-4600 Wels, Austria

---In a study of components from the aviation industry, we have applied the methods of Pulsed Thermography (PT) and 3D-Computed Tomography (CT). The components surveyed are functional elements consisting of Carbon Fibre Reinforced Plastics (CFRP) or Glass Fibre Reinforced Plastics (GFRP). The aim of our research is the development of fast and robust algorithms suitable for industrial applications and even for the usage of low-cost IR cameras. The results obtained from CT measurements are used as reference data thus enabling the calibration of PT related data. The quantities evaluated in PT experiments correspond to material properties which are given either as images of thermal conductivity, as in the case where CFRP components are discussed, or as images of the glass fibre density as far as GFRP components are concerned. Since all components studied are of complex shape, including varying thickness, curvatures, edges and U-shaped samples, we have to take into account the influence of the specific excitation conditions as well as geometry effects in the evaluation of PT results. The PT data are corrected with respect to excitation and geometry effects by means of numerical simulation and are shown to be in excellent agreement with the CT data after correction.

Evaluation of Delamination in CFRP Composite by Laser Generated Ultrasound

---**Young-Joon Ha**, Seung-Joon Lee, Joon-Hyun Lee, and Joon-Hyung Byun
Pusan National University, Department of Mechanical Design Engineering, Busan, Korea

---The objective of this research is to develop non-contact and real time inspection technique based on laser generated ultrasound to evaluate delamination in CFRP composite fabricated from recently developed 3-dimensional fiber placement system (FPS). The FPS stacks the narrow prepreg tape on the mold according to the designed sequence and thickness, so that can produce a more complex to and various shaped structures due to less limitations compared with conventional fabrication process. In this study, fiberized Nd:YAG pulse laser(532 nm , 32mJ) with linear slit array is used to generate ultrasonic guided wave in unidirectional CFRP specimen (24plies, 3mm thickness). Artificial delamination with the area of 20mm x 20mm is made of teflon film. In order to investigate the reception ability of ultrasonic guided wave propagated through the area of delamination air-coupled and piezoelectric transducers are used as reception of guided wave. The characteristic of time domain waveform and frequency spectrum of guided wave received from two different transducers based on contact and non-contact scheme is discussed.

Millimeter Wave Holographical Inspection of Honeycomb Composites

---Joseph T. Case, Sergey Kharkovsky, and **Reza Zoughi**, University of Missouri-Rolla, Electrical and Computer Engineering Department, Applied Microwave Nondestructive Testing Laboratory (amntl), 1870 Miner Circle, Rolla, MO 65409-0040; Gary Steffes, Wright-Patterson Air Force Base, Air Force Research Laboratory, Wright-Patterson, OH 45433; Frank L. Hepburn, NASA George C. Marshall Space Flight Center, Marshall Space Flight Center, AL 35812

---Microwave and millimeter wave nondestructive testing methods can produce high spatial resolution images of multi-layered composite structures manufactured with honeycomb, foam or balsa wood cores either using real-antenna focused or synthetic-aperture focused methods. In addition, incorporation of swept-frequency in the latter method (i.e., holography) results in high-resolution three-dimensional images. This paper presents the basic steps behind producing such images at millimeter wave frequencies and the results for three specific honeycomb composite panels (two flat and one curved) will be demonstrated at Q-band (33-50 GHz). In addition, these results will be compared to others using computed tomography and near-field microwave and millimeter wave methods.

Microwave and Millimeter Wave Near-Field Methods for Evaluation of Randome Composites

---Mourya M. Ravuri, Mohamed A. Abou-Khousa, **Sergy Kharkovsky**, and Reza Zoughi, University of Missouri-Rolla, Electrical and Computer Engineering Department, Applied Microwave Nondestructive Testing Laboratory (amntl), 1870 Miner Circle, Rolla, MO 65409-0040; Russell Austin, Texas Research Institute at Austin (TRI Austin), Austin, TX 78733

---Near-field microwave and millimeter wave nondestructive testing methods are well-suited for inspecting radome composites since signals at these frequencies readily penetrate through these structures and reflect from different interior boundaries revealing the presence of a wide range of defects such as disbond, delamination, moisture and oil intrusion, impact damage, etc. This paper presents the results of electromagnetic simulations for detecting and evaluating the presence disbonds in such structures as well as a comprehensive experimental effort using near-field imaging techniques (producing images with high spatial resolutions) at several frequency bands in the microwave and millimeter wave regions.

NDE for Water Ingression in Composite Radomes on Aircraft

---**David K. Hsu**, Daniel J. Barnard, and Adam H. Kite, Center for NDE, Iowa State University, Ames, IA 50011; Ki-Bok Kim, Korea Research Institute of Standards and Science, Daejeon, Korea

---Aircraft radomes, being an electronic window for the radar, are made of non-conducting composite sandwiches with glass or silica fiber-reinforced facesheet and Nomex honeycomb or foam core. Trapped water or moisture can produce shadow on the image and severely degrade the performance of the radar. To detect water ingression in radomes, the available NDE techniques include x-ray radiography, infrared thermography, and a radome moisture meter that measures the RF power loss caused by the presence of water. In this work we explore the utility of commercially available capacitive sensors with co-planar electrodes that measure the change of the dielectric constant in the fringing field. These capacitive sensors, such as the electronic stud finder and moisture meters for wood, can exploit the large dielectric constant of water and serve as one-sided detectors for water and moisture in radomes. The sensitivities of the various moisture meters were compared in the experimental detection of water introduced into radome panels and water and moisture trapped in retired radomes.---This material is based upon work supported by the Air Force Research Laboratory under Contract #FA8650-04-C-5228 at Iowa State University's Center for NDE.

Sources of and Remedies for Removing Unwanted Reflections in Millimeter Wave Images of Complex SOFI-covered Structures

---Sergey Kharkovsky, Joseph T. Case, and Reza Zoughi, University of Missouri-Rolla, Electrical and Computer Engineering Department, Applied Microwave Nondestructive Testing Laboratory (amntl), Rolla, MO 65409-0040; Frank L. Hepburn, NASA George C. Marshall Space Flight Center, Marshall Space Flight Center, AL 35812

---In the recent years, continuous-wave near-field and lens-focused millimeter wave imaging systems have been effectively used to demonstrate their utility for producing high-resolution images of metallic structures covered with spay on foam insulation (SOFI) such as the space shuttle external tank. However, for some specific structures a certain interference pattern may be superimposed on the produced images. There are methods by which the influence of this unwanted interference can be reduced, such as the incorporation of an incidence angle and the proper use of signal polarization. This paper presents the basics of this problem and describes the use of the methods for reducing this unwanted influence through several specific examples. A discussion on how the use of a swept-frequency or pulsed method may also alleviate this problem is also presented.

NDE of Bonded Aluminum Components on Aircraft Structures

---**Gary J. Steffes**, USAF AFRL/MLLP, 2230 Tenth Street, Suite 1, Building 655, WPAFB, OH 45433; David K. Hsu, Daniel J. Barnard, Cory Foreman, Scott Wendt, and Nicholas A. Kreitinger, Center for NDE, Iowa State University, Ames, IA 50011

---Bonded aluminum structures have been commonly used on aircraft for many years, and many of these applications include flight control surfaces. These bonded structures can be made up of aluminum face sheets adhesively bonded to a central honeycomb core, or they could also be composed of machined components that are bonded in a tongue-in-groove type manner called Grid-Lock. Nondestructive Inspection (NDI) methods of bonded aluminum structures usually involve the detection of skin-to-core disbonds, core buckling and damage caused by impacts. In the case of Grid-Lock, NDI techniques are focused on the detection of failures in the tongue-in-groove adhesive joint. Three nondestructive inspection methods were applied to honeycomb sandwich structures and Grid-Lock panels. The three methods were computer aided tap test (CATT), air-coupled ultrasonic testing (ACUT), and mechanical impedance analysis (MIA). The honeycomb structures tested consisted of structural panels and flight control surfaces from various aircraft. The Grid-Lock samples tested are laboratory specimens that simulate various defects. Experimental results and comparisons from each of these methods and samples will be presented.---This material was based on work supported by the Air Force Research Laboratory under Contract #FA8650-04-C-5228 at Iowa State University's Center for NDE.

Session 22

SESSION 22
X-RAYS
D. Barnard, Chairperson
Ballroom A

1:30 PM **Analysis of Fiber Organization on a Spool Using X-Ray CT**
---**M. A. Sala**, Corning Incorporated, SP-TD-00, Corning, NY 14831

1:50 PM **Developments in Using High Energy X-Ray Diffraction for Measuring Residual Stress**
---**A. Al-Shorman**, J. Gray, and T. Jensen, Center for NDE, Iowa State University, 1915 Scholl Road, Ames, IA 50011

2:10 PM **Recent Developments of a Computed Tomography Simulation Tool: CTSIM**
---**S. Wendt**, J. Gray, J. Xu, Center for NDE, Iowa State University, 1915 Scholl Road, Ames, IA 50011

2:30 PM **Virtual Examination Through High Resolution 3DCT Scans of Ancient Scrolls and Artifacts**
---**J. Gray**[1], B. Seals[2], Y. Lin[2], [1]Center for NDE, Iowa State University, 1915 Scholl Road, Ames, IA 50011; [2]University of Kentucky

2:50 PM **Selected Algorithms of Background Generation Used for Flaw Detection In Welded Joints**
---**T. Chady** and M. Caryk, Szczecin University of Technology, Department of Electrical Engineering, Szczecin, 70-313, Poland

3:10 PM ***Break***

Analysis of Fiber Organization on a Spool Using X-Ray CT

---**Martin A. Sala**, Corning Incorporated, SP-TD-00, Corning, NY 14831

---It has always been a mystery as to the actual organization of optical fibers as they are placed on a spool from the draw for distribution to customers. These fibers are theoretically wound in a specific manner, but often reality refuses to follow theory. In the past, it has been attempted to destructively analyze the lay-down by impregnating the lay with resin and then slicing the spool open with a saw; this method has its limitations. This year we have been able to for the first time ever image the lay-down organization using X-ray CT. As expected, the results were both surprising and comforting.

Developments In Using High Energy X-Ray Diffraction For Measuring Residual Stress

---**M. Al-Shorman**, J. Gray, and T. Jensen, Center for NDE, Iowa State University, 1915 Scholl Road, Ames, IA 50011

---We are developing a high energy (50-150 keV) diffraction method for use in measuring internal strain of moderately sized objects. Traditional x-ray strain measurements are limited to a few microns depths due to the limited penetration of Cu Kα and Mo Kα radiation. The high energy that we are using allows for greater penetration. We have completed demonstrations of high energy diffraction in aluminum and titanium with penetration depths of 600 microns. The spatial resolution of this depth profile is ~75 microns and at present we have demonstrated sensitivity to a lattice parameter change of 0.01 angstroms. We have also developed a simulation program for modeling the effect of monochromator slit alignment, detector collimator configurations and several scanning means. We will present recent results on the development of this new tool and on x-ray diffraction measurement at high energy, typically in the range of 60-100 keV.

Recent Developments of a Computed Tomography Simulation Tool: CTSIM

---**S. Wendt**, J. Gray, J. Xu, Center for NDE, Iowa State University, 1915 Scholl Road, Ames, IA 50011

---Computed Tomography is an NDE tool which is quickly becoming widely used in industrial settings. These situations cover a very wide range of parameters and inspection needs making the optimal CT scanner difficult to determine for any give application. As more detectors types become available and as more reconstruction algorithms add to the richness of options, the need for training in addition to technique optimization for this tool becomes important. We have developed a CT simulation program modeling the typical white spectrum of x-ray tubes and allow for a complex geometry of a part, as represented by a CAD model. Materials for the part s together with a dose dependent detector model makes for a flexible tool for examining the impact of a wide number of parameters on the resulting image quality. For example the source of image artifacts can be traced by applying realistic pixel variation as seen in detector arrays and studying how this non-optimal response produces ring artifacts. The sinogram output of the simulation allows for reconstruction efficacy to be determined. Beam hardening effects, limited data, high dynamic range or high aspect rations artifacts can be easily studied. An overview of the capabilities and physics modeled in CTSIM will be presented.

Virtual Examination Through High Resolution 3DCT Scans of Ancient Scrolls and Artifacts

---**J. Gray***, B. Seals**, Y. Lin**, *Center for NDE, Iowa State University, 1915 Scholl Road, Ames, IA 50011; **University of Kentucky, Lexington, KY 40506-0027

---Many items preserved from antiquity are fragile and can not bear much handling. These artifacts can be old book bindings, papyrus scrolls or clay tablets. In the case of written materials the scholarly desire to read these artifacts must be balanced with any damage that may effect the preservation of the materials. In most cases there are features about the artifact that obstruct interior surfaces from examination, in some case the obstruction can be simple dirt. In order to access this information from what can be quite complex surfaces, consider a compressed papyrus scroll; two requirements need to be met. First a non-destructive means to represent the volume must be available and second a means to untangle the surfaces to allow for a virtual examination needs to be at hand. We report on recent results using a high resolution 3DCT scanner developed at CNDE to generate a 3D data set of several old artifacts. Software scheme developed at University of Kentucky completes the two key elements needed to virtually unfold these fragile documents. We will show results on several items fabricated to model the properties of ancient materials and then finish with a summary of the results from book binding from the 1500AD.

Selected Algorithms of Background Generation Used for Flaw Detection in Welded Joints

---**T. Chady** and M. Caryk, Szczecin University of Technology, Department of Electrical Engineering, Szczecin, 70-313, Poland

---Flaws detection in welds radiographic images is a basic task in a digital radiography. The important stage in a flaw detection process is a background subtraction. In many cases the background image is generated from a base image using image processing algorithms. In this paper effectiveness of flaws detection process using various algorithms of background generation and various algorithms of an image thresholding was evaluated. The results of background generation using a median filter method, a polynomial approximation method and an iterative Gaussian approximation method were presented. The median filter method uses a large size of mask, that removes all defects from an image and generates the background. The second order polynomials are used in the polynomial approximation method. In case of the Gaussian approximation method a set of Gauss functions is fitted to each profile of weld. In order to accelerate the process function parameters achieved for previous weld profile were used as start parameters for the approximation of the next weld profile. The received background image was subtracted from the base image. After background subtraction process of global and local thresholding algorithms were applied. All analysis were carried out using digital radiographs of real welds in C and Matlab environment.---This work was supported by European Commission sponsored project FilmFree, which is a collaboration between the 32 European organizations (www.filmfree.eu.com). Contact for further details: exploitation manager S. Sood (scsood@cituk.com), project manager A. Wocial (adam.wocial@twi.co.United Kingdom). The Project is coordinated and managed by TWI Ltd and is partly funded by the EC under the IP SME programme, reference number: NMP2-CT-2005-515746.

Session 23

SESSION 23
STRUCTURAL HEALTH MONITORING II
S. Krishnaswamy, Chairperson
Ballroom A

3:30 PM **Matched Lamb-Wave Transducer Arrays for Structural Health Monitoring Applications**
---**G. R. Kirikera**, L. Sun, J. D. Achenbach, and S. Krishnaswamy, Northwestern University, Center for Quality Engineering and Failure Prevention, CAT #327, 2137 N. Sheridan Road, Evanston, IL 60208

3:50 PM **Modeling of Acoustic Wave Propagation Thru Varying Grain Size Structure**
---**S. A. Martin[2]**, K. V. Jata[1], R. W. Martin[3], and S. Sathish[3], [1]Air Force Research Laboratory, Metals, Ceramics and NDE Division, 2230 Tenth St., Wright Patterson AFB, Dayton, OH 45433-7817, [2]NDE Computational Consultants, Dublin, OH 43017-8530, [3]University of Dayton Research Institute, 300 College Park, Dayton, OH 45469-0127

4:10 PM **Shear Wave Imaging of Large Optics**
---**M. J. Quarry**, Lawrence Livermore National Laboratory, Engineering Technologies Division, Livermore, CA 94550

4:30 PM **Non-Contact Lamb-EMAT Technique for Health Monitoring of Piping**
---**I. K. Park**, Y. Cho*, Y. K. Kim, and J. H. Lee, Seoul National University of Technology, Seoul 139-743, Korea; *Pusan National University, School of Mechanical Engineering, South Korea

4:50 PM **Vibro-Enhanced Fluorescent Penetrant Inspection (FPI)**
---**K. Milne** and P. Cawley, Imperial College Longon, Mechanical Engineering, London, United Kingdom; D. Wright and T. Dunhill, Rolls-Royce plc, Derby, United Kingdom

5:10 PM **Acoustic Techniques and Systems for Structural Health Monitoring**
---**B. Frankenstein**, J. Augustin, D. Hentschel, F. Schubert, B. Koehler, and N. Meyendorf, Fraunhofer Institute for Non-Destructive Testing, Dresden, Germany

Matched Lamb-Wave Transducer Arrays for Structural Health Monitoring Applications

---**Goutham R. Kirikera**, Li Sun, Jan D. Achenbach and Sridhar Krishnaswamy, Northwestern University, Center for Quality Engineering and Failure Prevention, CAT #327, 2137 N. Sheridan Road, Evanston, IL 60208-3020

---Novel configurations of piezoelectric transducer arrays for ultrasonic structural health monitoring (SHM) of plate structures are investigated. Lamb waves are highly dispersive and multi-modal, necessitating careful design of the SHM sensor architecture to effectively locate and size any damage in the structure. In this work, we discuss a structural health monitoring system consisting of three sets of transducer arrays: energy-harvesting transducers, ultrasound generating transducers, and ultrasound receiving transducers. To simplify damage detection, the generating transducers consist of shaped piezoelectric arrays which can generate specific modes of Lamb waves in different directions in the plate. A matched transducer array is placed at a distance to receive the specific mode of interest. The generating and receiving arrays are geometrically shaped in several ways (linear arrays, radial arrays, etc) to generate appropriate wave-packets. The generating transducers are driven by the energy harvested from ambient vibrations using a set of energy-harvesting transducers. Different configurations (parallel and series) of the transducer arrays are described, and the configurations that are optimal for purposes of energy-harvesting, generating and detection are discussed. The SHM network is demonstrated on a test panel with induced flaws.

Modeling of Acoustic Wave Propagation Thru Varying Grain Size Structure

---Steven A. Martin[2], Kumar V. Jata[1], Richard W. Martin [3], and Shamachary Sathish[3], [1]Air Force Research Laboratory, Metals, Ceramics and NDE Division, 2230 Tenth St., Wright Patterson AFB, Dayton, OH 45433-7817, [2]NDE Computational Consultants, Dublin, OH 43017-8530, [3]University of Dayton Research Institute, 300 College Park, Dayton, OH 45469-0127

---Traditional models of ultrasonic wave propagation are primarily useful for NDE of homogeneous and isotropic materials. In the presence of spatial variations of elastic properties in materials, ultrasonic wave propagation simulation as well as NDE becomes challenging. In view of these challenges, the computational modeling approaches are suitable to incorporate the spatial elastic property variations and elastic anisotropy into simulations of ultrasonic wave propagation. This paper investigates the application of finite element based simulation of ultrasonic wave propagation in materials with varying grain sizes and associated ultrasonic wave velocities. As an example, the method is used to simulate ultrasonic wave propagation through Aluminum-Lithium high strength structure. Acoustic microscopically measured local elastic properties across the weld are incorporated into the simulation. Results of simulation of Rayleigh Surface Wave (RSW) and bulk acoustic wave propagation in the FSW structure are presented.

Shear Wave Imaging of Large Optics

---**Michael J. Quarry**, Lawrence Livermore National Laboratory, Engineering Technologies Division, Livermore, CA 94550

---When complete the National Ignition Facility (NIF) will be the world's largest and most energetic laser and will be capable of achieving for the first time fusion ignition in the laboratory. Detecting optics features within the laser beamlines and sizing them at diameters of 100 mm to 10 mm allows timely decisions concerning refurbishment and will help with the routine operation of the system. Horizontally polarized shear waves at 10 MHz were shown to accurately detect, locate, and size features created by laser operations from 500 micrometers to 8 mm by placing sensors at the edge of the optic. The shear wave technique utilizes highly directed beams. The outer edge of an optic can be covered with shear wave transducers on four sides. Each transducer sends a pulse into the optic and any damage reflects the pulse back to the transmitter. The transducers are multiplexed, and the collected time waveforms are enveloped and replicated across the width of the element. Multiplying the data sets from four directions produces a map of reflected amplitude to the fourth power, which images the surface of the optic. Surface area can be measured directly from the image, and maximum depth has been shown to be correlated to maximum amplitude of the reflected waveform.---This work was performed under the auspices of the U.S. Department of Energy by the University of California, Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48.

Non-Contact Lamb-EMAT Technique for Health Monitoring of Piping

--- **I. K. Park**, Y. Cho*, Y. K. Kim, and J. H. Lee, Seoul National University of Technology, Seoul 139-743, Korea; *Pusan National University, School of Mechanical Engineering, South Korea

---In this paper, the evaluation of thickness reduction in pipes by guided waves is presented. Ultrasonic guided wave techniques have been widely studied and successfully applied to various non-destructive tests with the advantage of long range inspection. The non-contact methods for ultrasonic wave generation and detection have become very useful and well combined with guided wave techniques due to their capability of ultrasonic wave generation and reception on surface of high temperature or on rough surface. A non-contact technique for detection of thickness reduction simulated corrosion in pipes using guided waves is proposed. The EMAT (Electro-Magnetic Acoustic Transducer) is applied to the non-contact generation and detection of guided waves in pipes. Interesting features of the dispersive behavior in selected wave modes are used to detect thickness reduction. The experimental results show that the mode cutoff measurements provide a qualitative measurement of thinning defects and change of the mode group velocity can be used as quantitative parameter of thinning depth measurement.

Vibro-Enhanced Fluorescent Penetrant Inspection (FPI)

---**Katherine Milne** and Peter Cawley, Imperial College London, Mechanical Engineering, London, United Kingdom; David Wright and Tony Dunhill, Rolls-Royce plc, Derby, United Kingdom

---Fluorescent penetrant is widely used by aeroengine manufacturers to inspect for surface breaking flaws in critical components. Even the most sensitive penetrant systems may not find short tight cracks (<1µm mouth opening). The potential of vibration as a means of encouraging penetrant to fill and bleed-out of cracks, by changing the crack closure or the surface energy of the liquid-solid interface, was investigated. For the technique to remain non-destructive, the threshold stress-intensity ΔK_{th} for crack propagation must not be exceeded. Tests were carried out on rectangular cross-section bars containing tight thumbnail fatigue cracks 0.4 to 1.5mm in length. To eliminate the subjectivity of a human inspector, an image-processing algorithm was used to automatically detect crack indications. The change in crack mouth opening with static load was measured using an optical method. To improve the penetrant process static cross-crack strains greater than 450 µs were required, exceeding ΔK_{th}; shorter cracks require higher strains. The possibility that an improvement could be obtained at lower dynamic strains was then investigated. The samples were vibrated after the penetrant process at around 17kHz. A bending mode was excited, generating cross-crack strains up to 300 µs; at these strain levels no improvement was obtained.

Acoustic Techniques and Systems for Structural Health Monitoring

---Bernd Frankenstein, Jörn Augustin, Dieter Hentschel, Frank Schubert, Bernd Koehler, and **Norbert Meyendorf**, Fraunhofer Institute for Non-Destructive Testing - Dresden - Germany

---Future safety and maintenance strategies for industrial components and vehicles are based on combinations of monitoring systems, which are permanently attached to or embedded in the structure, and periodic inspections. The latter belong to conventional nondestructive evaluation (NDE) and can be enhanced or partly replaced by structural health monitoring (SHM) systems. However, the main benefit of SHM in the far future will arise from the fact that improved safety philosophy including continuous monitoring makes a novel system design possible leading to an increase in the efficiency of inspection procedures and the reduction of inspection time. Additionally, system properties as reduced weight can be reached leading to substantial reduction in operational costs. One of the main SHM techniques uses acoustics signals. Especially for larger structures a net of acoustic sensors communicating with each other is necessary. The Dresden branch of Fraunhofer IZFP has developed network nodes, miniaturized transmitters and receiver systems for active and passive acoustic techniques and sensor systems that can be attached to or embedded in components or structures. These systems have been used to demonstrate intelligent sensor networks for monitoring of aerospace structures, railway systems, wind energy generators, pipes and others. This paper will give an overview of these activities and will discuss a resent application in more detail: The acoustic monitoring of railway wheels by a hollow shaft integrated monitoring system. The sensors, electronics, power generation and signal processing is discussed in detail. The performance of the system is demonstrated in various test runs. The paper will conclude with a discussion of further needs of research and development for improved SHM systems.

Session 24

SESSION 24
EDDY CURRENT TECHNIQUES AND PROBES
P. Nagy, Chairperson
Ballroom D

1:30 PM **Detection and Sizing of Fatigue Cracks in Steel Welds with Advanced Eddy Current Techniques**
---**E. I. Todorov**, W. C. Mohr, and M. G. Lozev, Edison Welding Institute (EWI), 1250 Arthur E. Adams Drive, Columbus, OH 43221-3585

1:50 PM **High Resolution Eddy Current Imaging with Atomic Force Microscope**
---V. Nalladega[1], **S. Sathish**[2], K. V. Jata, M. P. Blodgett, Air Force Research Laboratory, AFRL/MLLP, [1]Department of Mechanical Engineering, University of Dayton, Dayton, OH 45469; [2]University of Dayton Research Institute, 300 College Park, Dayton, OH 45469-0127

2:10 PM **Resonant Frequency Eddy Current Liftoff Measurements for Conductivity Assessment in Materials**
---R. T. Ko[1], M. P. Blodgett[2], S. Sathish, and T. R. Boehnlein, [1]University of Dayton Research Institute, 300 College Park, Dayton, OH 45469-0120; [2]USAF (AFRL/MLLP) 2230 10th Street, Suite 1, Wright-Patterson AFB, Dayton, OH 45433

2:30 PM **Diffusion of Pulsed Eddy Currents in Thin Conducting Plates**
---T. W. Krause, Royal Military College of Canada, Department of Physics, Kingston, Ontario, Canada; C. Mandache, National Research Council of Canada, Institute for Aerospace Research, Ottawa, Ontario, Canada; V. Lefebvre, Defence R&D Canada, Air Vehicles Research Section, Ottawa, Ontario, Canada

2:50 PM **Detection of Deep-Surface Defects and Far-Side Corrosion in Stainless Steel Components Using an Integrated Eddy Current-GMR Sensor**
---S. Balakrishnan, B. P. C. Rao, **T. Jayakumar**, U. K. Mudali, and B. Raj, Indira Gandhi Centre for Atomic Research, Kalpakkam, Tamil Nadu, India

3:10 PM ***Break***

3:30 PM **High Resolution Eddy Current Probe**
---**B. Marchand**, F. Vacher, C. Gilles-Pascaud, CEA Saclay, DRT/LIST/SYSSC, Bâtiment 611, Point courier 120, 91191 Gif sur Yvette, France; H. Polovy, C. Fermon, C. Pannetier-Lecoeur, DSM/DRECAM/SPEC, CEA, Saclay, 91191 Gif-Sur-Yvette, France

3:50 PM **Applications of Motorized Rotational RFEC Probes in Thick and Multiplayer Structure Crack Detection**
---**Y. Sun**, C. H. Sun, H. Zhu, T. Ouyang, X. Yang, and W. Wan, Innovative Materials Testing Technologies, Inc., 3141 W. Toeerys Peak Drive, Superior, CO 80027

4:10 PM **A New Eddy Current Probe for Detecting Very Long Surface Flaws**
---**H. Hoshikawa** and K. Koyama, Nihon University, Izumisho Narashino, Chiba 275-8575, Japan

4:30 PM **Eddy Current Differential Transducer for Nondestructive Evaluation of Aluminum Plates**
---**T. Chady** and P. Lopato, Szczecin University of Technology, Department of Electrical Engineering, Szczecin, Poland

4:50 PM **Pulsed Eddy Current System Characterization and Bench-Mark Waveforms**
---**C. Lo**, S. J. Lee, C. Lee, M. J. Johnson, and N. Nakagawa, Center for NDE, Iowa State University, 1915 Scholl Road, Ames, IA 50011

Detection and Sizing of Fatigue Cracks in Steel Welds with Advanced Eddy Current Techniques

---**Evgueni I. Todorov**, William C. Mohr, and Margarit G. Lozev, Edison Welding Institute (EWI), 1250 Arthur E. Adams Drive, Columbus, OH 43221-3585

---Service fatigue damage (cracks) in critical welded joints may often be hidden under a thick coating. Coating removal for performing liquid penetrant and magnetic particle (MPI) nondestructive inspection (NDI) is expensive and may even cause damage to steel surface. Both techniques provide the length of the crack only. More often, crack depth is the parameter determining structure life and repair actions. Eddy current NDI does not require coating removal and crack depth information might be possible to obtain in addition to crack length. In this study, butt-welded specimens were manufactured and fatigued to produce cracks. Modeling of eddy current inspection was performed to identify critical inspection factors. Advanced eddy current (AEC) techniques were used to detect and size the cracks through the coating. AEC results were compared with MPI and phased array ultrasonic. NDI findings were validated through destructive crack measurements. AEC techniques demonstrated very good detection and sizing capabilities. Factors such as geometry, surface treatment and crack tightness interfered with depth sizing. AEC inspection techniques have the potential of providing more accurate and complete sizing flaw data for manufacturing and in service inspections.

High Resolution Eddy Current Imaging with Atomic Force Microscope

---Vijay Nalladega[1], **Shamachary Sathish**[2], Kumar V. Jata, Mark P. Blodgett, Air Force Research Laboratory, AFRL/MLLP, [1]Department of Mechanical Engineering, University of Dayton, Dayton, OH 45469; [2]University of Dayton Research Institute, 300 College Park, Dayton, OH 45469-0127

---Eddy current testing is a widely used electromagnetic nondestructive evaluation technique of materials. This technique offers measurement of electrical conductivity and magnetic permeability of materials. Since the presence of defects significantly changes the electrical conductivity, eddy current testing is widely used to defects, cracks in materials. The resolution in eddy current imaging is mainly limited by the diameter of the sensor, which is most often greater than 500 mm. This paper presents development of an eddy current microscopy based on an Atomic Force Microscope to image local variations in the electrical conductivity of materials with submicron resolution. The newly developed methodology has been used to characterize carbon fiber composites, nano-composites and microstructure of aerospace metallic materials. AFM surface topography images and eddy current images of the same region of the samples are presented. The contrast observed in eddy current images is explained based on the local electrical conductivity variations in the materials. The advantages and limitations of the AFM based edd6y current imaging to study the electrically conductive materials are discussed.

Resonant Frequency Eddy Current Liftoff Measurements for Conductivity Assessment in Materials

---**Ray T. Ko**, Mark P. Blodgett[1], Shamachary Sathish, and Thomas R. Boehnlein, [1] Metals, Ceramics, and NDE Division, Air Force Research Laboratory, Wright-Patterson Air Force Base, Dayton, OH 45433; Structural Integrity Division, University of Dayton Research Institute, 300 College Park Drive, Dayton, OH 45469-0120

---An eddy current lift-off signal, which arises from a small variation of distance between a probe and a material, is often considered an undesirable test variable. Rotating the lift-off signal in the impedance plane or finding a position where the lift-off signal has the least impact on the desired signal is a routine step in an eddy current inspection. In this study, the material dependency of the lift-off signal using resonant frequency eddy current is evaluated. The feasibility of using the lift-off signal in monitoring a small change of conductivity in materials at high frequencies is examined. Experimental results were obtained from materials of various conductivities as well as shot peened specimens with different peening intensities and residual stresses. Preliminary results indicated that the lift-off measurements using resonant frequency eddy current could be a potential tool for evaluating small changes of conductivity in materials.---This work was performed on-site in the Nondestructive Evaluation Branch of the Air Force Research Laboratory (AFRL/MLLP) at WPAFB, Ohio under Air Force contract # F33615-03-C-5219.

Diffusion of Pulsed Eddy Currents in Thin Conducting Plates

---**Thomas W. Krause**, Royal Military College of Canada, Department of Physics, Kingston, Ontario, Canada; Catalin Mandache, National Research Council of Canada, Institute for Aerospace Research, Ottawa, Ontario, Canada; Vivier Lefebvre, Defence R&D Canada, Air Vehicles Research Section, Ottawa, Ontario, Canada

---Pulsed eddy current response from thin plates of varying thickness and conductivity was investigated. The data was obtained from three different conductivity materials, between 40 to 100% IACS, for plate thicknesses less than 1 mm. Time-domain pulsed eddy current signals were fit with an expression that takes into consideration the time-dependence of the pulse generated by a driver pick-up coil configuration (reflection-type probe) in air, and when mounted at minimum lift-off on conducting plates. In the presence of a conductor, two characteristic times were considered: First, the characteristic time associated with expulsion of electromagnetic flux from the conducting volume and second, the relaxation time associated with the diffusion of the electromagnetic field and the decay of associated currents within the conductor. Extracted values of the diffusion time were observed to vary linearly with conductivity as predicted by diffusion models and were consistent with those theoretically estimated for each material. An observed linear dependence of diffusion time with plate thickness was associated with the volume of currents induced into what was effectively an infinite plane sample.

Detection of Deep-Surface Defects and Far-Side Corrosion in Stainless Steel Components Using an Integrated Eddy Current-GMR Sensor

---Sasi Balakrishnan, Bhagi Purna Chandra Rao, **Tammana Jayakumar**, Uthandi Kamachi Mudali, and Baldev Raj, Indira Gandhi Centre for Atomic Research, Kalpakkam, Tamil Nadu, India

---For detection of deep-surface defects and far-side corrosion, it is beneficial to measure the secondary magnetic fields produced by eddy currents, rather than impedance changes in the exciter coil. For such applications, Giant magneto-resistive (GMR) sensors are very attractive. Working in this direction, a sensor comprising of an eddy current (EC) exciter coil and a GMR receiver measuring the tangential component of the magnetic field, was integrated. The detection capability of the sensor was tested on 6 mm and 12 mm thick stainless steel plates consisting of EDM notches and far-side corrosion, respectively. The 6 mm thick plate consisted of notches located at 4, 5 and 5.25 mm below surface. The 12 mm thick plate consisting of 24 mm diameter flat bottom holes of 2, 4, 6, 8 and 10 mm depth from far-side was sensitized and subjected to electrolytic etching to simulate corrosion attack. In the case of 6 mm thick plate, the integrated sensor reliably detected a deep-surface notch located at 5.25 mm below surface. Studies on specimens with far-side corrosion confirmed that it is possible to detect corrosion at a depth of 8 mm below surface using the integrated sensor.

High Resolution Eddy Current Probe

---**B. Marchand**, F. Vacher, C. Gilles-Pascaud, CEA Saclay, DRT/LIST/SYSSC, Bâtiment 611, Point courier 120, 91191 Gif sur Yvette, France; H. Polovy, C. Fermon, C. Pannetier-Lecoeur, DSM/DRECAM/SPEC, CEA, Saclay, 91191 Gif-Sur-Yvette, France

---The inspection of material used in aerospace, nuclear or transport industry is a critical issue for the safety of components exposed to stress or/and corrosion. The industry claims for faster, more sensitive and cost-effective techniques. Technologies based on Giant Magneto-Resistance (GMR) could be a promising alternative to inductive sensors thanks to its high sensitivity and its sharp spatial resolution. The CEA has recently developed a very high resolution Eddy Current (ED) probe, based on a GMR high sensitive element. Designed and optimized thanks to the fast semi-analytical models integrated in CIVA software, the prototype probe detects up to 50x50x50 µm3 surface breaking flaws. To make the inspection faster, a 22 GMRs array probe, composed with 100 µm GMR high sensitive elements, has been designed. Results using simultaneously 4 elements (400 µm scanning width) are shown. An 8 micro-coil probe has also been developed: each element is composed with two 1 mm-diameter coils etched on a flexible kapton. Thus, 2.5 mm wide strip can be scanned at one time. Results are shown and comparisons with GMR sensor are done.

Applications of Motorized Rotational RFEC Probes in Thick and Multiplayer Structure Crack Detection

---**Yushi Sun**, Chang hong Sun, Haiou Zhu, Tianhe Ouyang, Xinle Yang, and Weiqiang Wan
Innovative Materials Testing Technologies, Inc., 3141 W. Toeerys Peak Drive, Superior, CO 80027

---Crack detection in thick and multilayer structures has been a challenge to NDI/NDE societies. Remote field eddy current, RFEC, probes have shown features in deep penetration and high sensitivity. Signal processing and pattern recognition can play important role in recognizing and calibrating a crack from noisy back ground signals obtained from inspecting thick, complex geometry. Manual rotational probes do not offer highly consistent speed and repeatable signals in these situations. Motorizing the probes is an approach to improve the consistency of the rotational RFEC probes. We have recently developed a number of different motorized RFEC probes and a newer version of the super sensitive eddy current, SSEC, instrument that drives and controls the motorized probes and providing real-time signal processing and crack recognition. The newly developed systems provide higher reliability, repeatability and confidence in crack detection, as well as minimized human factor in crack detection.

A New Eddy Current Probe for Detecting Very Long Surface Flaws

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

---The authors have developed a new eddy current probe that comprises of a long rectangular surface exciting coil and multiple tangential detecting coils in order to detect very long surface flaws. Since the eddy currents on either side of a long flaw are induced in opposite directions, the tangential detecting coils on one side of the flaw generate signals with reversed polarity from those of the detecting coils on the other side. Thus the probe can detect long flaws by utilizing the polarity combination of the multiple detecting coil signals. The conventional eddy current testing has not been successful in detecting long flaws because the gradual variations of the probe lift-off, material electromagnetic characteristics and material configurations make the testing generate such low frequency signals that flaw signals are not distinguishable from other signals. When scanning through the multiple detecting coils in the new probe, the resultant signal forms a figure eight pattern, the phase of which corresponds to the flaw depth. Thus the authors have applied a neural network technique to evaluating depth of long flaws. The authors expect that the probe be applicable to detecting long flaws in production lines such as of bar steel in rolling mills.

Eddy Current Differential Transducer for Nondestructive Evaluation of Aluminum Plates

---**Tomasz Chady** and Przemyslaw Lopato, Szczecin University of Technology, Department of Electrical Engineering, Szczecin, Poland

---In this paper a new configuration of a differential E-type core eddy current transducer is presented. This transducer is proposed for evaluation of aluminum plates in order to detect shallow hidden flaws. The probe consists of one signal and three excitation coils. A main excitation coil and a pickup coil are wounded around a central column of the ferrite core. Two additional excitation coils are placed on the external columns. The main and the additional excitation coils produce opposite directed magnetic fluxes flowing through the pickup coil. Such configuration enables to work in the differential mode as opposed to the absolute mode of previously used transducers with the ferrite E-type cores. A finite element software package is used to analyze various configurations of the excitation coils and to select an optimal design. The proposed transducer was constructed and a set of experiments was carried out in order to prove its usability. Multi frequency and spectrogram method is utilized to evaluate artificial flaws located on an opposite surface of the 10mm thick aluminum planar samples.---This work was supported in part by the State Committee for Scientific Research, Poland, under the Grant no: 3T10A 017 30 (2006-2009).

Pulsed Eddy Current System Characterization and Bench-Mark Waveforms

---**Chester Lo**, S. J. Lee, C. Lee, M. J. Johnson, and N. Nakagawa, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---Eddy current (EC) NDE modeling can be useful in improving and optimizing performance of EC instrumentation, and in aiding interpretation of inspection results. However, to apply any model to predict signals for a given instrument, one must understand the relationship, or the system transfer function, that relates instrument output signals to predicted signals. For pulsed eddy current (PEC) waveforms, the relationship is more complicated than conventional frequency-domain relationships, because it generally involves a convolution integral over the linear response function. This paper reports on a system transfer function determination for a proprietary PEC instrument. We determine the linear response function in frequency domain, assisted by the analytical Cheng-Dodd-Deeds model. Specifically, PEC waveforms measured from generalized half-space samples are compared with model-predicted waveforms in frequency domain, leading to the determination of the PEC instrument transfer function. We present studies of half-space and layered samples in various material combinations, so that we not only determine the transfer function but also validate it among the variety of the sample configurations. The output includes PEC waveforms for defect specimens, both instrument and converted waveforms.---This material is based upon work supported by the Air Force Research Laboratory under Contract # FA8650-04-C-5228 at Iowa State University's Center for NDE.

SPECIAL EVENING SESSION
Ballroom A

8:00 PM **Challenges and Opportunities in NDE & Material State Awareness for Aircraft Structures: US Air Force Perspective**

---**C. F. Buynak**, Air Force Research Laboratory, 2230 Tenth Street, Suite 1, WPAFB, OH 45433-7817

---As one of the primary data and information sources in the maintenance of USAF Aging Military Fleet, NDE plays a major role in the definition and operation of maintenance processes on these aircraft. To focus new NDE developmental efforts, the AFRL NDE R&D group has the charter to research, develop and transition new capabilities to the field and depot users. This multi-faceted task is achieved through a balanced NDE and on-board sensor development program with the ultimate goal to transition technology to the Air Force user Commands. Technology requirements for NDE and Material State Awareness emerge from Air Force Initiatives to realize Condition Based Maintenance and to develop the “Depot of the Future”. This evening session will present an overview of Air Force Initiatives, emerging R&D issues for Structural Health Monitoring and NDE methodologies as well as basic research initiatives within the Air Force Research Laboratory. It is intended that the session provide an open forum to pursue paths for new technology development and application.

THURSDAY

Session 25

SESSION 25
EMAT APPLICATIONS
G. Alers and H. Ogi, Co-Chairpersons
Ballroom D

8:30 AM **A History of EMAT Applications**
---**G. A. Alers**, EMAT Consulting, 1328 Tanglewood Drive, San Luis Obispo, CA 93401

8:50 AM **Crack and Coating Disbondment Detection with the High-Resolution EMAT Pipeline Inspection Tool**
---**M. Klann** and J. Damaschke, ROSEN Research & Technology Center, R&D – Physics Department, Lingen, Germany

9:10 AM **Enhancement to EMAT Generation Using Ferrite Coil Backing Material**
---S. Dixon, X. Jian, and **Y. Fan**, University of Warwick, Department of Physics, Coventry CV4 7AL, England

9:30 AM **Use of Electromagnetic Acoustic Tansducers (EMATs) for Cement Bond Logging of Gas Storage Wells**
---**A. O. Bolshakov**, E. J. Domangue, G. J. Barolak, and D. J. Patterson, Baker Hughes, Houston, TX 77073

9:50 AM **Application of Large Aperture Phased Array EMATs to Weld Inspection**
---**D. T. MacLauchlan**, S. P. Clark, and J. W. Hancock, BWXT Services, Nondestructive Evaluation and Inspection Systems, Lynchburg, VA 24504

10:10 AM ***Break***

10:30 AM **Development of a Laser-EMAT Sytem for Detection of Cracks on Hot Steel Billets**
---I. Baillie[1], X. Jian, and **S. Dixon**, University of Warwick, Department of Physics, Coventry CV4 7AL, England; [1]Corus Technology Centre Teeside, Middlesbrough TS6 6UB, England

10:50 AM **Tube Inspection with Circumferential Guided Waves**
---**R. B. Alers**, Sonic Sensors of EMAT Ultrasonics, Inc. San Luis Obispo. CA 93406-1889; G. A. Alers, EMAT Consulting, San Luis Obispo, CA 93401

11:10 AM **EMATs for Immunosensors**
---**H. Ogi**, K. Motohisa, K. Hatanaka, T. Ohmori, and M. Hirao, Osaka University, Graduate School of Engineering Science, Toyanaka, Osaka 560-8531, Japan

11:30 AM **New EMAT Instrumentation, Sensors and Applications**
---**Borja R. Lopez**, Innerspec Technologies, Inc., 4004 Murray Place, Lynchburg, VA 24501

11:50 AM **Extracting Acoustic Birefringence Data from Shear Wave EMAT Measurements**
---**S. Dixon**, M. Fletcher, and G. Rowlands, University of Warwick, Department of Physics, Covenry CV4 7AL, England

12:10 PM **Lunch**

A History of EMAT Applications

---**George A. Alers**, EMAT Consulting, 1328 Tanglewood Drive, San Luis Obispo, CA 93401

---The earliest use of electromagnetic coupling to ultrasonic waves in metals was in the 1930's for physics-of-metals studies. In the 1950's, D.O. Thompson used the same technique to study radiation damage in copper single crystals and in the early 1970's. R.B. and D.O. Thompson used electromagnetic resonance (EMR) to study adhesive bonds in aircraft panels. The first "commercial" application was a patent issued to a Cornell University group that described replacing a piezoelectric disc with a coil and magnet to perform NDT of metal objects without a coupling fluid. Elimination of the coupland AND the ability to excite guided waves in plate-like structures were the real driving forces behind applications to a host of industrial NDE problems. During the past 30 years, the electromagnetic acoustic transducer (EMAT) has been used to inspect large gas pipelines, small heat exchanger tubes, hot billets, munitions, sheet, tube and bar products in steel and aluminum mills, railroad wheels and rails in the field as well as the miles of piping in the petro-chemical industry.

Crack and Coating Disbondment Detection with the High-Resolution EMAT Pipeline Inspection Tool

---**Martin Klann** and Jörg Damaschke, Rosen Research & Technology Center, R&D - Physics Department, Lingen, Germany

---In succession of a research project to develop an EMAT inline inspection technology for the detection of stress corrosion cracking (SCC) and disbonded coating in pipelines, a 16" EMAT pipeline inspection tool was manufactured and tested. This 16" EMAT Crack Detection (ECD) Tool establishes a new high-resolution approach to effective and accurate crack inspection technology. EMAT inspection technology, originally designed for detection of SCC, is independent of the medium in the pipeline and also sensitive to areas of disbonded coating, other crack-like features, and anomalies like gouging and channeling. The performance of the ECD 16" tool was tested on several pipe samples containing natural SCC as well as artificial anomalies and laminations. To distinguish between different types of pipeline integrity threats, a qualitative defect identification and evaluation process was developed. Field runs were conducted, which detail the tools performance under operational conditions. Following an introduction into EMAT guided wave theory, data from a series of full-scale tests obtained with 34" prototype sensors and the complete 16" ILI-EMAT tool will be presented. Evaluated inspection data will be compared with dig-up results, including several verified areas of disbonded coating as well as verified crack-like features.

Enhancement to EMAT Generation Using Ferrite Coil Backing Material

---Steve Dixon, Xiaoming Jian, and **Yichao Fan**, University of Warwick, Dept. of Physics, Coventry CV4 7AL, England

---When an electromagnetic acoustic transducer (EMAT) is used to generate ultrasound in an electrically conducting sample, eddy currents are generated in the sample's skin depth as the first stage in transduction. The resultant acoustic wave amplitude is proportional to the amplitude of this eddy current, and so anything that can be done to increase amplitude of the eddy current, without changing it frequency content, will lead to the generation of larger amplitude ultrasonic waves. In eddy current testing, wire coils are often wound onto a ferrite core to increase the generated eddy current, with the effect that inductance of the coil increases greatly. When we are dealing with an EMAT, any increase in the coil inductance is usually unacceptable as it leads to a reduction in the amplitude of a given frequency of eddy current from a limited voltage source. This is particularly relevant where current arises from capacitor discharge, as is typically used in EMAT driver current circuitry. We present a method for electromagnetic acoustic transduction where ferrite is used to increase eddy current amplitude, without significantly increasing coil inductance or changing the frequency content of the eddy current or the generated acoustic wave.

Use of Electromagnetic Acoustic Transducers (EMATs) for Cement Bond Logging of Gas Storage Wells

---**Alexei O. Bolshakov**, Edward J. Domangue, Greg J. Barolak, and Doug J. Patterson, Baker Hughes, Houston, TX 77073

---According to the Department of Energy (DOE), there are approximately 110 operators maintaining more than 17,000 gas storage wells in over 415 underground storage facilities across the USA. In virtually every application, steel casing, cemented into place, serves to isolate the well from the underground formations. The process of cementing wellbore casing provides two major benefits: 1) cement prevents gas migration between the casing and formation; 2) cement transfers stress from the casing to the formation, increasing the effective strength and working pressure of the casing. Current cement evaluation techniques use an acoustic wave generated and received by a logging tool within the wellbore to detect cement placed outside the casing. These techniques rely on fluid in the casing to provide acoustic coupling between the logging tool and the casing and therefore are unable to operate in gas-filled boreholes. This paper details efforts to confirm the validity and applicability of the use of EMATs for evaluating cement in gas-filled boreholes. The methods and techniques proposed for the cement bond logging using EMATs are confirmed and validated based on the results obtained from the numerical modeling and experiments with physical cement models. Partial funding for this investigation was provided by the DOE and Gas Storage Technology Consortium.

Application of Large Aperture Phased Array EMATs to Weld Inspection

---**Daniel T. MacLauchlan**, Steve P. Clark, and Jimmy Wade Hancock, BWXT Services, Nondestructive Evaluation and Inspection Systems, Lynchburg, VA 24504

---One of the most significant developments in EMAT operation is the incorporation of phased array techniques. Phased array EMATs enable electronic beam steering and focusing while operating with temporally short pulses for good range resolution. Using phased array EMAT operation, multiple high powered pulsers are combined in the generation of the ultrasonic wave and multiple elements are combined in the reception of the ultrasonic wave, for improved sensitivity. EMATs make it practical to operate with shear horizontal (SH) waves and scan over a metal part's surface. An EMAT generated line force at the surface launches shear horizontal waves with uniform amplitude for beam angles from -90° to 90°. Shear horizontal waves also reflect without mode conversion from surfaces that are parallel to the polarization of the shear wave displacements. The combination of these advantages makes phased array EMATs well suited for weld inspection. Recently, BWXT Services has developed a 32 active channel EMAT phased array system for operation up to 5 MHz. In addition, each element can be constructed with several sub-elements alternating in polarity, to effectively multiply the number of active elements for a restricted range of beam angles. For example by using elements comprised of 4 sub elements, a 128 active element aperture designed for operation with a nominal 60° beam angle provides good beam steering and focusing performance for 45° to 70° beam angles. The large active apertures allow the use of highly focused beams for good defect detection and high resolution imaging of weld defects. Application of this system to weld inspections has verified that good defect detection and imaging is possible. In addition, operation with SH waves has proven to provide improved detection of lack of fusion at the cap and root of the weld for certain weld geometries. The system has also been used to demonstrate the inspection of submerged metal arc welds while welding.

Development of a Laser-EMAT System for Detection of Cracks on Hot Steel Billets

---Iain Baillie*, Xiaoming Jian, and **Steve Dixon**, University of Warwick, Dept. of Physics, Coventry CV4 7AL, England; *Corus Technology Centre Teeside, Middlesbrough TS6 6UB, England

---The use of pulsed laser beams to generate ultrasound in metal samples combined with the use of EMATs to detect the resulting ultrasonic waves has been well documented by previous workers. The use of such methods has been reported at temperature in excess of 1000C. We describe the development of a system that is being deployed on a steel billet continuous caster pilot plant at sample surface temperatures in excess of 800C. We are primarily looking at detection of surface breaking cracks, orientated in any direction using the wideband Rayleigh waves generated by the pulsed laser beam. The formation of such cracks is indicative of an issue earlier on in the production line and the ultimate aim is to use the ultrasonic system as a feedback mechanism to modify casting conditions and reduce the amount of surface cracking. There are significant cost and quality benefits in being able to provide this type of information on the production line. We will explain the basic principles of operation a description of some of the issues that we need to consider for continuous operation of the system online and a summary of some preliminary results.

Tube Inspection with Circumferential Guided Waves

---**Ron B. Alers**, SonicSensors of EMAT Ultrasonics, Inc. San Luis Obispo, CA 93406-1889; George A. Alers, EMAT Consulting, San Luis Obispo, CA 93401

---EMATs that use the meander shape of coil are particularly well suited to the excitation and detection of guided waves in the walls of pipes and tubes. Furthermore, the frequency of operation can be chosen to enhance the sensitivity to particular flaws by the choice of a specific wave mode. If the direction of propagation is circumferential, the receiver can detect signals that arise from multiple trips around the pipe as well as signals reflected from defects anywhere in a circumferential belt. The former signals can detect circumferential cracks and corrosion pits by the dimunition or attenuation of the acoustic wave by scattering processes. The latter signals are particularly well suited to the detection of longitudinal cracks. By mounting the transducers on a wheeled carriage, a motor can be employed to propell the device through the ID of small natural gas distribution pipes or along the OD of larger liquid filled pipes in petro-chemical plants. In either case, the inspection results can be sent to the operator through a tether cable for permanent recording.

EMATs for Immunosensors

---**Hiotsugu Ogi**, Kazuma Motohisa, Kenichi Hatanaka, Toshinobu Ohmori, and Masahiko Hirao, Osaka University, Graduate School of Engineering Science, Toyonaka, Osaka 560-8531, Japan

---Electromagnetic acoustic transducers (EMATs) allow excitation and detection of through-thickness shear resonances of thin metallic and thin piezoelectric plates without using any mechanical contacts. This aspect is essential for achieving a high-sensitivity immunosensor, which monitors biochemical reactions through the change of the resonance frequency caused by the adsorption of biomolecules on the oscillator surface. Because the sensitivity is increased by decreasing the oscillator thickness, the resonance-frequency measurement with the wireless and electrodeless manner allows a high-sensitivity immunosensor. We have used 0.03-mm AT-cur quartz plates and 0.05-mm aluminum foils for detecting human immunoglobulin G via protein A immobilized on the oscillator surfaces. Their sensitivity significantly exceeded that of a conventional QCM immunosensor.

New EMAT Instrumentation, Sensors and Applications

---**Borja R. Lopez**, Innerspec Technologies, Inc., 4004 Murray Place, Lynchburg, VA 24501

---Electro Magnetic Acoustic Transducer (EMAT) technology was developed in the 80s as a non-contact, dry-inspection alternative to piezoelectric transducers. Initially confined to laboratories and high-end applications, it has experienced growing popularity with the advent of more powerful equipment and greater understanding of its capabilities. As the world leader in EMAT technology, Innerspec Technologies will present the latest developments in EMAT instrumentation and sensors. We will review in detail the capabilities of the new equipment, and the fields that this technology opens. We will also review new EMAT applications that have been installed in the last few years, and the empirical results from this work.

Extracting Acoustic Birefringence Data from Shear Wave EMAT Measurements

---**Steve Dixon**, Marc Fletcher, and George Rowlands, University of Warwick, Dept. of Physics, Coventry CV4 7AL, England

---When a radially polarized SH wave EMAT is used on a rolled steel or aluminum sheet, weak elastic anisotropy splits the shear wave into two discrete polarizations that lie along and orthogonal to the rolling direction of the sheet and is referred to as acoustic birefringence. Each polarization has a slightly different propagation velocity leading to interference effects between these two signals in the time domain waveform. We have developed wideband EMAT systems with frequency content between approximately 0.5 - 12MHz, where the SH wave pulses are temporally sharp, giving good measurement resolution. On thin sheets the two polarizations will interfere in the time domain. One approach to extract the reverberation frequencies is to apply a Fast Fourier Transform (FFT) to the A-scan. From these reverberation frequencies, one can calculate quantities that relate to the crystallographic texture or stress state of the material. Earlier work showed that there is a significant and non-trivial interference effect between the peaks in the FFT. This is due to an interference term, that links the two distinct reverberation frequencies in the FFT, and it would appear that some other factors that are present, limit the accuracy to which the individual reverberation frequencies can be identified.

Session 26

SESSION 26
NDE SENSORS
J. Michaels, Chairperson
Ballroom B

8:30 AM **Ultrasonic Measurement of Rolling Element Bearing Lubrication Using Piezoelectric Thin Film Transducers**
---**B. W. Drinkwater**[1], J. Zhang[1], K. Kirk[2], J. Elgoyhen[2], R. S. Dwyer-Joyce[3], [1]RCNDE, Department of Mechanical Engineering, University of Bristol, University Walk, Bristol, BS8 1TR, United Kingdom; [2]School of Engineering and Science, University of Paisley, Paisley, PA1 2BE, United Kingdom; [3]Department of Mechanical Engineering, University of Sheffield, Sheffield, S1 3JD, United Kingdom

8:50 AM **Distributed Fibre-Optic Sensors Based on Counter-Programming Waves**
---**A. Dubey**, H. Tharwani, and A. Kumar, National Institute of Technology, Raipur, Metallurgical Engineering Department, G. E. Road, Raipur 492010, India

9:10 AM **Pipeline Anti-Destruction Technology Based on Fiber Bragg Gratings**
---**S. Lin**, Chinese Academy of Sciences, Academy of Opto-Electronics, No. 51 Jinguang Street, Langfang, Heibei, China (PRC)

9:30 AM **Novel Multi-Sensor Probe Design for Corrosion Detection and Sizing in Cast Iron Water Pipes**
---**J. W. Wilson** and G. Y. Tian, University of Newcastle upon Tyne, School of Electrical, Electronic and Computer Engineering, Newcastle, United Kingdom

9:50 AM **Magnetic Flux Leakage NDE Using Giant Magneto-Resistive (GMR) Sensors**
---W. S. Singh, B. P. C. Rao, S. Thirunavukkarasu, S. Vaidyanathan, **T. Jayakumar**, and B. Raj, Indira Gandhi Center for Atomic Research, Non Destructive Evaluation Division, Kalpakkam, Tamil Nadu, India; K. K. Nand, B.M.S. Engineering College, Bangalore, Karnataka, India

10:10 AM ***Break***

10:30 AM **Advanced NDE Modeling of Magneto-Resistive Sensors**
---**B. E. C. Koltenbah** and R. H. Bossi, The Boeing Company, Applied Physics, Seattle, WA 98108; G. Steffes, AFRL/MLLP, Dayton, OH; L. Udpa, Y. Deng, L. Xin, and Z. Zeng, Michigan State University, Electrical and Computer Engineering, East Lansing, MI 48823

10:50 AM **A Low-Power Wireless Sensor Network for Monitoring the Microcrack Initiations in Aerospace Composites**
---**J. Li**, Y. Plotnikov, and W. Lin, GE Global Research Center, One Research Circle, Niskayuna, NY 12309

11:10 AM **Solid-State Multi-Sensor Array System for Real Time Imaging of Magnetic Fields and Ferrous Objects**
---**D. Benitez**, P. Gaydecki, S. Quek, and V. Torres, School of Electrical and Electronic Engineering, The University of Manchester, P. O. Box 88, Manchester M60 1QD, United Kingdom

11:30 PM ***Lunch***

Ultrasonic Measurement Of Rolling Element Bearing Lubrication Using Piezoelectric Thin Film Transducers

---**Bruce W. Drinkwater**[1], Jie Zhang[1], Katherine Kirk[2], Jocelyn Elgoyhen[2], Rob S. Dwyer-Joyce[3], [1]RCNDE, Department of Mechanical Engineering, University of Bristol, University Walk, Bristol, BS8 1TR, United Kingdom; [2]School of Engineering and Science, University of Paisley, Paisley, PA1 2BE, United Kingdom; [3]Department of Mechanical Engineering, University of Sheffield, Sheffield, S1 3JD, United Kingdom

---In a rolling bearing a thin film of lubricant separates the rolling elements. The material properties and thickness of this oil-film are critical for its correct operation. Collapse of the film leads directly to bearing damage and eventually seizure. This paper describes a novel design of oil-film monitoring sensor capable of measuring oil-film thickness to high accuracy in concentrated contacts. The approach is to use a thin (approx. 4 □m) sputtered coating of piezoelectric material, such as Aluminium Nitrite. When correctly electroded this acts as an ultrasonic sensor with a usable bandwidth from 20-200 MHz. This sensor allows the interrogation of the small lubricated region between the ball and raceway. Typically the contact region is less than a millimetre wide. This sensor system is then demonstrated experimentally on a conventional ball bearing (type 6016, shaft diameter 80 mm, ball diameter 12.7 mm) with the piezoelectric thin film on the external surface of the bearing outer raceway. The interaction of ultrasound with the oil-film is modelled using a quasi-static spring model and this allows properties such as film thickness to be extracted. The measured thicknesses are shown to agree well those obtained from classical elastohydrodynamic lubrication theory. Measurement of oil film thickness in the region of 0.1-10μm is then demonstrated.

Distributed Fibre-Optic Sensors Based on Counter-Programming Waves

---**Animesh Dubey**, Honey Tharwani, and Ankit Kumar, National Institute of Technology, Raipur, Metallurgical Engineering Department, G. E. Road, Raipur 492010, India

---A novel fiber optic approach is taken in this project to the distributed sensing of forces and temperatures simultaneously at different locations with a single long optical fiber probe. This concept uses temperature- and/or force-dependent stimulated light amplification processes at each sensing point along the fiber probe. The approach is designed to generate, at each sensing point along the fiber, optical signals unaffected or only minimally affected by the magnitude of the forces and/or temperatures at other points along the fiber. In contrast to presently known methods, our approach does not require measurements of the state of polarization of the light at any point along the fiber probe, and it should be implementable with relatively simple instrumentation. The system should find applications in the monitoring of the structural integrity of buildings, bridges, pipelines, and aircraft structures, and for implementing effective process control in a wide variety of industrial processes.

Pipeline Anti-Destruction Technology Based on Fiber Bragg Gratings

---**Song Lin**, Chinese Academy of Sciences, Academy of Opto-Electronics, No. 51 Jinguang Street, Langfang, Heibei, China (PRC)

---In this paper, we introduce a kind of Fiber Bragg Grating (FBG) sensor to security detection system of oil/gas pipeline. Underground pipelines are popular nowadays for oil/gas transportation, such pipelines face many security problems or damages, such as landslide, deliberate damages by drilling and so on. Rupture or leakage of pipelines leads to not only economic loss of pipeline companies but also danger to people living or passing nearby, therefore anti-destroy sensor is needed to detect where, when and how the damage happens before it really causes danger. Pipeline companies do have some traditional methods but we employ FBG sensors to realize the detection. FBG sensor is widely used in bridge or building security detection but when it refers to underground pipelines there are some new problems. Design of FBG sensors in this paper solves these problems of application, and from different experiments we demonstrate that FBG sensors can detect the location, time and way of damage to pipelines.

Novel Multi-Sensor Probe Design for Corrosion Detection and Sizing in Cast Iron Water Pipes

---**John W. Wilson** and Gui Y. Tian, University of Newcastle upon Tyne, School of Electrical, Electronic and Computer Engineering, Newcastle, United Kingdom

---Magnetic flux leakage (MFL) has good defect detection and location capabilities, but defect sizing capabilities, especially for sub-surface defects, are limited. Recently, the pulsed magnetic flux leakage (PMFL) technique has been introduced and shown to have great potential for automated defect sizing for surface breaking defects using time-frequency signal processing techniques, but sizing of sub-surface defects has proved problematic. In this paper, pulsed magnetic reluctance (PMR), a new electromagnetic non-destructive evaluation (NDE) technique, is introduced and incorporated into a dual PMFL/PMR probe for the characterization of corrosion sites in cast iron water pipe. Experimental results using the new multi-sensor probe on calibrated steel samples are presented initially, then the technique is applied to the location and sizing of internal and external corrosion sites in pit-cast and spun-cast iron water pipe. Results are analyzed using time-frequency analysis and show that the techniques offer complementary information, with PMFL providing defect location data and data for the characterization of surface defects and PMR offering sub-surface defect characterization capabilities. The work concludes that integration of the inspection techniques in the new pulsed electromagnetic probe can provide enhanced defect characterization capabilities for flux leakage based inspection systems using relatively simple time-frequency signal processing techniques.

Magnetic Flux Leakage NDE Using Giant Magneto-Resistive (GMR) Sensors

---Waikom Sharatchandra Singh, Bhagi Purna Chandra Rao, Sannasi Thirunavukkarasu, Subramanian Vaidyanathan, **Tammana Jayakumar**, and Baldev Raj, Indira Gandhi Center for Atomic Research, Non Destructive Evaluation Division, Kalpakkam, Tamil Nadu, India; Keshavamurthy Krishna Nand, B.M.S. Engineering College, Bangalore, Karnataka, India

---Giant magneto-resistive (GMR) sensors are characterized by high sensitivity for low magnetic fields, good signal-to-noise ratio and high spatial resolution. Besides, they are inexpensive, easy to use, consume less power and operate at room temperature. These attractive features make them very good candidate sensors for magnetic flux leakage (MFL) and eddy current NDE applications. Authors have used GMR sensors for detection of sub-surface as well as deep-surface defects in ferritic steel plates. EDM notches of depths 1, 2, 3, 6 and 9 mm are machined in 12 mm thick ferritic steel plates and the tangential component of the leakage magnetic field is measured using a GMR sensor. The sensor output is further amplified selectively to enable detection of notches located 9 mm below the surface. MFL images of surface and sub-surface notches are obtained by raster scan imaging. In order to suppress variations in magnetic permeability, surface roughness and stresses that produce incoherent disturbing noise, a new approach that uses Eigen values is proposed. In this approach, the energy packing property of the Eigen values is effectively utilized to reconstruct images free from disturbing noise. This paper discusses the results of the studies and the Eigen value based approach.

Advanced NDE Modeling of Magneto-Resistive Sensors

---**Benjamin E.C. Koltenbah** and Richard H. Bossi, The Boeing Company, Applied Physics, Seattle, WA 98108; Gary Steffes, AFRL/MLLP, Dayton, OH; Lalita Udpa, Yiming Deng, Liu Xin, and Zhiwei Zeng, Michigan State University, Electrical and Computer Engineering, East Lansing, MI 48864-1226

---We report on an on-going AFRL-funded program called "Advanced NDE Sensor Modeling for Multi-Site Inspection." Electromagnetic finite element modeling of Magneto-Resistive (MR) Sensors is providing better understanding of these sensors, how well they perform, how sensitive they are to a variety of physical parameters, and how better to utilize the sensors for greater optimization. We show a comparison between the modeling and experimental measurements on a variety of test standards that simulate real features of concern on Air Force platforms. This forward modeling serves to perfect the models as well as to provide detailed parameter surveys of performance as function of scan frequency, scan depth, crack size, crack orientation, etc. We will detail more long-term plans of MR Sensor development, both in modeling and in measurement, and how eventual backward modeling will serve the customer's needs in better identifying features of interest from MR Sensor scanning.

A Low-Power Wireless Sensor Network for Monitoring the Microcrack Initiations in Aerospace Composites

---**Jian Li**, Yuri Plotnikov, and Wendy Lin, GE Global Research Center, One Research Circle, Niskayuna, NY 12309

---A low power wireless sensor network was developed to monitor the microcrack events in aerospace composites. The microcracks in the composites mostly result from a stress loading or temperature and/or humidity cycles. Generally, the individual microcracks are too small to be detected by conventional techniques such as X-ray or ultrasonic C-scan. The whole developed sensor network is aimed to capture the released acoustic signals by the microcracking events in real time. It comprises of a receiving station as well as a series of sensor nodes. Each sensor node includes two acoustic emission transducers as well as two signal amplification and data acquisition channels. Much of our development effort has been focused on reducing the power consumption of each node and improving the detection reliability for each event. Each sensor node is battery-powered and works in a sleep mode most of time. Once a microcrack is initiated in the composite, the acoustic signal triggers the node and wakes it up. The node will then react in several microseconds and digitize the signal. The digitized data is sent to the station wirelessly. The developed wireless sensor network system has been validated with microscopy of microcracked samples after temperature and humidity cycling and has proved to be an effective tool for microcracking detection. Furthermore, our low power consumption design and sophisticated wireless transmission mechanism enables a system with great potential for field structural health monitoring applications.

Solid-State Multi-Sensor Array System for Real Time Imaging of Magnetic Fields and Ferrous Objects

---Diego Benitez, Patrick Gaydecki, Sung Quek, and Vladimir Torres, School of Electrical and Electronic Engineering, The University of Manchester, PO Box 88, Manchester M60 1QD, United Kingdom

---In this paper the development of a solid-state sensors based system for real-time imaging magnetic fields and ferrous objects is described. The system comprises 1089 magneto inductive solid state sensors arranged in a 2D array matrix of 33 x 33 files and columns, equally spaced in order to cover an approximate area of 300 by 300 mm. The sensor array is located within a large current- carrying coil. Data is sampled from the sensors by several DSP controlling units and finally streamed to a host computer via a USB 2.0 interface and the image generated and displayed at a rate of several frames per second. The development of the instrumentation has been complemented by extensive numerical modeling of field distribution patterns using boundary element methods. The system was originally intended for deployment in the nondestructive evaluation (NDE) of reinforced concrete. Nevertheless, the system is not only capable of producing real-time, live video images of the metal target embedded within any opaque medium, it also allows the real-time visualization and determination of the magnetic field distribution emitted by either permanent magnets or geometries carrying current. Although this system was initially developed for the NDE arena, it could also have many potential applications in many other fields, including medicine, security, manufacturing, quality assurance and design involving magnetic fields.

Session 27

SESSION 27
SIGNAL PROCESSING
S. Dixon, Chairperson
Ballroom C

8:30 AM **Characterization of Hydrogen Cracks in Stainless Steel Through the Analysis of Acoustic Emission Signals**
---K. S. de Assis, O. R. Mattos, and J. M. A. Rebello, Federal University of Rio de Janeiro, Department of Metallurgical and Materials Engineering, Rio de Janeiro, RJ, Brazil; A. P. Vieira, **L. L. Goncalves**, and H. M. Vasconcelos, Federal University of Ceara, Department of Metallurgical and Materials Engineering, Fortaleza, CE, Brazil

8:50 AM **Flaw Characterization Using Mumford-Shah Regularization for Deconvolution**
---T. P. Negron and **P. Ramuhalli**, Michigan State University, Department of Electrical and Computer Engineering, 2120 Engineering Building, East Lansing, MI 48824

9:10 AM **Deconvolution Techniques in Time-Domain and Fourier-Domain Optical Coherence Tomography**
---**D. Lévesque**, S. Vergnole, G. Lamouche, M. Dufour, and B. Gauthier, Industrial Materials Institute, NRC, Boucherville, Québec, J4B 6Y4, Canada

9:30 AM **A Study on Ultrasonic Evaluation of Defects in Composite Materials Using Wavelet Analysis**
---S. Nirmala, Hindustan Aeronautics Limited, Bangalore, Karnataka, India; **C. R. L. Murthy**, Indian Institute of Science, Department of Aerospace Engineering, Bangalore, Karnataka, India

9:50 AM **Pulse Compression Technique Considering Velocity Dispersion of Guided Wave**
---**K. Toiyama**, Hiroshima Prefectural Technology Research Institute, West Resion Industrial Research Center, Material Processing Research Division, 2-10-1 Aga-Minami, Kure Hiroshima 737-0004, Japan; T. Hayashi, Nagoya Institute of Technology

10:10 AM ***Break***

10:30 AM **Inner Damage Detection Method for Cantilever Beams**
---**Z. Li**, W. Zhang, and K. Gong, Department of Mechanics and Aerospace Engineering, Peking University, Beijing 100871, China (PRC)

10:50 AM **Ultrasonic Detection of Surface-Breaking Railhead Defects**
---**R. S. Edwards**, Y. Fan, and S. Dixon, University of Warwick, Department of Physics, Coventry CV4 7AL, United Kingdom; M. Papaelias, C. L. Davis, and C. Roberts, University of Birmingham, Rail Research United Kingdom Centre, Birmingham B15 2TT, United Kingdom

11:10 AM **Data Fusion of Eddy Current NDT Signals**
---**T. Chady**, G. Psuj, and P. Lopato, Szczecin University of Technology, Department of Electrical Engineering, Szczecin, Poland

11:30 AM **An Ultrasonic Inverse Modeling Approach for Simultaneous Measurement of Density and Viscosity of Fluids**
---**K. Balasubramaniam**, Centre for Nondestructive Evaluation, Department of Mechanical Engineering, Indian Institute of Technology Madras, Chennai 600 036, India

11:50 AM **Non Destructive Stress Evaluation as an Inverse Problem**
---**V. Vengrinovich** and B. Bryantsev, Institute of Applied Physics, Laboratory for Computer Diagnostics, Akademicheskaya str. 16, Minsk, Belarus

12:10 PM ***Lunch***

Characterization of Hydrogen Cracks in Stainless Steel Through the Analysis of Acoustic Emission Signals

---K. S. de Assis, O. R. Mattos, and J. M. A. Rebello, Federal University of Rio de Janeiro, Department of Metallurgical and Materials Engineering, Rio de Janeiro, RJ, Brazil; A. P. Vieira, **L. L. Goncalves**, and H. M. Vasconcelos, Federal University of Ceara, Department of Metallurgical and Materials Engineering, Fortaleza, CE, Brazil

---The objective of this work is to identify the nature of hydrogen cracks in supermartensitic and martensitic stainless steel, through the analysis of acoustic emission signals emitted during their formation. Two types of cracks were created in the samples, namely, blistering crack and brittle crack. The samples were exposed to an environment containing NaOH 0.1M. In each experiment, a cathodic galvanostatic polarization was carried out to generate the atomic hydrogen in the surface of the sample, using an electric current density of 1.5 mA/cm2 and 5.0 mA/cm2, which have produced blistering and and brittle cracks respectively. The interstitial atomic hydrogen introduced in the samples gives origin to flaws and to the emission of ultrasonic signals which have been captured with acoustic emission sensors in the A-scan mode. Optical microscopy analysis has also been conducted in samples in order to confirm the presence and nature of the flaws. A detailed numerical investigation of acoustic emission signals has been performed in order to obtain the fractal characteristics of the signals by means of the Hurst analysis, detrended fluctuation analysis, minimal cover analysis and boxcounting analysis. A pricipal component analysis was then used to classify the curves obtained from the fractal analyses of the various signals, and a study of the classification errors was performed. The obtained results indicate that fractal analyses can be an effective additional tool for recognition of the different hydrogen flaws in stainless steel.

Flaw Characterization Using Mumford-Shah Regularization for Deconvolution

---Timothy P. Negron and **Pradeep Ramuhalli**, Michigan State University, Department of Electrical and Computer Engineering, 2120 Engineering Building, East Lansing, MI 48824

---The ability to accurately estimate flaw sizes and shapes is important for practical NDE techniques. However, most probes used in practice are not point probes, and the resulting measurement of a flaw tends to be “blurred”, causing the footprint (or extent) of the flaw to appear to be larger and resulting in an overestimate of the flaw size. Image deconvolution methods have been used to address this issue. These techniques assume a convolutional model for the measurement process, with a probe point spread function (PSF) used to model the fact that the probes are not point probes. The techniques then attempt to determine the “true” flaw footprint by eliminating the effect of the probe PSF. Conventional deconvolution methods either assume complete knowledge or no knowledge of the probe PSF. In this paper, we examine a semi-blind deconvolution technique based on Mumford-Shah regularization that assumes partial knowledge of the probe blur kernel. Results of applying the technique for estimation of the flaw size from a variety of NDE measurements are presented.

Deconvolution Techniques in Time-Domain and Fourier-Domain Optical Coherence Tomography

---**Daniel Lévesque**, Sébastien Vergnole, Guy Lamouche, Marc Dufour, and Bruno Gauthier, Industrial Materials Institute, NRC, Boucherville, Québec, J4B 6Y4, Canada

---Much of the current activity in optical coherence tomography aims at increasing the imaging resolution. Nowadays, two kinds of OCT techniques are available. The first approach is the Time-Domain OCT (TD-OCT) which usually relies on a moving part into the reference arm to probe the sample in depth. The second approach is the Fourier-Domain OCT (FD-OCT) in which the signal is acquired as a function of the wavelength and the depth profile of the sample is obtained by Fourier transform. Theoretically, in both techniques, the resolution is limited by the center wavelength and the width of the source. Nevertheless, this resolution may be improved by using deconvolution techniques. In this paper, it is shown that we can improve the resolution by a factor 3 in TD-OCT and 2 in FD-OCT using a technique based on Wiener filtering and autoregressive spectral extrapolation (ASE). As an illustration, the approach is applied to TD and FD-OCT measurements of the profile of a carbon-epoxy composite to evaluate the performance in determining the thickness of the upper layer within a resolution better than that provided by the OCT envelope.

A Study on Ultrasonic Evaluation of Defects in Composite Materials Using Wavelet Analysis

--- S. Nirmala, Hindustan Aeronautics Limited, Bangalore, Karnataka, India; **C. R. L. Murthy**, Indian Institute of Science, Department of Aerospace Engineering, Bangalore, Karnataka, India

---Ultrasonic ‘C’ scan technique is widely used as an NDE tool to evaluate composite structures. Ultrasonic signals obtained from these materials are noisy in nature due to scattering effects. So, it is difficult to distinguish flaw signals of different types of defects. To obtain high probability of defect detection, special signal processing techniques are required to de-noise the ultrasonic RF data. In this study, ‘Wavelet Analysis’ of raw (RF) ultrasonic signals has been attempted on experimental data obtained from different composite laminates with intentionally introduced defects. The present approach is based on thresholding the wavelet co-efficients produced by the Discrete Wavelet Transformation of the raw Ultrasonic RF data obtained from a pulse-echo system using of 2, 5 and 10 MHz transducers. The ‘C” scan images obtained after wavelet de-noising clearly depicted the defects that could be quantified. For this purpose, an algorithm had been developed to identify a specific wavelet application for a typical defect-material combination. The results of a detailed study carried out on carbon and glass fiber laminates of different thickness with known defects such as de-laminations, porosity and de-bonding are presented in this paper.

Pulse Compression Technique Considering Velocity Dispersion of Guided Wave

---**Kiyokazu Toiyama**, Hiroshima Prefectural Technology Research Institute, West Resion Industrial Research Center, Material Processing Research Division, 2-10-1 Aga-Minami, Kure Hiroshima 737-0004, Japan; Takahiro Hayashi, Nagoya Institute of Technology

---An improved pulse compression technique was developed that is applicable to long range testing using dispersive guided waves. This technique not only improves signal-to-noise-ratio (SNR) of the guided wave signals, but also compensates for the signal spreading caused by dispersion characteristics of the guided wave. A fast calculation algorism was designed. It consists of integrations of both cross-correlation (pulse compression) and compensation process in wave number domain. Experimental verification was carried out. Then the improvement of both spatial resolution and signal-to-noise-ratio was confirmed.

Inner Damage Detection Method for Cantilever Beams

---**Zheng Li**, Wei Zhang, and Kezhung Gong, Department of Mechanics and Aerospace Engineering, Peking University, Beijing 100871, China (PRC)

---In this paper, continuous wavelet transform has been performed to extract the inner damage information from the guided waves in cantilever beams, and the location and size of damage can be detected exactly. The inner damage can be imitated by hard or soft inclusions and flaws respectively. Simultaneously, the damage with different location and various sizes in beams has been investigated and detected. Considering its best time-frequency property, Gabor continuous wavelet transform is employed to analyze the complicated flexible wave signals in cantilever beam, which is inspirited by an impact on the free end. Otherwise, in order to enhance the sensitivity of detection for some small damages, an improved method is discussed. Here, both computational and experimental methods are carried out for comparing the influence of different damage location in beam, and the damage character also can be identified. Therefore, the method proposed can be expected to expand to a powerful damage detection method in a broad engineering application, especially for complicated damage situation.

Ultrasonic Detection of Surface-Breaking Railhead Defects

---**Rachel S. Edwards**, Yichao Fan, and Steve Dixon, University of Warwick, Department of Physics, Coventry CV4 7AL, United Kingdom; Mayorkinos Papaelias, Claire L. Davis, and Clive Roberts, University of Birmingham, Rail Research United Kingdom Centre, Birmingham B15 2TT, United Kingdom

---We recently presented measurements of defects on the railhead, using a novel pitch-catch ultrasonic system comprising of two electro-magnetic acoustic transducers (EMATs) generating and detecting Rayleigh waves. Current systems used on the United Kingdom rail network for detecting surface breaking defects are limited in speed (< 30 mph) and accuracy (> 5 mm). The non-contact EMAT system has the potential to operate at higher line speed, improving network inspection coverage. The current system detects signals and performs an FFT in less than 1ms, and changes in the detected signal amplitude and frequency content are used to characterize defects. A new set of simulated defects on sections of rail have been produced, including half-face slots machined normal to the railhead surface, clusters of angled slots, and pocket defects more typical of real defects. The smallest pocket defects are difficult to detect, with changes in signal amplitude and cutoff falling close to the noise level. However, at chosen higher frequencies a drop in FFT magnitude indicates the presence of a defect, and this indicator can be logically combined with amplitude and cutoff measurements to provide a more reliable result. Preparation for testing on a rotating rail rig at high speeds is ongoing, and initial results from these experiments will also be presented.

Data Fusion of Eddy Current NDT Signals

---**Tomasz Chady**, Grzegorz Psuj, and Przemyslaw Lopato, Szczecin University of Technology, Department of Electrical Engineering, Szczecin, Poland

---The main purpose of a multi-sensor data fusion approach is to combine different sources of information to improve the performance of a measuring system. In this paper advantages carried by two differently sized eddy current probes will be combined to produce a coherent global result. A smaller ECT probe has a greater spatial resolution than bigger one so it can locate a flaw more precisely. However, at the same time it can be insensitive to minor flaws. A fusion process is split into two parts: a data preprocessing unit and a fusion center unit. The data preprocessing unit is used to perform a preliminary analysis of the signals and to generate a set of parameters for to the fusion center unit. The final data fusion is done using Bayes decision theory. The proposed fusion of signals provides the possibility of combining the sensitivity of bigger sensor and the resolution of the smaller one in advantage of obtaining higher probability of detection and more precise indication of potential flaws than it could be done using a single sensor.---This work was supported in part by the State Committee for Scientific Research, Poland, under the Grant no: 3T10A 017 30 (2006-2009).

An Ultrasonic Inverse Modeling Approach for Simultaneous Measurement of Density and Viscosity of Fluids

---**Krishnan Balasubramaniam**, Centre for Nondestructive Evaluation, Department of Mechanical Engineering, Indian Institute of Technology Madras, Chennai, 600 036 India

---Density and viscosity are two important parameters in process monitoring of liquids. In this paper, an inverse modeling approach based on Levenberg-Marquardt algorithm has been implemented in order to determine simultaneously the density and viscosity of the fluid from the attenuation measurement. The attenuation of the fundamental longitudinal wave mode, L(0,1) and fundamental torsional wave mode, T(0,1) in a cylindrical structure embedded in a viscous fluid depends on both density and viscosity of the surrounding fluid. The L(0,1) and T(0,1) were generated 0.5 mm copper wire using 0.5 MHz shear transducers and the attenuation of the fundamental modes were measured. Results of the experiments performed on various concentrations of glycerol-water mixtures have also been presented to show the applicability of such a device as a real time, on-line sensor for process control. Further, simulations were also performed in order to understand the nature of variation of error with respect to density and viscosity of fluid.

Non Destructive Stress Evaluation as an Inverse Problem

---**V. Vengrinovich** and D. Bryantsev, Institute of Applied Physics, Laboratory for Computer Diagnostics, Akademicheskaya str. 16, Minsk, Belarus

---The uncertainty of stress evaluation by ND techniques is usually due to the masking effect of microstructure, plastic deformation, calibration material and procedure, state of a surface, etc. It is shown the necessity for biaxial calibration procedure. Simple portable calibration hardware is proposed. The Bayesian posterior probabilistic analysis is applied to extract uncertain information on stress values out off fuzzy data obtained by Barkhausen noise (BN) and other ND techniques. The facility to use prior knowledge, both quantitative and qualitative, is discussed, one of the main being angle dependence of a measured signal. The other is elasto-plastic dependence of BN. The new "gutter" function is proposed in some cases as an alternative to r.m.s. values of BN amplitude. The experimental confirmation for theoretic results is implemented with BN measurements made on several types of mild carbon steels specimens.

Session 28

SESSION 28

MATERIALS NDE (WELDS, COATING, AND DAMAGE)

M. Lowe, Chairperson
Ballroom A

8:30 AM **Simulation and Modelling of Ultrasonic Wave Propagation in Austenitic Steel Welds**
---**G. Connolly**, M. J. S. Lowe, and A. Temple, Imperial College, 682 Mechanical Engineering, London SW7 2AZ, United Kingdom; S. Rokhlin, Ohio State University, Industrial Welding and Systems Engineering, Columbus, OH 43221

8:50 AM **Detectability of Wormhole Defects in Friction Sitr Welds**
---**T. A. Gray**[1], T. C. Jensen[1], N. Richter[1], R. B. Thompson[1], K. Chimbli[2], D. J. Medlin[2], C. Allen[2], and W. J. Arbegast[2], [1]Center for NDE, Iowa State University, Ames, IA 50011; [2]Center for Friction Stir Processing, South Dakota School of Mines and Technology, Rapid City, SD 57701

9:10 AM **Investigation of Local Elastic Properties in Friction Stir Welded Ti-6Al-4V Using Scanning Acoustic Microscopy**
---**R. W. Martin** and S. Sathish, University of Dayton Research Institute, 300 College Park, Dayton, OH 45469-0127; K. V. Jata, Air Force Reseach Laboratory, Wright Patterson Air Force Base, Dayton, OH 45469-0127

9:30 AM **Use of Metallographic Analysis to Improve Ultrasonic Phased-Array Evaluation of Resistance Spot Welds**
---**D. L. Hopkins** and W. B. Davis, Lawrence Berkeley National Laboratory, Engineering Division, Mailstop 46A-1123, 1 Cyclotron Road, Berkeley, CA 94720

9:50 AM **Comparison of Selected Weld Defect Extraction Methods**
---**R. Sikora**, P. Baniukiewicz, T. Chady, W. Rucinski, K. Swiadek, and M. Caryk, Szczecin University of Technology, Department of Electrical Engineering, 70-313 Szczecin, Poland

10:10 AM ***Break***

10:30 AM **Evaluation of Thin Coating Layers Using Rayleigh-Like Waves**
---**H.-J. Kim**, S.-J. Song, and D.-Y. Kim, Sungkyunkwan University, School of Mechanical Engineering, 300 Chunchun-Dong, Jangan-gu, Suwon, Kyunggi-do, 440-746, Korea; S. D. Kwon, Andong National University, Department of Physics, Andong, 760-749, Korea

10:50 AM **Pressure-Temperature Effects on Dispersion of Rayleigh's Waves on Coated Surfaces Using High Order Elastic Constants**
---**M. A. Hussain**, Benet Laboratories, 1 Buffington Street, Watervliet, NY 12189

11:10 AM **Estimation of Fatigue Damage for an Austenitic Stainless Steel (SUS304) Using a Pancake Type Coil**
---M. Oka, S. Nagato, Oita National College of Technology, Department of Computer and Control Engineering, 1666 Maki, Oita, 870-0152, Japan; T. Yakushiji, Oita National College of Technology, Department of Mechanical Engineering, 1666 Maki Oita, 870-0152, Japan; **Y. Tsuchida**, M. Enokizono, Faculty of Engineering, Oita University, Department of Electric and Electronic Engineering, 700 Dannoharu, Oita, 870-1192, Japan

11:30 AM **Measurement of the Ultrasonic Attenuation of Neutron Irradiated Specimens by Electromagnetic Acoustic Resonance Method**
---**Y. Kamada**, Iwate University, Faculty of Engineering, NDE & Science Research Center, Moioka, Japan; T. Ohtani, Shonan Institute of Technology, Department of Mechanical Systems Engineering, Fujisawa, Japan; H. Ogi, Osaka University, Faculty of Engineering Science, Toyonaka, Japan; H. Kikuchi, S. Kobayashi, and S. Takahashi, Iwate University, Faculty of Engineering, NDE & Science Research Center, Moioka, Japan

11:50 AM ***Lunch***

Simulation and Modelling of Ultrasonic Wave Propagation in Austenitic Steel Welds

---**George Connolly**, Michael J. S. Lowe, and Andrew Temple, Imperial College, 682 Mechanical Engineering, London SW7 2AZ, United Kingdom; Stanislav Rokhlin, Ohio State University, Industrial, Welding and Systems Engineering, Columbus, OH 43221

---Inspection of austenitic welds is particularly difficult because the materials tend to form anisotropic grains resulting in an inhomogeneous structure whose properties are specifically unknown. These grains, which are of a dimension comparable to the applied ultrasonic wavelength, are responsible for both scattering and beam-steering. A reliable method of ultrasonic NDE would remove the need for radiography, reducing inspection time and cost. Numerical methods such as finite element analysis and ray-tracing are increasingly used to gain understanding of wave propagation and scattering in complex structures, aiding the development of inspection techniques and qualification of procedures. This paper will present several case studies comparing a semi-analytical ray-tracing function and a finite element model using a simplified anisotropic continuously inhomogeneous weld model in which elastic constants are oriented in the direction of maximum heat flow during cooling. Simulations comparing the two approaches will be shown, to include model studies of reflections from defects, demonstrating the significance of incorporating the inhomogeneity of the weld in the modelling. Future directions will also be discussed.

Detectability of Wormhole Defects in Friction Stir Welds

---**T. A. Gray**[1], T. C. Jensen[1], N. Richter[1], M. Clayton[1], R. B. Thompson[1], K. Chimbli[2], D. J. Medlin[2], C. Allen[2], and W. J. Arbegast[2], [1]Center for NDE, Iowa State University, Ames, IA 50011; [2]Center for Friction Stir Processing, South Dakota School of Mines and Technology, Rapid City, SD 57701

---As part of an NSF TIE Project between the Center for Nondestructive Evaluation (CNDE) at Iowa State University and the Center for Friction Stir Processing (CFSP) at South Dakota School of Mines and Technology, detectability of wormholes in friction stir welds (FSW) was considered. Test samples were fabricated at CFSP and comprised butt-joined aluminum 7075-T7351 panels of 0.25" or 0.125" thickness. Eight panels of each thickness were prepared. Specific nominal wormhole sizes in the joints were achieved by controlling the linear speed, rotational speed, and forge force parameters of the FSW spindle tool. The actual sizes of the wormholes were verified from metallographic cross-sectional images provided by CFSP. Ultrasonic and x-ray radiographic inspections were performed at CNDE to assess the range of detectable sizes of the wormholes. The ultrasonic measurements were conventional pulse-echo immersion tests from the bottom face of the panels, while x-ray measurements were via film radiography. Wormholes as small as 0.0003 mm^2 in cross-sectional area were readily detectable by ultrasonic measurements, and as small as 0.001 mm^2 via radiography. The primary hindrance to detectability for both NDE modalities was measurement "noise" caused by surface geometry. Surface irregularities included both the typical swirl pattern on the top surface of the FSW joint and deformations of the bottom surface, such as excessive root flow. Efforts are now underway at CNDE to use model-assisted approaches to estimate the probability of detection of wormhole defects.---This work was supported by the NSF Industry/University Cooperative Center for Nondestructive Evaluation at Iowa State University and Center for Friction Stir Processing at South Dakota School of Mines and Technology.

Investigation of Local Elastic Properties in Friction Stir Welded Ti-6Al-4V Using Scanning Acoustic Microscopy

---**Richard W. Martin** and Shamachary Sathish, University of Dayton Research Institute, 300 College Park, Dayton, OH 45469-0127; Kumar V. Jata, Air Force Research Laboratory, Wright Patterson Air Force Base, Dayton, OH

---Local changes in the microstructure and ultrasonic wave velocity variation across a friction weld in Ti-6Al-4V are investigated using scanning acoustic microscopy. Surface and bulk focused acoustic wave velocity and amplitude measurements performed across the weld are presented. The changes in the characteristics of the surface waves are related to the near surface microstructure in different parts of the weld. The bulk velocity and amplitude changes thru the thickness show bright and dark bands particularly in the nugget region. Possible reasons for formation of such bands are discussed. Application of acoustic microscopy to detect localized process induced defects in friction stir welds is discussed.

Use of Metallographic Analysis to Improve Ultrasonic Phased-Array Evaluation of Resistance Spot Welds

---**Deborah L. Hopkins** and W. Bart Davis, Lawrence Berkeley National Laboratory, Engineering Division, Mailstop 46A-1123, 1 Cyclotron Road, Berkeley, CA 94720

---Ongoing collaborative research with the automotive industry is focused on sizing and characterizing resistance spot welds based on analysis of processed phased-array images. Previous work has demonstrated the ability to collect and analyze more than 4000 signals per weld using a probe unit composed of an ultrasonic phased array and a miniature scanning system. Weld outcomes range from very weak stick and cold welds, to undersized, satisfactory and burnt welds. All of these welds transmit acoustic energy across the interface between the welded sheets, and measurements performed on hundreds of welds strongly indicates that sizing and assessing weld quality are more complex than simply identifying and measuring the zone of ultrasonic transmission. Understanding how the acoustic signals are affected by the microstructure in the weld zone is, therefore, key for determining both the capabilities and limitations of ultrasonic weld characterization. For the most recent study, 75 weld samples were imaged with the phased-array system, and then sectioned, polished and etched to reveal the microstructure in and around the weld. The resulting metallographic images have been analyzed, along with the weld buttons obtained from destructive teardown of the samples, to better understand and interpret ultrasonic transmission through the welds.

Comparison of Selected Weld Defect Extraction Methods

---**Ryszard Sikora**, Piotr Baniukiewicz, Tomasz Chady, Wojciech Rucinski, Kamil Swiadek and Marcin Caryk, Szczecin University of Technology, Department of Electrical Engineering, 70-313 Szczecin, Poland

---In this paper four different methods of welding defects detection from radiographs are presented. All of them could be applied in digital radiography for automatic defects detection process. The first two methods are dedicated for extraction of flaws directly from radiograms. They are based on the artificial intelligence algorithms such as Artificial Neural Networks (ANN) and Fuzzy Logic (FL). In both cases data are acquired from rectangular window moved through the radiographs. Obtained intensities of all window pixels are processed by statistical operators in the FL method or used directly as ANN input. The fuzzy logic system considers whether the pixel belongs to crack (or background) using defects probability maps together with simple fuzzy rules. Neural network method uses knowledge gathered from radiographs with known defects. The other two methods extract defects by subtracting background from the radiograph or using various local thresholding methods. All algorithms have been tested on radiographic images of welds, which contain real defects. An accuracy of those methods is evaluated by two factors, which are: POD (Probability of Detection) and PFA (Probability of False Alarm). Results of the defects extraction and accuracy analysis of each algorithm will be presented in the full paper.
This work was supported by European Commission sponsored project FilmFree, which is a collaboration between the 32 European organizations (www.filmfree.eu.com). Contact for further details: exploitation manager S. Sood (scsood@cituk.com), project manager A. Wocial (adam.wocial@twi.co.United Kingdom).---The Project is coordinated and managed by TWI Ltd and is partly funded by the EC under the IP SME program, reference number: NMP2-CT-2005-515746.

Evaluation of Thin Coating Layers Using Rayleigh-Like Waves

---**Hak-Joon Kim**, Sung-Jin Song, and Dong-Yeol Kim, Sungkyunkwan University, School of Mechanical Engineering, 300 Chunchun-Dong, Jangan-gu, Suwon, Kyunggi-do, 440-746, Korea; Sung D. Kwon, Andong National University, Department of Physics, Andong, 760-749, Korea

---For enhancement of mechanical properties, thin layer coating techniques such as titanium nitride (TiN), diamond-like carbon (DLC) and chemical vapor deposit (CVD) diamond are widely used in heavy-duty and/or high performance machinery components. However, performances of thin layer coating components are critically dependent of the bonding condition between thin layer and substrate. Also, surface properties of the layered substrates tend to gradually change due to exposure to severe environment for a long time. Therefore, it is necessary to evaluate the characteristics of such thin coating layers nondestructively. To address such a need, in this study, we will perform simulations of thin layered substrates with imperfect interfaces to find relation between dispersion characteristics of Rayleigh-like waves and quality of thin coating layer that can be used for bonding quality evaluation. Also, we will propose a new method, named as ¡°minimum reflection profile¡± which measures energy variation of reflected waves from the surface and/or sub-surface of specimens as the angle of incident wave changes from normal to beyond Rayleigh angle in a pitch-catch immersion setup. So, using Rayleigh-like waves, we will evaluate the characteristics of this coating layer for CVD diamond coating specimens with various coating thickness, substrate roughness, and bonding strengths. In this presentation, simulated dispersion characteristics of Rayleigh-like waves and experimental results for thin coating layers and performances of the minimum reflection profiles will be discussed.

Pressure-Temperature Effects on Dispersion of Rayleigh's Waves on Coated Surfaces Using High Order Elastic Constants

---**Moayyed A. Hussain**, Benet Laboratories, 1 Buffington Street, Watervliet NY 12189

---The present work is motivated by the need of obtaining mechanical and thermal properties of coating material on a substrate at high temperature and/or under initial uniform stress. These properties may differ considerably from the bulk properties of the layered media. These properties are used in other models e.g. in prediction of wear and erosion under harsh environments. Dispersion characteristics obtained from laser generated signal at different temperatures are used to obtain such properties. The signal is analyzed using wavelet transform and matched with velocities obtained from finite deformation solutions. By exploiting Finite Deformation Theory involving higher order elastic constants, implicit expressions for the change in longitudinal and transverse velocities of a material at elevated temperatures and pressure as a function of a uniform deformation parameter have been derived. Theoretical and experimental data are matched with a least-squares fit to obtain the 3rd order elastic constants. The experimental data was collected with a laser ultrasonic system at temperatures ranging from 20 - 300 C. This approach was used on samples of aluminum and coated specimen of tantalum on steel and chromium on steel.

Estimation of Fatigue Damage for an Austenitic Stainless Steel (SUS304) Using a Pancake Type Coil

---Mohachiro Oka, Shinya Nagato, Oita National College of Technology,Department of Computer and Control Engineering, 1666 Maki, Oita, 870-0152, Japan; **Terutoshi Yakushiji**, Oita National College of Technology,Department of Mechanical Engineering, 1666 Maki, Oita, 870-0152, Japan; Yuji Tsuchida, Masato Enokizono, Faculty of Engineering, Oita University, Department of Electric and Electronic Engineering, 700 Dannoharu, Oita, 870-1192, Japan

---A lot of piping used in the chemical plant are made of austenitic stainless steels because austenitic stainless steels show excellent corrosion resistance. Then, it is very important to know the state of deterioration of austenitic stainless steels. On the other hand, the plastic deformation induced by fatigue damage causes the change in electromagnetic properties of austenitic stainless steels. The electromagnetic properties of the typical semi-stable austenitic stainless steel such as SUS304 (ANSI-304) is changed greatly by the transformation from an austenite to a martensite by fatigue damage. It is thought that fatigue damage can be evaluated if the change in the electromagnetic properties of it by fatigue damage can be measured. Accordingly, we are investigating the eddy current method using a pancake type coil for evaluation of fatigue damage of structural components made of SUS304. The relationship between the inductance element of the pancake type coil and fatigue damage of SUS304 by using the LCR meter is measured. From the experimental results, there is a high correlation between these two. In this paper, the experimental results of the fatigue damage evaluation of SUS304 using the pancake type coil are reported.

Measurement of the Ultrasonic Attenuation of Neutron Irradiated Specimens by Electromagnetic Acoustic Resonance Method

---**Yasuhiro Kamada,** Iwate University, Faculty of Engineering, NDE&Science Research Center, Morioka, Japan; Toshihiro Ohtani, Shonan Institute of Technology, Department of Mechanical systems Engineering, Fujisawa, Japan; Hirotsugu Ogi, Osaka University, Faculty of Engineering Science, Toyonaka, Japan; Hiroaki Kikuchi, Satoru Kobayashi, and Seiki Takahashi, Iwate University, Faculty of Engineering, NDE&Science Research Center, Morioka, Japan

---Evaluation of irradiation embrittlement of steel used in nuclear reactor pressure vessels (RPVs) is an important safety and economic issue. Ultrasonic characterization is a promising nondestructive evaluation technique because ultrasonic attenuation is a property that is sensitive to the effects of radiation. For precise measurement of the ultrasonic attenuation coefficients of irradiated specimens, we have developed a measurement instrumentation based on an electromagnetic acoustic resonance method. Specimens of Cu enriched RPV steel and Fe-Cu-Ni-Mn model alloy, neutron irradiated up to 3.3×10^{23} n/m^2 (E>1MeV) at 563K, were investigated in this study. A special electromagnetic acoustic transducer (EMAT) was designed for these small plate-shaped specimens. The EMAT and a RITEC RAM10000 system were used to obtain the resonant spectrum in a 0.5 - 10 MHz range. The attenuation coefficients were determined at each resonant frequency. It is reported that the attenuation of single crystal pure metals reduced by irradiation due to the dislocation damping effect. Contrary to the case of a pure metal, the attenuation coefficients of the present RPV steel and model alloy increased with increasing the neutron fluence.

Session 29

SESSION 29 – POSTERS

NDE METHODS, NEW TECHNIQUES AND APPLICATIONS, SENSORS, TRANSDUCERS, AND PROBES, MATERIAL PROPERTIES, CIVIL STRUCTURES, DESIGN, MANUFACTURING, AND PROCESS CONTROL, NDE RELIABILITY

Green Center

1:30 PM

NDE Methods

Impedance Method Application for Multi-Layer Structure Testing
---**M. M. Krishan**, Al-Balqa' Applied University, Ma'an University College, University Street, Ma'an, Ma'an 195, Jordan

Impedance Method for Multi-Layer Panel Testing
---**M. M. Krishan**, Al-Balqa' Applied University, Ma'an University College, University Street, P. O. Box 194, Ma'an, Jordan

New Techniques and Applications

Nondestructive Evaluation for Wall Thinned Pipe Using Laser Based Ulrasound
---**J. H. Kim**, J. H. Lee, and J. H. Park, Pusan National University, Department of Mechanical Design Engineering, Changjeon-dong, Kumjeong-gu, Busan, Korea

Measurement of Strain Distribution Around Wall Thinning Defect in Pipe Bends by Laser Speckle Interferometry
---K.-S. Kim and **H.-C. Jung**, Chosun University, Department of Mechanical Design Engineering, Gwangju, Korea; H.-M. Kim, Chosun University, Graduate School, Department of Advanced Parts and Materials Engineering, Gwangju, Korea; D.-P. Hong, Chonbuk National University, Department Jeonju, Jeonbuk, Korea; M.-Y. Choi, Korea Research Institute of Standards and Science, Safety Metrology Group, Daejeon, Korea; H.-S. Chang, Chosun University, Laser Center, Gwangju, Korea

Development of Deposit Detection System in Pipelines of the Steelworks Using Cs-137 Gamma-Ray
---**W.-J. Song**, S.-H. Lee, and H.-D. Jeong, Research Institute of Industrial Science & Technology, Mechanical & Electrical Engineering Research Department, #32 Hyoja-Dong, Nam-Ku, Phang, Kyungbuk, 790-330, Korea

Eddy Current Monitoring of Surface Roughness
---**R. T. Ko** and N. D. Schehl, Structural Integrity Division, University of Dayton Research Institute, 300 College Park Drive, Dayton, OH 45469-0120

Fast Multipole Solutions for Diffusive Scalar and Electromagnetic Problems
---**M. Yang**[1,2], J. Song[2], and N. Nakagawa[1], [1]Center for Nondestructive Evaluation, Iowa State University, Ames, IA 50011-3042; [2]Department of Electrical and Computer Engineering, Iowa State University, Ames, IA 5011-3060

Ultrasonic Diagnostics of Light-Emitting Diodes
---**E. K. Naimi**[1] and O. I. Rabinovich[2], Moscow State Institute of Steel and Alloys (Technological University), [1]Institute of Basic Education, [2]Institute of Physics and Chemistry of Materials, 119991, Leninsky prospect, 4, Moscow, Russia

New Developments in Simulating NDT/NDE Physics with the CIVA Modeling Platform
---**A. Perregaux**, Magsoft Corporation, 20 Prospect Street, Ballston Spa, NY 12020; P. Benoist, CEA, Gif-sur-Yvette, Cedex, France

Deep Defect Detection Within Thick Multilayer Aircraft Structures Containing Steel Fasteners Using a Giant-Magneto Resistive (GMR) Sensor
---R. T. Ko and **G. J. Steffes***, *Metals, Ceramics, and NDE Division, Air Force Research Laboratory, Wright-Patterson Air Force Base, Dayton, OH 45433; Structural Integrity Division, University of Dayton Research Institute, 300 College Park Drive, Dayton, OH 45469-0120

Inspection of Complex Components Using a 3-D Smart Flexible Phased Array
---**G. Toullelan**, A. Nadim, and O. Casula, Comm. a l'Energie Atom., DRT/LIST, France

Sensors, Transducers, and Probes

PMN-PT Ultrasonic Transducer for NDE Applications and Evaluation of Its Performance
---**B. Ahn**[1], K.-B. Kim[1], Y.-G. Kim[1], S.-K. Park[1], D. K. Hsu[2], and D. J. Barnard[2], [1]Korea Research Inst. of Standards & Science, Daejeon, Korea; [2]ISU, CNDE, 1915 Scholl Road, Ames, IA 50010

Accurate Simulation of Phased Array Received Signals from Media Containing Arbitrarily Shaped Impedance Discontinuities with Experimental Validation
---**V. Lupien**, Acoustic Ideas, 27 Eaton Street, Wakefield, MA 01880

Magnetostrictive Transduction of Guided Waves in Fluid-Filled Pipes
---**A. P. Y. Phang** and R. E. Challis, The University of Nottingham, School of Electrical and Electronic Engineering, Nottingham, Nottinghamshire, NG7 2RD, United Kingdom

Evaluation of Hardening for Carbon Steel by Measuring Magnetic Properties
---Y. Kai, JSPS Research Fellow, Faculty of Engineering, Oita University, 700 Dannoharu, Oita, 870-1192, Japan; **Y. Tsuchida** and M. Enokizono, Faculty of Eng. Oita University, Oita, Japan

Metal Detection System to Reuse Woods from Wooden Houses
---T. Yasutake, **Y. Tsuchida**, and M. Enokizono, Oita University, Faculty of Engineering, 700 Dannoharu, Oita, 870-1192, Japan; T. Chady, Szczcin University of Technology, Department of Electrical Engineering, Szczecin, Poland

Material Properties

Analysis of Shear Wave Acoustic Velocity in Duplex Stainless Steel
---**A. Ruiz-Marines**, H. Carreon, and N. Ortiz-Lara, Univ. Michoacana de San Nicolas de Hidalgo, Inst. de Investigacions Metalúrgicas, Edificio U.C.U., Morelia, Michoacan, 58000 Mexico

Estimation of Porosity Contents in Composites by Applying Discrete Wavelet Transform to Ultrasonic Backscattered Signal
---K.-B. Kim[1], **D. K. Hsu**[2], D. J. Barnard[2], and A. Kite[2], [1]Korea Research Institute of Standards and Science, Daejeon, Korea; [2]Iowa State University, CNDE, 1915 Scholl Road, Ames, IA 50011

Ultrasonic Guided Waves for Health Monitoring of High Pressure Composite Tanks
---**M. Castaings** and B. Hosten, Laboratoire de Mécanique Physique, UMR CNRS 5469, 351 cours de la Libération, Université Bordeaux 1, 33400 Talence, France

One-Sided Measurement Approach on Ultrasonic Beam Path Analysis in CFRP Composite Laminates
---**K.-H. Im**, Department of Automotive Eng., Woosuk University,490, Hujung-ri, Samrae-up, Wanju-kun, Chonbuk, 565-701, Korea; H.-J. Kim and S.-J. Song, School of Mechanical Engineering, Sungkyunkwan University, Kyonggi-do, 440-746, Korea; D. K. Hsu, V. Dayal, and D. Barnard, Center for NDE, Iowa State University, Ames, Iowa 50011; K.-S. Lee, Y.-J. Yang, and I.-Y. Yang, BK21 Education Center of Mould Technology for Advanced Materials & Parts, Chosun University,375 Seosuk-dong, Dong-gu, Kwangju 501-759, Korea; J.-W. Park, Dept. of Naval Architecture and Ocean Eng., Chosun University, Gwangju 501-759, Korea

Modeling of Ultrasonic Wave Propagation in Composite Airframe Components
---**M. Mienczakowski**, A. K. Holmes, and R. E. Challis, The Applied Ultrasonics Laboratory, School of Electrical and Electronic Engineering, The University of Nottingham, University Park, Nottingham, NG7 2RD, United Kingdom

Civil Structures

NDE of FRP Wrapped Columns Using Infrared Thermography
---**U. B. Halabe**, S. S. Dutta, and H. V. S. GangaRao, West Virginia University, Constructed Facilities Center, Dept. of Civil and Environmental Engineering, Morgantown, WV 26506-6103

Assessment of Alkali-Silica Reaction Damage in Mortars with Nonlinear Ultrasonic Technique
---**J. Chen**, R. J. Amal, J.-Y. Kim, K. E. Kurtis, and L. J. Jacobs, Georgia Institute of Technology, School of Civil & Environmental Engineering, Atlanta, GA 30332; L. J. Jacobs, Georgia Institute of Technology, Woodruff School of Mechanical Engineering, Atlanta, GA 30332

Finite Element Modeling for Infrared Thermography of GFRP Bridge Decks
---C. L. Hing and **U. B. Halabe**, West Virginia University, Constructed Facilities Center, Department of Civil and Environmental Engineering, Morgantown, WV 26506-6103

Design, Manufacturing, and Process Control

Quantitative Detection of Blasting Abrasive Residue by Pulse-Thermography
---**G. Zenzinger**, H. Zisik, and J. Fleischmann, MTU Aero Engines, Munich, Germany; V. Carl, T-ZfP, Dinslaken, Germany

Simulations to Improve Structural Defect Detection and Classification in Swiss-Cheese
---**J. Eskelinen** and E. Haeggström, Department of Physical Sciences, P. O. Box 64, FIN-00014, Helsinki, Finland; A. Alavuotunki and T. Alatossava, Department of Food Technology, P. O. Box 66, FIN-00014, Helsinki, Finland

Nondestructive Characterization of Controlled Wood Destruction
---**A. Salmi**, T. Hintikka, T. Karppinen, and E. Haeggström, Electronics Research Unit, Department of Physical Sciences, P. O. Box 64, FIN-00014, University of Helsinki; E. Saharinen, KCL – Keskuslaboratoriot Inc., P. O. Box 70, FIN-02151, Espoo, Finland

Theoretical Modeling of GPR Reflection from Vadose Zone in Silty Soils
---**U. B. Halabe**, West Virginia University, Department of Civil and Environmental Engineering, Morgantown, WV 26506-6103

NDE Reliability

Optimization of High Sensitivity Ultrasonic Scanning
---**T. N. Claytor**, Los Alamos National Laboratory, MS C914, Los Alamos, NM 87544; R. K. Torney, Stanford University, Stanford, CA 94305

Analysis of Round Robin Test for Ultrasonic Thickness Measurement of Wall Thinned Pipe in Nuclear Power Plant
---**D.-H. Lee**, S.-J. Lee, J.-H. Lee, Pusan National University, Department of Mechanical Design Engineering, Busan, Korea

3:10 PM ***Break***

Impedance Method Application for Multi-Layer Structure Testing

---**Monzer Moh'd Krishan**, Al-Balqa' Applied University, Ma'an University College, University Street, Ma'an, Ma'an 195, Jordan

---Multi-layer materials and structures are widely used in the modern aircraft industry. The main defect of these structures is delamination. The most appropriate method for detection of such kind flaws is the impedance testing method. This paper is devoted to the features of the impedance method for multi-layer panel testing. The theoretical and experimental investigations of mechanical impedance were provided for honeycomb panels. As a result of the theoretical investigation it was obtained the analytic expression, which enabled to determine action of such object parameters as honeycomb density and thickness, covering thickness and cylindric rigidity on a test result. The assembly of a combined probe was proposed for experimental investigations of mechanical impedance. An amplitude of the output signal of this probe is depended on the testing object mechanical impedance and flexibility of contact area. Numerical simulation results demonstrate influence of the object parameters on effectiveness of the defect detection in honeycomb structure.

Impedance Method for Multi-Layer Panel Testing

---**Monzer Moh'd Krishan**, Al-Balqa' Applied University, Ma'an University College, University Street, P. O. Box 194, Ma'an, Jordan

---This paper is devoted to the features of the impedance method for multi-layer panel testing. The theoretical and experimental investigations of mechanical impedance were provided for honeycomb panels. As a result of the theoretical investigation it was obtained the analytic expression, which enabled to determine action of such object parameters as honeycomb density and thickness, covering thickness and cylindric rigidity on a test result. The assembly of a combined probe was proposed for experimental investigations of mechanical impedance. An amplitude of the output signal of this probe is depended on the testing object mechanical impedance and flexibility of contact area. Numerical simulation results demonstrate influence of the object parameters on effectiveness of the defect detection in honeycomb structure.

Nondestructive Evaluation for Wall Thinned Pipe Using Laser Based Ultrasound

---**Jin Hyun Kim**, Joon Hyun. Lee, and Jong Ho. Park, Pusan National University, Department of Mechanical Design Engineering, Changjeon-dong, Kumjeong-gu, Busan, Korea

---This study describes hybrid system of laser generation and air-coupled detection of guided wave in wall thinned pipe. The specimens of wall thinned pipe were produced with elliptical shape in consideration of real shape of wall thinning. These are 2 types with 3 different sizes in terms of depth and width for each type. Linear slit array was used to launch selective mode of guided wave and the gap of slit array is the same as wave length which is calculated from dispersion curve. The oblique angle of air-coupled transducer for reception of selective mode is also calculated from dispersion curve and Snell¡¯s law. The characteristic of sensitivity in mode conversion between L(0,1) and L(0,2) depending on the size of depth and width in wall thinned defect is discussed. The effectiveness of the amplitude ratio between two different mode for quantitative evaluation of local corrosion area is shown in this study.

Measurement of Strain Distribution Around Wall Thinning Defect in Pipe Bends by Laser Speckle Interferometry

---Koung-Suk Kim and **Hyun-Chul Jung**, Chosun University, Department of Mechanical Design Engineering, Gwangju, Korea; Hyun-Min Kim, Chosun University, Graduate School, Department. of Advanced Parts and Materials Engineering, Gwangju, Korea; Dong-Pyo Hong, Chonbuk National University, Department Jeonju, Jeonbuk, Korea; Man-Yong Choi, Korea Research Institute of Standards and Science, Safety Metrology Group, Daejeon, Korea; Ho-Seob Chang, Chosun University, Laser Center, Gwangju, Korea

---The strain distribution measurement for wall thinned pipe bends by ESPI is presented. Defect types observed in the steel piping in the nuclear power plants (NPP) are the crack at the weld part and the wall thinning defect in the pipe bends. Especially, the wall thinning defects in the pipe bends due to the flow-accelerated corrosion (FAC) is a main type of defects observed in the carbon steel piping system. ESPI is one of the optical non-destructive testing methods and can measure the stress and the strain distribution of the object subjected by the tensile loading or the internal pressure. In this paper, the strain distribution of the wall thinned pipe bends due to the internal pressure will be measured by ESPI technique and the results are discussed. From the results, the size of the wall thinning defect can also be measured approximately.

Development of Deposit Detection System in Pipelines of the Steelworks Using Cs-137 Gamma-Ray

---**Won-Joon Song**, Seung-Hee Lee, and Hee-Don Jeong, Research Institute of Industrial Science & Technology, Mechanical & Electrical Engineering Research Department, #32 Hyoja-Dong, Nam-Ku, Pohang, Kyungbuk, 790-330, Korea

---The deposit is built up in the pipeline of the steelworks by the chemical reaction among COG (coke oven gas), BFG (blast furnace gas), moisture, and steel in the high temperature environment and obstructs the smooth gas flow. In this study, a gamma-ray system is developed to detect the deposit accumulated in pipelines and calculate the accumulation rate with respect to the cross section area of pipes. Cs-137 is used as the gamma-ray source and the system is designed to apply to pipes of various diameters. This system also includes the DB for storage and display of the measurement results so that it can be used for the efficient management of the pipelines.

Eddy Current Monitoring of Surface Roughness

---**Ray T. Ko** and Norman D. Schehl, Structural Integrity Division, University of Dayton Research Institute, 300 College Park Drive, Dayton, OH 45469-0120

---The asperity of a rough surface produces a coil lift-off effect similar to raising a coil off the surface of the test material. Although the lift-off effect is often suppressed during a conventional eddy current inspection for defect detection and conductivity measurements, it carries critical information about the surface topography due to the sensitivity of the effective coil impedance to lift-off changes. In this study, the effect of surface roughness on the lift-off signal is examined. To be able to monitor the effective lift-off and thus the surface roughness, the research and lab testing are focused on the following: (a) a sensitivity study to evaluate the liftoff response of a reference specimen and (b) assessment of apparent surface roughness based on the eddy current data acquired. Preliminary test results of the eddy current monitoring of surface roughness are to be presented. The advantage of using eddy current to monitor the surface roughness over other approaches is also to be discussed.

Fast Multipole Solutions for Diffusive Scalar and Electromagnetic Problems

---**Ming Yang**[1,2], Jiming Song[2], and Norio Nakagawa[1], [1]Center for Nondestructive Evaluation, Iowa State University, Ames, IA 50011-3042; [2]Department of Electrical and Computer Engineering, Iowa State University, Ames, IA 50011-3060

---Nondestructive evaluation (NDE) of airframe structures may involve finding eddy-current distributions in complicated geometrical features including cracks, fasteners, sharp corners/edges, multi-layered structures, complex ferrite-cored probes, etc. The eddy-current problem can be formulated by the boundary integral equations (BIE), which can be discretized into matrix equations by the method of moments (MoM) or the boundary element method (BEM). The Fast Multipole Method (FMM) is a well-established and effective method for accelerating numerical solutions of the matrix equations. Accelerated by the FMM, the BIE method can now solve large-scale electromagnetic wave propagation and diffusion problems. The traditional BIE method requires $O(N^2)$ operations to compute the system of equations and another $O(N^2)$ operations to solve the system using iterative solvers, with N being the number of unknowns; in contrast, the BIE method accelerated by the two-level FMM can potentially reduce the operations and memory requirement to $O(N^{3/2})$. This paper introduces the procedure of the FMM accelerated BIE method, which is not only efficient in meshing complicated geometries, accurate for solving singular fields or fields in infinite domains, but also practical and often superior to other methods in solving large-scale problems. Computational tests of the numerical FMM solutions against the conventional BIE results and exact solutions are presented for the two-dimensional Helmholtz equation with a complex wave number and the three-dimensional diffusive electromagnetic problem.---This material is based upon work supported partially by the Federal Aviation Administration under Contract #DTFA03-98-D-00008, Delivery Order #0039 and performed at Iowa State University's Center for NDE as part of the Center for Aviation Systems Reliability program.

Ultrasonic Diagnostics of Light-Emitting Diodes

---**Eugene K. Naimi**[1] and Oleg I. Rabinovich[2], Moscow State Institute of Steel and Alloys (Technological University), [1]Institute of Basic Education, [2]Institute of Physics and Chemistry of Materials, 119991, Leninsky prospect, 4, Moscow, Russia

---One of the main factors which influence considerably on the degradation rate of the light-emitting diodes (LED's) performance characteristics is ultrasonic action [1]. It allows to use ultrasonics as the tool for the diagnostics of the LEDs degradation during their work. Action of ultrasonic vibration on GaP and InGaN LED`s was investigated. Ultrasonic action was made by the piezoelectric transducer - quartz bar which was excited at the first harmonic. LEDs were mounted on piezoquartz bar where the antinode of stress standing wave was situated. It was found that the action of the ultrasonic vibration upon GaP and InGaN LEDs at frequencies 60-100 kHz during several hours can lead to the decrease of LEDs power characteristic about in 2 times, to the red shift for 4-5 nm for GaP LEDs and for 2-4 nm InGaN LEDs. The model, describing changing of the characteristics proposes that of ultrasonic action in GaP heterostructure induces the transition of nitrogen atoms from sites into interstitial position. The result of it is the increase of nonradiation component by creating the centers of nonradiation recombination and at the same time the reduction of the radiative recombination and therefore performance characteristics degradated. In InGaN LED ultrasonic action caused defect generation due to the strong piezoelectric field and therefore performance characteristics degradated.

New Developments in Simulating NDT/ NDE Physics with the CIVA Modeling Platform
---**Adrian Perregaux**, Magsoft Corporation, 20 Prospect Street, Ballston Spa, NY 12020; Philippe Benoist, CEA, Gif-sur-Yvette, Cedex France

---The different tools developed over the years in the CIVA simulation platform have allowed one to fulfill the needs of NDE/ NDT probes, processes and applications. However, there is an ever increasing demand for these simulation tools: the qualification and performance demonstration of existing techniques, the design of new inspection methods, new probe design (for instance advanced phased-arrays probes), help with diagnosis, data reconstruction, and also training and teaching. The following techniques have recently been added to the CIVA tools to address some new NDT/NDE configurations In the Ultrasonic module, new features for Phased Array applications (Matrix, Reconstruction) and advanced modeling of Time Of Flight Diffraction (TOFD) have been incorporated. In the Eddy Current module, new capabilities are now available to simulate the use of ferromagnetic materials. Finally, a new radiographic module has been developed, and it will include both x-ray and gammagraphy capabilities. These are a sampling of new features which will be detailed in the poster which will provide an overview of the various simulation capabilities of CIVA; including experimental validations.

Deep Defect Detection Within Thick Multilayer Aircraft Structures Containing Steel Fasteners Using a Giant-Magneto Resistive (GMR) Sensor
---Ray T. Ko and **Gary J. Steffes*, ***Metals, Ceramics, and NDE Division, Air Force Research Laboratory, Wright-Patterson Air Force Base, Dayton, OH 45433; Structural Integrity Division, University of Dayton Research Institute, 300 College Park Drive, Dayton, OH 45469-0120

---There are many applications throughout the aerospace industry that involve aluminum structures joined with steel fasteners. Steel fasteners are ideal for use due to their lower cost and higher strength properties. Unfortunately, over time these dissimilar metals can cause issues when these structures need to be assessed using Nondestructive Inspection (NDI) techniques. In many instances, the NDI methods used are based on or derived from conventional eddy current. However, the particular task of inspection becomes very challenging when structures with steel fasteners are thicker, more complex, and when the requirement is evaluation of subsequent layers beneath the surface. Two reasons for this difficulty are the permeability of materials in the structure and the sensitivity of eddy currents. The magnitude of the permeability in steel fasteners is a source of noise in background signals in defect and conductivity evaluation using eddy current. In addition, the sensitivity of eddy current inspections in thick and highly conductive materials is degraded when using lower frequencies appropriate for thick and complex structures. To address these issues, a magnet has been applied to the fasteners to reduce the noise caused by the permeability. In addition, a GMR sensor coupled with a lock-in amplifier was used obtain data and to cut down on the eddy current sensitivity issues at low frequencies. Experimental results have shown within this application that second layer defects occurring 10 mm below the surface can be detected using this setup. Additional results from this and other applications of thick aluminum structures with steel fasteners along with data processing plans will be presented.---
This work was performed on-site in the Nondestructive Evaluation Branch of the Air Force Research Laboratory (AFRL/MLLP) at WPAFB, Ohio under Air Force contract # F33615-03-C-5219.

Inspection of Complex Components Using a 3-D Smart Flexible Phased Array

---**G. Toullelan**, A. Nadim, O. Casula**,** Commissariat à l'Energie Atomique, DRT/LIST, CEA Saclay, France

---The inspection of piping in nuclear power plants is mainly performed in contact with ultrasonic wedge transducers. During the scanning, the fixed shape of wedges cannot fit the irregular surfaces and complex geometries of components (butt weld, nozzle, elbow). The variable thickness of the coupling layer, between the wedge and the local surface, leads to beam distortions and losses of sensitivity. Developments of 3-d ultrasonic flexible phased array techniques are presented here, applied to the ultrasonic inspection of a welded pipe. This example of a complex geometry component is typical of the field of application for such sensor. The phased array is flexible to fit the complex profile and to minimize the thickness of the coupling layer. The independent piezoelectric elements composing the radiating surface are mechanically assembled in order to build an articulated structure. A profilometer, embedded in the transducer, measures the local surface distortion allowing to compute in real-time the optimized delay laws and compensating the distortions of 2d or 3d profiles. Those delay laws are transferred to the ut acquisition system, which applies them in real-time to the piezoelectric elements. Experiments presented here aim in determining the detection abilities of this technique using multi-shot configurations (e.g. Angular scanning, several points focusing).

PMN-PT Ultrasonic Transducer for NDE Applications and Evaluation of Its Performance

---**Bongyoung Ahn**[1], Ki-Bok Kim[1], Young-Gil Kim[1], Sang-Ki Park[1], David K. Hsu[2], and Daniel J. Barnard[2], [1]Korea Research Institute of Standards and Science, Daejeon, Korea; [2]Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50010

---Ultrasonic transducers for NDE applications based on the PZT (lead zirconate titanate) ceramics have been widely used because of higher performance and ease of manufacturing. The PZT based ultrasonic transducer has some limitations for application to the highly attenuative materials. Recently, a new class of single-crystal piezoelectric materials such as lead metaniobate doped with lead titanate (PMN-PT) has been synthesized and was found to further enhance the electromechanical coupling factor compared to PZT. These materials can potentially offer significantly improved performance of ultrasonic transducers through enhanced bandwidth and sensitivity, both in transmission and transmit-receive configurations. This paper describes the theoretical and experimental investigation for fabricating the PMN-PT single crystal ultrasonic transducer. The design conditions of components of ultrasonic transducer such as front matching layer between test material and piezo-materials and backing materials were investigated based on the simulation results by KLM model. Prototype transducers having different acoustical impedances of backing materials were manufactured with a centre frequency of approximately 1 to 5 MHz. The fabricated transducers were compared with the commercial PZT transducer with same size of active element. Overall, the PMN-PT single crystal ultrasonic transducer shows considerably improved performance over the PZT based ultrasonic transducer as demonstrated by its greater back wall echo amplitude.

Accurate Simulation of Phased Array Received Signals from Media Containing Arbitrarily Shaped Impedance Discontinuities, with Experimental Validation
---**Vincent Lupien**, Acoustic Ideas, 27 Eaton Street, Wakefield, MA 01880

---Computational ultrasonic models with focal law calculation and ultrasonic beam modeling capabilities accelerate phased array ultrasonic application development. It may be useful to simulate the actual A, B, C, D and S-scan responses received by a proposed phased array transducer and inspection technique, in the presence or absence of defects, to aid in assessing the adequacy of the resolution and sensitivity of the inspection. The usefulness of such simulations depends on the accuracy of the computational models which handle the propagation of waves and their interaction with scattering boundaries. Accurate computation of wave propagation is already possible in tools such as Continuum Ultrasonic Modeler™. In an effort to provide highly accurate received responses, we have been working on developing a scattering model to handle both reflection-like discontinuities, such as those adequately represented by a Kirchhoff approximation, and diffraction-like discontinuities, such as sharp edges. The superposition of both phenomena should be sufficiently general to handle the modeling of arbitrarily shaped voids, inclusions, cracks, delaminations, and rough interfaces. In this paper we concentrate on comparisons of our scattering model with experimental results for spherical and plane discontinuities.

Magnetostrictive Transduction of Guided Waves in Fluid-Filled Pipes
---**Albert P. Y. Phang** and Richard E. Challis, The University of Nottingham, School of Electrical and Electronic Engineering, Nottingham, Nottinghamshire, NG7 2RD, United Kingdom

---Magnetostrictive transducers provide a compact and robust alternative to conventional piezoelectric devices for guided wave propagation in cylindrical waveguides. In this work we present a model of the whole transduction system and guided wave signal path to establish design criteria and optimize transducer performance for measurement conditions requiring low excitation currents, and to reduce the bulk and complexity of the associated electronic equipment. The design was optimized by trading off between overall transducer sensitivity and the operating bandwidth, which are determined by the number of turns on the transducer coils and their interactions with the driving and loading impedances on the electrical transmission and reception circuits. The guided wave signal path is modelled on the basis of the guided wave excitability function and the effects of the dynamic excitation magnetic field in the spatial domain on the range of wavenumbers excitable, and thence the equivalent frequencies obtained from guided wave dispersion relations. Guided wave propagation in an empty pipe, a pipe filled with water, and a pipe filled with supercritical CO2 is analyzed using the reassigned spectrogram method.

Evaluation of Hardening for Carbon Steel by Measuring Magnetic Properties

---Yuichiro Kai, JSPS Research Fellow, Faculty of Engineering, Oita University, 700 Dannoharu, Oita, 870-1192, Japan; **Yuji Tsuchida** and Masato Enokizono, Faculty of Engineering, Oita University, Oita, Japan

---Heating treatments are applied to improve mechanical properties of steel. The steel, which requires high strength, is hardened by using induction heating. However, it is difficult to control hardening depth and hardness. Therefore, it is very important to evaluate the hardening depth and the hardness. We have proposed a non-destructive evaluation system of the hardening depth and the hardness by using an electromagnetic method. We suggested to evaluate the hardening depth and the hardness by measuring magnetic flux density B and the magnetic field strength H from outside. It is possible to obtain the plenty of information inside the hardened steel, which means the permeability, the coercive force and the residual magnetic flux density. We developed a magnetic sensor to measure the B and the H and obtain the magnetic properties depending on the depth by changing the frequency to control the penetration depth of the magnetic flux. In this paper, the hardened carbon steel by the different hardening temperature is examined by using the developed magnetic sensor. And we propose to measure the magnetic properties depending on the depth by changing the excitation frequency.

Metal Detection System to Reuse Woods from Wooden Houses

---Tomoharu Yasutake, **Yuji Tsuchida**, and Masato Enokizono, Oita University, Faculty of Engineering, 700 Dannoharu, Oita, 870-1192, Japan; Tomasz Chady, Szczcin University of Technology, Department of Electrical Engineering, Szczecin, Poland

---Heavy waste materials are produced by scrapping wooden houses in Japan. The main woods of scraped architectural structure such as a pole and a timber in the residence waste materials are called ‘‘used woods from houses’’. The used woods from houses can be converted into bonded woods which are worth of reusing because of high strength and high precision. However, the metallic pieces such as nails are contained in the used woods from houses. The used woods cannot be used as bonded woods unless all of the metallic pieces are removed. At present, pieces of metal in the used woods from houses can be found by using conventional metal detectors. However, it is difficult to identify the exact position and the shape of the metallic pieces by the conventional metal detectors. A metal detection system, which is able to detect the exact position and the size, is necessary for the reuse of many used woods from houses for the bonded woods.

Analysis of Shear Wave Acoustic Velocity in Duplex Stainless Steel

---**Alberto Ruiz-Marines**, Hector Carreon, and Noemí Ortiz-Lara, Universidad Michoacana de San Nicolas de Hidalgo, Instituto de Investigaciones Metalúrgicas, Edificio U.C.U., Apartado Postal 888, Morelia, Michoacan, 58000 Mexico

---We report on the ultrasonic measurements of crystallographic texture in a solution treated 2205 duplex stainless steel aged isothermally at 700°C and 900°C for different time intervals. Texture measurements were performed by shear wave birefringence. Evidence is found of changes in the velocity of the fast mode of shear wave as aging time increases while the velocity of the slow mode of shear wave remains unaffected. The corresponding microstructure of aged specimens was observed and impact toughness was measured. Comparison is made with measurements of ferrite content for the two temperatures and different aging times.

Estimation of Porosity Contents in Composites by Applying Discrete Wavelet Transform to Ultrasonic Backscattered Signal

---Ki-Bok Kim[1], **David K. Hsu[2]**, Danial J. Barnard[2], and Adam Kite[2], [1]Korea Research Institute of Standards and Science, Daejeon, Korea; [2]Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---As the use of composite materials in the aerospace industry is increasing, the development of advanced nondestructive evaluation (NDE) technique for composite materials is required. Ultrasonic quantitative NDE technique for composite materials may provide good information on manufacturing quality, material strength and perhaps useful lifetime. It is well known that the effects of porosity in composite laminates on ultrasonic attenuation and velocity can be used in the gauging of porosity content in composites. Measuring the porosity content in composite material by ultrasonic backscattering signal is a significant challenging problem in NDE of composite material. Backscattering signals are random and sensitive to volume fraction of porous and thickness of ply in composite material. Therefore the backscattering signal has various frequency bands and hence signal decomposition method is required to analyze the ultrasonic backscattering signals. In this study, the Discrete Wavelet Transform using a MATLAB decomposition algorithm was applied to ultrasonic backscattered signals acquired in porous composite laminates containing the porosity content ranges of 0 to 6%. The ultrasonic backscattered signals were decomposed into two parts: the high frequency components called “Details” and the low frequency component called “Approximation”. And then, the correlation analysis was performed between the porosity content and the peak amplitude and magnitude of peak frequency of the decomposed signal. Overall, the correlation was reasonably good. As a conclusion, the DWT technique showed good benefits for analyzing the ultrasonic backscattered signal from composite materials.

Ultrasonic Guided Waves for Health Monitoring of High Pressure Composite Tanks

---**M. Castaings** and B. Hosten, Laboratoire de Mécanique Physique, UMR CNRS 5469, 351 cours de la Libération, Université Bordeaux 1, 33400 Talence, France

---Ultrasonic guided wave modes are proposed to control the integrity of high-pressure composite tanks produced by EADS - ASTRIUM, France. The purpose is to demonstrate the potentiality of air-coupled transducers to set-up a contact-less, single-sided technique for testing the moisture content and/or the micro-cracking of carbon epoxy composite wound around a Titanium liner, as well as to detect local disbonds between the composite and the liner. First of all, a laboratory experimental system and numerical tools are used to quantify the sensitivity of specific parameters (wave numbers or attenuations) of some modes to the moisture content and to the micro-cracking in composite plate samples. These results are then used to set an experimental strategy for testing the carbon epoxy component of a high pressure composite tank, and the use of air-coupled transducers for generating-detecting sensitive wave modes is demonstrated. Secondly, the air-coupled system is employed for detecting a local disbond in the tank, simulated by a Teflon insert.---This work was supported by EADS - ASTRIUM and Conseil Regional Aquitain, France.

One-Sided Measurement Approach on Ultrasonic Beam Path Analysis in CFRP Composite Laminates

---**Kwang-Hee Im**, Department of Automotive Eng., Woosuk University,490, Hujung-ri, Samrae-up, Wanju-kun, Chonbuk, 565-701, Korea; Hak-Joon Kim and Sung-Jin Song, School of Mechanical Engineering, Sungkyunkwan University, Kyonggi-do, 440-746, Korea; David K. Hsu, Vinay Dayal, and Dan Barnard, Center for NDE, Iowa State University, Ames, Iowa 50011; Kil-Sung Lee, Yong-June Yang, and In-Young Yang, BK21 Education Center of Mould Technology for Advanced Materials & Parts, Chosun University, 375 Seosuk-dong, Dong-gu, Kwangju 501-759, Korea; Je-Woong Park, Dept. of Naval Architecture and Ocean Eng., Chosun University, Gwangju 501-759, Korea

---Composite materials are attractive for a wide range of applications due to the advantages associated with their very large strength-to-weight and stiffness-to-weight ratios. Increasingly, high performance engineering structures are being built with critical structural components made from composite materials. In particular, the importance of carbon-fiber reinforced plastics (CFRP) has been generally recognized in both space and civil aircraft industries, and CFRP composite laminates are widely used. It is very important to detect fiber orientation error in composite laminates because the layup of a CFRP composite laminates affects the properties of the laminate, including stiffness, strength and thermal behavior. As well known for ultrasonic technique for evaluating the defect of CFRP composite laminates, a pitch-catch technique was found to be more practical than normal incidence backwall echo of longitudinal wave to arbitrary flaw conditions in the composite, including fiber orientation, low level porosity, ply waviness, and cracks. The measurement depth using Rayleigh probes can be increased by increasing the separation distance of the transmitting and receiving probes. Also, with the aid of the automatic scanner, the one-sided pitch-catch probe was used to produce C-scan images for mapping out the images with beam profile amplitude. Especially pitch-catch mode was nondestructively characterized for the specimens when measuring a peak-to-peak amplitude and time-of-flight in order to build the beam profile modelling in the unidirectional CFRP composite laminates. Therefore, it is found that the variation of ultrasonic amplitude and time was consistent with results based on a calculated equation and the pitch-catch measurement was very sensitive to fiber of CFRP composite.

Modeling of Ultrasonic Wave Propagation in Composite Airframe Components

---**M. Mienczakowski**, A. K. Holmes, and R. E. Challis, The Applied Ultrasonics Laboratory, School of Electrical and Electronic Engineering, The University of Nottingham, University Park, Nottingham, NG7 2RD, United Kingdom

---A multi-layer ultrasonic bulk wave propagation model, *MLM-Propmat*, is used to simulate the reflection and transmission responses of carbon fibre reinforced panels (CFRPs). Each layer is modelled as an effective medium using conventional mixture rules for the physical properties. These have been augmented to include the frequency dependence of wave attenuation which is based on the scattering theories of Epstein and Carhart and Allegra and Hawley. A comparison between A-scan signals obtained using the model and experimental data indicated that the simulations showed stronger inter-ply resonances than were observed experimentally. A better match between model and experiment was observed when the thicknesses of the layers in the simulated composite were randomised by small variations about their mean values. The model will be used in a programme to develop techniques to detect, localise and characterise porosity in CFRPs.

NDE of FRP Wrapped Columns Using Infrared Thermography

---**Udaya B. Halabe**, Shasanka Shekhar Dutta, and Hota V. S. GangaRao, West Virginia University, Constructed Facilities Center, Department of Civil and Environmental Engineering, Morgantown, WV 26506-6103

---This paper investigates the feasibility of using Infrared Thermography (IRT) for detecting debonds in Fiber Reinforced Polymer (FRP) wrapped columns. Laboratory tests were conducted on FRP wrapped concrete cylinders of size 6'' x 12'' (152.4 mm x 304.8 mm) in which air-filled and water-filled debonds of various sizes were placed underneath the FRP wraps. Air-filled debonds were made by cutting plastic sheets into the desired sizes whereas water-filled debonds were made by filling water in custom made polyethylene pouches. Both carbon and glass fiber reinforced wraps were considered in this study. Infrared tests were conducted using a fully radiometric digital infrared camera which was successful in detecting air-filled as well as water-filled subsurface debonds. In addition to the laboratory testing, two field trips were made to Moorefield, West Virginia for detecting subsurface debonds in FRP wrapped timber piles of a railroad bridge using infrared testing. The results revealed that infrared thermography can be used as an effective nondestructive evaluation tool for detecting subsurface debonds in structural components wrapped with carbon or glass reinforced composite fabrics.

Assessment of Alkali-Silica Reaction Damage in Mortars With Nonlinear Ultrasonic Technique

---**J. Chen**, R. J. Amal, J.-Y. Kim, K. E. Kurtis and L. J. Jacobs, Georgia Institute of Technology, School of Civil & Environmental Engineering, Atlanta, GA 30332; L. J. Jacobs, Georgia Institute of Technology, Woodruff School of Mechanical Engineering, Atlanta, GA 30332

---In this work, the nonlinear ultrasonic modulation technique is employed to assess the damage state of mortar samples induced by alkali-silica reaction (ASR). Due to the nonlinear interaction of propagating waves caused by distributed micro-cracks that are agitated from its equilibrium state, the ultrasonic responses of samples produce sideband frequencies around the frequency of propagating waves. The amplitude of the sidebands depends on the amplitude of input signals and is particularly sensitive to the certain state of damage evolved in the sample. Therefore, the development of internal micro-cracks with increasing duration of exposure to aggressive conditions can be quantitatively related to the variation of external ultrasonic measurements. The ultrasonic results are compared with outputs from standard ASR expansion measurements (ASTM C 1260), and a proportionally increasing relation is found in the early stages. This agreement clearly indicates that the developed nonlinear ultrasonic method is potentially a good alternative for a more rapid and still reliable assessment of those aggregates which may exhibit alkali-reactivity. In addition, aggregates with different alkali-reactivity (i.e., low reactivity or no reactivity) were examined in a similar manner. The results indicate that the nonlinear parameter obtained from ultrasonic tests directly reflects the difference of aggregate reactivity.

Finite Element Modeling for Infrared Thermography of GFRP Bridge Decks

---Cheng L. Hing and **Udaya B. Halabe**, West Virginia University, Constructed Facilities Center, Department of Civil and Environmental Engineering, Morgantown, WV 26506-6103

---Glass Fiber Reinforced Polymer (GFRP) composite bridge decks are increasingly being used as replacements for old concrete decks and for new construction. The service performance of the GFRP bridge decks can be adversely affected by the formation of debonds between the wearing surface and the underlying bridge deck. Past experimental studies by the authors have shown the usefulness of the infrared thermography technique in detecting the subsurface debonds prior to maintenance and rehabilitation work. This paper investigates the use of finite element (FE) heat transfer modeling to predict infrared thermography images from GFRP bridge decks with subsurface debonds. The paper includes measurement of thermal properties of the GFRP bridge deck and the wearing surface, and heat transfer FE modeling of decks with debonds of different thicknesses. The results show that FE modeling can be a useful tool for predicting surface temperature profile under different heating conditions and debond sizes. Such predictions can help determine the required heat intensity and detectable debond sizes prior to experimental data acquisition in the field using an infrared camera.

Quantitative Detection of Blasting Abrasive Residue by Pulse-Thermography

---**Guenter Zenzinger**, Herbert Zisik, and Johann Fleischmann, MTU Aero Engines, Munich, Germany; Volker Carl, T-ZfP, Dinslaken, Germany

---The quality of a thermal sprayed coating depends on the subsurface condition of the ground material. Dry blasting is used for the activation and the keying of the surface. The abrasive medium, corundum (Al2O3) is used to generate the desired roughness of the ground material and ensures a good adhesion for the coating later on. Due to the blasting process inclusions from Al2O3 will occur on the surface but only a certain percentage is allowed. Nowadays the portion of the inclusions is determined at polished micro sections of sample sheet metals by counting. A new approach shows that Pulse Thermograpgy can be used for the fast detection of the corundum particles on the surface, using a microscope lens and morphological image processing tools for the analysis of the thermal images. The heat pulse, induced from Xenon flash lamps, warms up the inclusions more intensively, due to the high emissivity and the low thermal conductivity of the material. In this way the inclusions can be distinguished from the surroundings and the percentual portion can be calculated trustworthy.

Simulations to Improve Structural Defect Detection and Classification in Swiss-Cheese

---**Joona Eskelinen** and Edward Hæggström, Department of Physical Sciences, PO Box 64, FIN-00014, Helsinki, Finland; Antti Alavuotunki and Tapani Alatossava, Department of Food Technology, PO Box 66, FIN-00014, Helsinki, Finland

---Swiss-cheese production suffers from product wastage due to structural defects, which are detected only at the packing line. A NDE system, capable of reliable defect detection would allow significant savings. We continue to develop an ultrasonic NDE method for structural quality control of Swiss cheese. The project, a co-operation with two Finnish dairy-companies, strives to implement an ultrasonic device capable of on-line analysis. The device should allow reliable cheese-eye development monitoring as well as defect detection for structural quality assurance. Herein we report on a simulation study of structural defects in Swiss-cheese. Correct interpretation of backscattered real-life signals improves the probability of detection and correct classification of defects by allowing one to categorize signal features caused by different scattering mechanisms (specular, diffuse, single, multiple etc.). Hence we generated simulation phantoms of the most economically relevant structural elements prevalent in Swiss-cheese. We simulated the ultrasonic field scattered from the phantoms using transient excitation in longitudinal mode. Simulated back-scattered signals from cheese-eye, whey-nest and crack phantoms are presented and their similarity is compared to corresponding measured signals by cross-correlation. Possibility to exploit scattering response and signal characteristics (e.g. spectral content, shape) from investigated defects for on-line analysis is discussed.

Nondestructive Characterization of Controlled Wood Destruction

---**Ari Salmi**, Tuomas Hintikka, Timo Karppinen, and Edward Haeggström, Electronics Research Unit, Department of Physical Sciences, P.O.B. 64, FIN-00014 University of Helsinki; Erkki Saharinen, KCL - Keskuslaboratoriot Inc., P.O.B. 70, FIN-02151, Espoo, Finland; Edward Haeggström, Helsinki Institute of Physics, P.O.B. 64, FIN-00014 University of Helsinki

---Controlled wood destruction, which ensures quality pulp, is a crucial process step in industrial paper making. The energy consumption in this process step needs to be minimized for environmental and productivity reasons. To thoroughly understand the processes involved, we propose a theoretical relation for the efficiency (consumed electrical energy vs. deposited energy vs. generated damage) for a piston-based wood damaging setup and compare the predictions to experimental results. We launch 100 kHz longitudinal wave ultrasonic tone bursts to allow NDT in the radial direction (direction of the damage) through 10x10x2 cm3 wet spruce samples which were damaged in a controlled manner. The control parameters of the damaging device (static pre-load, impacting amplitude, frequency and time) were varied according to theoretical predictions. From ex post time-of-flight and attenuation measurements, the elastic and loss moduli which are related to the damage as a function of deposited energy into the samples were calculated. A FEM-based simulation of the damaging process is also presented and the results obtained are compared to the theoretical prediction and the experimental results.

Theoretical Modeling of GPR Reflection From Vadose Zone in Silty Soils

---**Udaya B. Halabe**, West Virginia University, Department of Civil and Environmental Engineering, Morgantown, WV 26506-6103

---Ground Penetrating Radar (GPR) is routinely being used for subsurface investigations including detection of water table and contaminant flow pattern. Past laboratory studies on water table detection in silty soils has shown that GPR actually detects reflection from within the unsaturated capillary (vadose) zone, which is just above the water table. While this phenomenon has been observed from experimental studies, no attempt has been made so far to explain the theoretical basis for the occurrence of GPR reflection within the vadose zone above the water table and not at the level of the actual water table. Understanding this phenomenon from a theoretical stand point requires modeling of GPR reflection from the vadose zone where the moisture content varies with depth. This paper describes the theoretical model which includes discretization of the vadose zone into a number of thin layers with different moisture contents. The model also includes the dry soil above the vadose zone and the underlying fully saturated zone. The GPR waveforms are generated from this model utilizing frequency domain synthesis which accounts for all the multiple reflections within the thin layers. These synthetic waveforms have been used to explain the phenomenon of GPR reflection from the vadose zone.

Optimization of High Sensitivity Ultrasonic Scanning

---**Thomas N. Claytor**, Los Alamos National Laboratory, MS C914, Los Alamos, NM 87544; Robert K. Torney, Stanford University, Stanford, CA 94305

---In order to improve image quality, ultrasonic imaging systems are gradually migrating to the use of high speed digitizer boards capable of 12-bit (or greater) amplitude resolution at speeds of 400MS/s or greater. Finer amplitude resolution will reveal more about materials and assemblies than could be detected previously; however, various effects (such as pulser output noise and amplitude wander) that were not always appreciated or apparent with 8 bit digitizing systems are now noticeable. These effects, if not recognized and minimized, can severely limit the full capability of these boards to detect small amplitude or subtle time variations. In this report, we test several digitizer boards, from three suppliers, suitable for use in ultrasonic imaging systems. Using Winspect ultrasonic scanning software we have measured the trigger jitter, the amplitude variability, and the intrinsic noise level of these boards as a function of several variables (for instance, output pulse width and averaging) important for ultrasonic imaging. Our results have allowed us to optimize image quality given various constraints inherent in a total image acquisition system. An ultrasonic scan of an item with a low contrast feature is shown to illustrate the clearly visible difference between an image obtained with an 8 bit board and a 12 bit board.

Analysis of Round Robin Test for Ultrasonic Thickness Measurement of Wall Thinned Pipe in Nuclear Power Plant

---**Dae-Hoon Lee**, Seung-Joon Lee, and Joon-Hyun Lee, Pusan National University, Department of Mechanical Design Engineering, Busan, Korea

---It is well recognized that one of the most serious problems on the maintenance of pisystem ping in Nuclear Power Plants (NPPs) is the wall thinning of carbon steel pipe components. The objective of this research is to verify confidence of wall thinning measurement system by conducting Round Robin Test (RRT). Artificial corrosion flaw of varying depths 20, 40, 60 or 80% of nominal thickness were machined on the specimen with 2, 4, 6, 8 or 12 inch nominal diameter for all types of pipe, elbow, tee, and reducer. To compare with artificial mock-up specimen, 4 types of field specimens with natural corrosion used in NPPs were prepared. The RRT was preformed by 4 teams consisting of 3 members per team from 3 certified inspection companies. 23 specimens with different size and shape of pipe were used according to standard practice in RRT. The gage R&R analysis was introduced for each sigma quality level, so that repeatability and reproducibility can be estimated from RRT results. In addition, confidence intervals of thickness measurement system were obtained by analyzing bias and linearity.

Session 30

SESSION 30

PERSPECTIVES ON NDE EDUCATION
Ballroom A

3:30 PM **Speakers/Panelists:**

M. Dubois
T. Dunhill
D. Fei
X. Han
T. Jayakumar
A. Lavrentyev
E. Lindgren

FRIDAY

Session 31

SESSION 31

UT APPLICATIONS (TIME REVERSAL, NON-LINEAR UT, MEDICAL APPLICATIONS, AND IRREGULAR GEOMETRIES)

L. Jacobs, Chairperson
Ballroom A

8:30 AM **Improving Focal Determination of Time Reversed Acoustic Signals**
---**T. J. Ulrich**, B. E. Anderson, and M. Griffa, Los Alamos National Laboratory, EES-11, MS D443, Los Alamos, NM 87545

8:50 AM **Selective Source Reduction to Identify Masked Smaller Sources Using Time Reversal Acoustics**
---**B. E. Anderson**, T. J. Ulrich, M. Griffa, and P. A. Johnson, Los Alamos National Laboratory, Geophysics Group, EES-11, MS D443, Los Alamos, NM 87545; M. Scalerandi and A. S. Gliozzi, Politecnico di Torino, Physics Department, Torino, Italy

9:10 AM **Non-Linear Ultrasonic to Assess Localized Plastic Deformation During High Cycle Fatigue**
---**S. P. Sagar**, A. Metya, N. Parida, R. N. Ghosh, National Metallurgical Laboratory, Materials Science & Technology Division, Burmamines, Jamshedpur 831 007, Jharkhand, India

9:30 AM **Static Displacement Component and Its Significance in Nonlinear Ultrasonic Measurements**
---K. Thimmavajjula, E. Kannan, and **K. Balasubramaniam**, Center for Nondestructive Evaluation and Department of Mechanical Engineering, Indian Institute of Technology Madras, Chennai-600036, India

9:50 AM **A Rayleigh Wave Technique to Measure the Absolute Acoustic Nonlinearity Parameter of Materials**
---**J.-Y. Kim**, Georgia Institute of Technology, Civil and Environmental Engineering, Atlanta, GA 30332; G. Shui, Beijing Jiaotong University, Institute of Mechanics, Beijing, China; L. J. Jacobs, Georgia Institute of Technology, Civil and Environmental Engineering, Atlanta, GA 30332

10:10 AM ***Break***

10:30 AM **Ultrasonic Arrays: A Comparison Between Medical and NDE Requirements**
---**B. W. Drinkwater** and P. D. Wilcox, RCNDE, Department of Mechanical Engineering, University of Bristol, Bristol, BS8 1TR, United Kingdom

10:50 AM **Ultrasonic Imaging Techniques for Early Breast Cancer Detection**
---**T. N. Claytor**, J. D. Marquez, L. Huang, and B. Nadler, Los Alamos National Laboratory, MS C914, Los Alamos, NM 87544; N. R. Goulding, New Mexico Technology, Computer Science Department, Socorro, NM 87801; E. M. Prewitt, Purdue University, Mechanical Engineering Department, W. Lafayette, IN 47907

11:10 AM **Complex Source and Radiation Behaviors of Small Elements of Linear and Matrix Flexible Ultrasonic Phased-Array Transducers**
---V. Amory and **A. Lhémery**, CEA, LIST, Laboratoire de Simulation et de Modélisation, Gif-sur-Yvette, France

11:30 AM **Characterization of Sub-Wavelength Defects in Solids with the DORT Method**
---**S. Robert**, J. G. Minonzio, D. Clorennec, and C. Prada, Laboratoire Ondes et Acoustique, Université Denis Diderot, UMR CNRS 7587, ESPCI, Paris, France

11:50 AM **Parametric Studies of Wave Propagation Through Imperfect Interfaces Using Micromechanics Based Effective Stiffness**
---**A. Misra** and O. Marangos, University of Missouri-Kansas City, Department of Civil Engineering, Kansas City, MO 64110

12:10 PM ***Adjourn***

Improving Focal Determination of Time Reversed Acoustic Signals

---**Timothy J. Ulrich**, Brian E. Anderson, and Michele Griffa, Los Alamos National Laboratory, EES-11, MS D443, Los Alamos, NM 87545

---Recent studies have been conducted which employ time reversed acoustics for locating damage/cracks in solids. To accomplish this task it is necessary to accurately determine focal events from the time reversal process. Introduced in this paper is a new method for determining and investigating focal events of time reversed acoustic signals. This method employs the temporally symmetric nature of focused signals as the time reversed acoustic focused signals are akin to the autocorrelation function of the forward received signals. Contrasting this symmetry with the degree of asymmetry at regions away from true focal events provides details about the original source that cannot be seen when using the standard maximum amplitude method for determining focal events.

Selective Source Reduction to Identify Masked Smaller Sources Using Time Reversal Acoustics

---**Brian E. Anderson**, T.J. Ulrich, Michele Griffa, and Paul A. Johnson, Los Alamos National Laboratory, Geophysics Group, EES-11, MS D443, Los Alamos, NM 87545; Marco Scalerandi and Antonio S. Gliozzi, Politecnico di Torino, Physics Department, Torino, Italy

---This paper introduces a method to selectively reducing a large time reverse focal event thereby providing the potential to illuminate a smaller time reverse focal event which has been masked by the larger time reverse focal event. Experimental results which demonstrate the method, and a discussion of experimental considerations and limitations in the method, will be given. Results are presented from measurements conducted on two different solid samples, aluminum and doped silica glass. The method is demonstrated for two elastic wave pulses emitted simultaneously from two spatially separated sources of differing amplitudes. Results show that even with a larger source which is up to 13 times greater than a smaller source that more information can still be obtained about the masked smaller source, using the proposed method. The measurements show that the source reduction method's limitations are chiefly due to imperfect reconstruction of the source function in the time reverse focal signal. This method may be used to improve upon the abilities of time reversal acoustics in nondestructive evaluation applications to identify sample characteristics such as cracks which may be considered as elastic wave scattering sources.

Non-Linear Ultrasonic to Assess Localized Plastic Deformation During High Cycle Fatigue

---**Sarmishtha Palit Sagar**, Avijit Metya, Narayan Parida, and Rabindra Nath Ghosh, National Metallurgical Laboratory, Materials Science & Technology Division, Burmamines, Jamshedpur 831 007, Jharkhand, India

---Non-linear ultrasonic (NLU) is coming up as a potential non-destructive technique for materials damage and degradation study especially for fatigue damage assessment. When a purely sinusoidal acoustic wave propagates through a degraded material, it distorts and generates harmonics of the fundamental waveform because of the nonlinearity of the propagation medium. A quantitative measure of the wave distortion is the 'acoustic' nonlinearity parameter. This nonlinearity parameter is proportional to the ratio of the amplitude of the 2nd harmonic to the square of the amplitude of the fundamental of the transmitted ultrasonic signal. In the present work our aim is to apply the NLU to detect the location of maximum localized plastic deformation occurred during fatigue which could be useful for fatigue damage assessment of industrial components to avoid catastrophic failure. We have chosen polycrystalline copper for high cycle fatigue (HCF) study as the microstructure of the polycrystalline copper has been well established during fatigue. In this work we have applied both conventional ultrasonic and NLU techniques to evaluate the fatigue hardening and softening in polycrystalline copper during HCF. For conventional ultrasonic, longitudinal velocity and attenuation coefficients have been determined. It has been observed that the position of maximum localized plastic deformation can not be detected by longitudinal velocity and attenuation coefficients , where as the NLU parameter detects the same at the stage of only 30% of damage corresponds to the total fatigue life of the material. The result of NLU has also been correlated with the hardness during fatigue. This work reveals the potential of NLU to assess the localized plastic deformation during high cycle fatigue much earlier to the failure.

Static Displacement Component and Its Significance in Nonlinear Ultrasonic Measurements

---Karthik Thimmavajjula, Elankumaran Kannan, and **Krishnan Balasubramaniam**, Center for Nondestructive Evaluation and Department of Mechanical Engineering, Indian Institute of Technology Madras, Chennai-600036, India

---In the recent times nonlinear ultrasonics is being extensively studied to explore its viability to discern early material damage. The propagation of an ultrasonic wave through a damaged material leads to the generation of the harmonics of the original wave. The second harmonic generated quantifies the amount of nonlinearity present in the material and is related to the third order elastic constants of the material. However if the frequency spectrum of the transmitted wave is examined we find that there is an induced static displacement component due to the nonlinearities present in the material. This static displacement component is also related to the third order elastic constants of the material. The present paper presents a numerical simulation of propagation of an ultrasonic wave through a damaged material with focus on the generation of a static displacement component and suggests a simplified technique for measuring it. Demonstrating the fact that an asymmetry in the stress strain relationship of the material is required for the generation of a static displacement component, this paper explores its dependence on various parameters like the input amplitude, input frequency, propagation distance and the nonlinearity parameters of the material. The numerical simulations are validated against existing theories for generation of static displacement.

A Rayleigh Wave Technique to Measure the Absolute Acoustic Nonlinearity Parameter of Materials

---**Jin-Yeon Kim**[1], [1]Georgia Institute of Technology, Civil and Environmental Engineering, Atlanta, GA 30332; Guoshuang Shui, Beijing Jiaotong University, Institute of Mechanics, Beijing, China; Laurence J. Jacobs[1], Georgia Institute of Technology, Civil and Environmental Engineering, Atlanta, GA 30332

---Nonlinear ultrasonic techniques have shown great potential for evaluating accumulated damage early in the fatigue life, and ultimately for predicting remaining lifetime of a structural component. The acoustic nonlinearity parameter, a direct measure of the accumulated fatigue damage, is determined from the second harmonic amplitude in finite amplitude ultrasonic waves transmitted through the material. An absolute determination of the acoustic nonlinear is notoriously difficult for numerous reasons. In this paper, a new experimental technique based on the Rayleigh surface waves is presented for determining the absolute acoustic nonlinearity parameter of a material. Rayleigh waves are efficiently generated in a material specimen by exciting at its edge, and the surface normal velocity of the propagating Rayleigh waves is measured with a laser interferometer system. The high efficiency of the excitation method allows us to drive the transmitting piezoelectric transducer at as low as 60 Vpp or below, and thus to avoid the inherent harmonic distortion from the transducer. The absolute acoustic nonlinearity parameter is then determined from the measured magnitudes of the fundamental and second harmonic surface normal velocities. This technique is applied to determine the acoustic nonlinearity parameters of aluminum alloys 2024 and 6061; the results are compared well with those available in the literature. The present technique is especially well-suited for relatively thin components, and much simpler and efficient than the traditional longitudinal wave technique.

Ultrasonic Arrays: A Comparison Between Medical and NDE Requirements

---**Bruce W. Drinkwater** and Paul D. Wilcox, RCNDE, Department of Mechanical Engineering, University of Bristol, Bristol, BS8 1TR, United Kingdom

---Ultrasonic arrays have been used for NDE applications since the 1980s but their use for medical imaging goes back to the 1950s. Historically, the medical market has been the main driver in the development of array transducers and array instrumentation technology, with the NDE sector adapting the technology to its own applications. This paper addresses the question of designing and optimising arrays and image processing specifically for NDE applications. There are two key differences between medical and NDE array applications. Firstly, in medical applications the target is non-stationary and it is therefore essential to obtain a high image frame rate both to avoid motion blur and to observe phenomena such as the human heartbeat. Hence while a high frame rate may be desirable in NDE it is a necessity in medicine. A second difference is that NDE images are dominated by signals from a relatively small number of strong scatterers and there is a high acoustic contrast between defects (e.g. cracks) and the parent material. In comparison, medical images are characterised by low amplitude scattering, observable throughout an image. Taken together these differences mean that NDE requirements are not best met by simple transfer of medical technology. For example, the concept of capturing and post processing the full matrix of raw data (i.e. the time-trace from every possible transmitter receiver combination) is appealing in NDE and too slow for the medical field. Using this approach, the best possible imaging resolution can be obtained by focussing an array on every imaging point in both transmission and reception. Improved reflector characterisation can be achieved by considering the array as a number of sub-apertures to determine reflector orientation and shape. The full matrix of data also provides the information necessary to apply super-resolution imaging algorithms that allow the wavelength diffraction limit for resolution to be overcome.

Ultrasonic Imaging Techniques for Early Breast Cancer Detection

---**Thomas N. Claytor**, Joel D. Marquez, Lianjie Huang, and Brett Nadler, Los Alamos National Laboratory, MS C914, Los Alamos, NM 87544; Nathan R. Goulding, New Mexico Tech., Computer Science Department, Socorro, NM 87801; Emily M. Prewitt, Purdue University, Mechanical Engineering Department, W. Lafayette, IN 47907

---Improving the resolution and specificity of current ultrasonic imaging technology can enhance its relevance to detection of early-stage breast cancers. Ultrasonic evaluation of breast lesions is desirable because it is quick, inexpensive, and does not expose the patient to potentially harmful ionizing radiation. Improved image quality and resolution enables earlier detection and more accurate diagnoses of tumors, thus reducing the number of biopsies performed, increasing treatment options, and lowering mortality, morbidity, and remission percentages. In this work, a novel ultrasonic imaging reconstruction method that exploits straight-ray migration is described. This technique, commonly used in seismic imaging, accounts for source-detector scattering more accurately than standard ultrasonic approaches, thus providing superior image resolution. A breast phantom with various inclusions is imaged using a pulse-echo approach. The data are processed using the ultrasonic migration method and results are compared to standard linear ultrasound and to x-ray computed tomography (CT) scans. For an ultrasonic frequency of 2.25 MHz, imaged inclusions and features of approximately 1mm are resolved, although better resolution is expected with minor modifications. Refinement of this application using other imaging techniques such as time-reversal mirrors (TRM), synthetic aperture focusing technique (SAFT), decomposition of the time reversal operator (DORT), and factorization methods is also briefly discussed.

Complex Source and Radiation Behaviors of Small Elements of Linear and Matrix Flexible Ultrasonic Phased-Array Transducers

---Vincent Amory and **Alain Lhémery**, CEA, LIST, Laboratoire de Simulation et de Modélisation, Gif-sur-Yvette, France

---Angle-beam contact inspection of geometrically irregular components is problematical: the non-adjustment of transducer shoes to irregular surfaces causes huge aberrations. Flexible phased-arrays (FPAs) for maximizing contact are developed at CEA. They are driven by delay laws to compensate for irregularities and radiate beams of chosen characteristics (L or T beams in a given direction). Linear arrays or 2D matrices are designed depending on symmetries of component geometry. Optimizing FPA for a given application requires dedicated simulation tools. The behavior of a small element (sides comparable to thickness) radiating through a thin coupling layer is computed by FEM. Fields at the component surface and radiated farther are observed, the latter being successfully compared with experiments. Computational efforts for one element make the optimization of a full FPA (tens of elements) impossible by FEM. A model is proposed to efficiently compute radiation by FPA. Each element is modeled as surface distributions of time-varying nonuniform normal and tangential stresses (computed once by FEM). Exact and asymptotic formulas for Lamb's problem are used as time and space convolution kernels for the radiation of longitudinal, transverse and head waves; the latter contribution is of primary importance for angle beam T-wave inspections while negligible for L-wave.

Characterization of Sub-Wavelength Defects in Solids with the DORT Method

---**Sébastien Robert**, Jean-Gabriel Minonzio, Dominique Clorennec, and Claire Prada, Laboratoire Ondes et Acoustique, Université Denis Diderot, UMR CNRS 7587, ESPCI, Paris, France

---A nondestructive evaluation method using elastic waves and large arrays of transducers is proposed to characterize defects of cylindrical geometry and sub-wavelength diameter. The method, well-known as DORT method (French acronym for 'Décomposition de l'Opérateur de Retournement Temporel'), derives from the mathematical analysis of the time reversal process and is based on the singular value decomposition of the array response matrix. In the present work, experiments performed on an aluminum block with air-filled holes of different diameters demonstrate the possibility to estimate the size of a defect by analyzing the singular value distribution and the singular vectors. These results, confirmed by theoretical results and numerical simulations, offer a new perspective towards solution in the inverse problem and a complementary approach to the classical phased array imaging techniques limited by classical Rayleigh resolution limit. Other numerical results performed for different kinds of defects (holes with a circular or rectangular cross-section, cracks) will also be shown bringing out the possibility to discriminate defects of different geometries.

Parametric Studies of Wave Propagation Through Imperfect Interfaces Using Micromechanics Based Effective Stiffness

---**Anil Misra** and Orestes Marangos, University of Missouri-Kansas City, Department of Civil Engineering, Kansas City, MO 64110

---Imperfectly bonded interface models have been widely used to investigate the plane wave propagation through contact between two rough solids. In this model, the contact behavior is represented through effective interface stiffnesses. The authors have developed a micromechanical methodology for modeling contact behavior that incorporates the effects of surface roughness, anisotropy, existing stress conditions and rate-dependent asperity contact force laws. This methodology is applied to determine complex-valued effective normal and shear stiffnesses of interfaces. We find that the effective normal stiffness is significantly affected by the interface normal stress and the initial closure. We also find that the effective shear stiffness varies nonlinearly with roughness and becomes anisotropic with loading. Moreover, the effective normal and shear stiffness are coupled and the coupling stiffness varies with shear loading. These findings have critical implication on the interpretation of wave propagation through rough interfaces. We find that the amplitudes of the reflected and transmitted waves are significantly influenced by the interface roughness, stresses and anisotropy. We also find that the frequency dependence of reflected and transmitted wave amplitudes is significantly different for rate-dependent and rate-independent interfaces. The micromechanical model may thus be used to elucidate the results of wave transmission through rough interfaces.

Session 32

SESSION 32
MATERIAL PROPERTIES
J. Harris, Chairperson
Ballroom D

8:30 AM **Measurement and Modeling of Ultrasonic Pitch/Catch Grain Noise**
---**F. J. Margetan**, T. A. Gray, and R. B. Thompson, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

8:50 AM **Evaluation of Isothermal Aged 9Cr-2W Steel Using Ultrasonic Method**
---**D.-Y. Kim**, H.-J. Kim, S.-J. Song, B.-J. Kim, and B.-S. Lim, School of Mechanical Engineering, Sungkyunkwan University, 300 Chunchun-dong, Jangan-gu, Suwon, Gyeonggi-do 440-746, Korea

9:10 AM **Ultrasonic Characterization of Austenitic Stainless Steels**
---**T. Jayakumar**, A. Kumar, and B. Raj, Indira Gandhi Center for Atomic Research, Non Destructive Evaluation Division, Kalpakkam, Tamil Nadu, India

9:30 AM **Electromagnetic Acoustic Resonance to Assess Creep Damage in a Martensitic Stainless Steel**
---**T. Ohtani**, Shonan Institute of Technology, Department of Mechanical Systems Engineering, 1-1-25 Tsujodo-Nishikaigan, Fujisawa, Kanagawa 251-8511

9:50 AM **Magnetic Evaluation of Aging Behavior in Modified 9Cr-1Mo Steel**
---J. N. Mohapatra, A. K. Panda, and **A. Mitra**, National Metallurgical Laboratory, Jamshedpur-831007, India

10:10 AM ***Break***

10:30 AM **Post-Irradiation Annealing Effect on Hardness, Microstructure and Magnetic Properties of Reactor Pressure Vessel Steel**
---**Y. Kamada**, H. Kikuchi, S. Kobayashi, K. Ara, and S. Takahashi, Iwate University, Faculty of Engineering, NDE&Science Research Center, Morioka, Japan; H. Watanabe and N. Yoshida, Kyusyu University, Research Institute for Applied Mechanics, Kasuga, Japan; N. Ebine and M. Suzuki, Japan Atomic Energy Agency, Tokai, Japan

10:50 AM **Application of Continuum Damage Mechanics to Determine Fracture Toughness of Ductile Materials Through Ball Indentation Technique**
---**G. Das**, S. Tarafder, S. Prasad, S. Ghosh, M. Das, and R. N. Ghosh, National Metallurgical Laboratory, Materials Science & Technology Division, Burma Mines, Jamshedpur, Jharkhand, India

11:10 AM **Influence of the Precipitation in Nimonic-263 by Ultrasonic and Ball Indentation Techniques**
---**G. V. S. Murthy**, G. Sabitha, D. Mouasami, D. Goutam, R. N. Ghosh, Materials Science and Technology Division, National Metallurgical Laboratory, Jamshedpur-831007, Jharkhand, India

11:30 AM ***Adjourn***

Measurement and Modeling of Ultrasonic Pitch/Catch Grain Noise

---**Frank J. Margetan**, Timothy A. Gray, and R. Bruce Thompson, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---Ultrasonic grain noise arises from the scattering of sound waves by microstructural boundaries, and can limit the detection of weakly-reflecting internal defects in metals. In some cases of practical interest, such as focused-transducer inspections of aircraft engine components, so-called “single scattering” or “independent scatterer” models have proven to be accurate in predicting grain noise characteristics. In pulse/echo inspections it is difficult to experimentally assess the relative contributions of single scattering and multiple scattering, because both can generally contribute to the backscattered noise seen at any given observation time. For pitch/catch inspections, however, it is relatively easy to construct inspection geometries for which single-scattered noise should be insignificant, and hence any observed noise is presumably due to multiple scattering. This concept is demonstrated using pitch/catch shear-wave measurements performed on a well-characterized stainless-steel specimen. The inspection geometry allows us to control the overlap volume of the intersecting radiation fields of the two transducers. As we proceed from maximally overlapping fields to zero overlap, the single-scattering contribution to the observed grain noise is expected to decrease. Measurements are compared to the predictions of a single-scatterer model, and the relative contributions of single and multiple scattering to the observed grain noise are estimated.---This work was sponsored by Pratt & Whitney, a United Technologies Company.

Evaluation of Isothermal Aged 9Cr-2W Steel Using Ultrasonic Method

---**Dong-Yeol Kim**, Hak-Joon Kim, Sung-Jin Song, Bum-Joon Kim, and Byeong-Soo Lim, School of Mechanical Engineering, Sungkyunkwan University, 300 Chunchun-dong, Jangan-gu, Suwon, Gyeonggi-do 440-746, Korea

---9Cr-2W steel is widely used as structural materials of high temperature and pressure components in power plant. These components can be degraded as increasing their operation time. Since isothermal aged 9Cr-2W steel is subject to precipitation or cavities between grain boundaries, it is one of major cause of early breakage of these components. Therefore, nondestructive evaluation of creep damage is necessary to insure stability of power plants. So, in this study, we evaluate isothermal aged 9Cr-2W steel specimens using ultrasound because ultrasonic method can detect variation of micro structures and very small inclusions. These specimens were prepared by isothermal aging at 600^{o}C with variation aging time. we measure attenuations and velocities experimentally using a high frequency ultrasonic transducer. From the measured data, we calculate relation between attenuations and area of precipitation and velocities and hardness, respectively. And then, we will show experimental results obtain from the isothermal aged 9Cr-2W steel and relation between ultrasound and isothermal damage.

Ultrasonic Characterization of Austenitic Stainless Steels

---**Tammana Jayakumar**, Anish Kumar, and Baldev Raj, Indira Gandhi Center for Atomic Research, Non Destructive Evaluation Division, Kalpakkam, Tamil Nadu, India

---Studies undertaken towards development and application of ultrasonic methodologies for characterization of grain size, texture, degree of recrystallization, deformation and dynamic recrystallization behavior during hot forging process in austenitic steels have been discussed. Various methodologies based on different ultrasonic parameters, such as attenuation, relative attenuation, longitudinal, shear and surface wave velocities and spectral analysis have been developed for grain size measurement in AISI type 316 austenitic stainless steel. A thickness independent ultrasonic velocity based ratio parameter has been developed to estimate the degree of recrystallization in 15Cr-15Ni-2.2Mo-Ti modified austenitic stainless steel (alloy D9). Ultrasonic velocity measurements have been found to be useful for assessment of the degree of cold work and for determination of texture coefficients in AISI type 304 stainless steel. Ultrasonic C-scan based methodology has been developed for imaging of grain size variations in thermomechanically processed D9 alloy to different stain levels at 1273 K. Various deformation zones, including dynamic recrystallization in a shear band of the specimen forged to 0.5 strain, could be imaged based on the amplitude of the ultrasonic first back wall echo.

Electromagnetic Acoustic Resonance to Assess Creep Damage in a Martensitic Stainless Steel

---**Toshihiro Ohtani**, Shonan Institute of Technology, Department of Mechanical Systems Engineering, 1-1-25 Tsujodo-Nishikaigan, Fujisawa, Kanagawa 251-8511

---The microstructure evolution of a martensitic stainless steel, Type-403, subjected to tensile creep at 873K has been studies by monitoring of shear-wave attenuation and velocity using electromagnetic acoustic resonance (EMAR). The study revealed an attenuation peak at around 20% of the creep life, independent of the applied stress. This novel phenomenon is interpreted as a result of microstructural changes, especially including dislocation structure. This interpretation is supported by TEM observations of dislocation structure. The relationship between attenuation change and microstructure evolution can be explained with the string model. The study results have suggested that EMAR possesses a potential to assess the progress of creep damage and predict the remaining creep life of metals.

Magnetic Evaluation of Aging Behavior in Modified 9Cr-1Mo Steel

---J. N. Mohapatra, A. K. Panda, and **A. Mitra**, National Metallurgical Laboratory, Jamshedpur-831007, India

---Modified 9Cr-1Mo steels are used in petrochemical and power plants owing to their high temperature strength, good corrosion and creep resistance properties. As Cr-Mo steel is ferromagnetic and as magnetic properties are very much sensitive to microstructural changes, magnetic technique has been utilized in the present work to evaluate the degradation behavior. The investigation was carried out on modified 9Cr-1Mo steel. To investigate the ageing behavior, the materials were exposed to 600oC for different durations. The structure sensitive magnetic properties like coercivity and remanence were correlated with the microstructures obtained by Transmission Electron Microscopy (TEM). In the initial ageing stage, material exhibited magnetic softening with a decrease in coercivity and remanence that is attributed to stress relaxation. However, with further increase in the duration of ageing, there was subsequent magnetic hardening (increase in coercivity and remanence) which was due to the precipitation of MX type fine carbides, secondary carbides and new phases. When there was extended ageing, there was migration of carbides towards the grain boundaries and also coarsening of existing carbides. These large carbides decrease the pinning density towards magnetic domain wall motion. The investigation throws light on the use of non-destructive magnetic hysteresis loop technique for assessment of degradation in thermal power components made of modified CrMo steels.

Post-Irradiation Annealing Effect on Hardness, Microstructure and Magnetic Properties of Reactor Pressure Vessel Steel

---**Yasuhiro Kamada**, Hiroaki Kikuchi, Satoru Kobayashi, Katsuyuki Ara, and Seiki Takahashi, Iwate University, Faculty of Engineering, NDE&Science Research Center, Morioka, Japan; Hideo Watanabe and Naoaki Yoshida, Kyusyu University, Research Institute for Applied Mechanics, Kasuga, Japan; Noriya Ebine and Masahide Suzuki, Japan Atomic Energy Agency, Tokai, Japan

---Development of nondestructive evaluation (NDE) technique on neutron irradiation embrittlement of reactor pressure vessel (RPV) steels is a worldwide interest because of the life extension of present nuclear power plants. Magnetic measurement is one of the promising NDE techniques because of the sensitiveness to various types of lattice defect. In order to establish the technique, it is important to clarify the relations between irradiation microstructure, and mechanical and magnetic properties. It is well known that neutron irradiation causes hardening of RPV steels and the hardening recovers by post-irradiation annealing (PIA). Hence, PIA experiment is useful for understanding of the evolution of material properties related to the irradiation effects. In this study, A533B-type RPV steel, neutron irradiated up to 5*10^23 n/m^2 (E>1MeV) at 563K, was isochronal annealed at temperature ranges from 663 to 943 at 70K interval for 0.5h. Vickers hardness and BH loop measurements were carried out after each PIA, and transmission electron microscopy observation was performed for clarification of microstructural evolution. Hardness recovered and coercive force decreased at around 703K. These behaviors can be explained by the disappearance of irradiation lattice defects due to the PIA.

Application of Continuum Damage Mechanics to Determine Fracture Toughness of Ductile Materials through Ball Indentation Technique

---**G. Das**, S. Tarafder, Shiva Prasad, Sabita Ghosh, Mousumi Das, and R. N. Ghosh, National Metallurgical Laboratory, Materials Science & Technology Division, Burma Mines, Jamshedpur, Jharkhand, India

---The standard methods for determining fracture toughness (KJC) of ductile materials are involved complicated test procedure and the test materials should be adequate. Therefore, determination of KJC either through small amount of test specimen or in-situ has a great importance. In the present work an advanced ball indentation technique (BIT) on the basis of continuum damage mechanics (CDM) has been applied to determine mechanical properties and KJC. The basic principal of the BIT is multiple indentations by a spherical indenter at the same test location with intermediate partial unloading. Under compressive loading the material does not undergo necking and so does not attain instability condition. Hence the mechanical properties were determined in an indirect way. The indentation energy to fracture (IEF) can be correlated with energy required to fracture in ductile materials. Therefore, it is necessary to determine the indentation depth corresponding to probable fracture. The damage variable due to formation of voids surrounding the indentation can be correlated with the elastic modulus of the damaged and undamaged materials and can be used to determine IEF and subsequently the KJC. Mechanical properties were determined for SS304 LN and SA333 steels. The BIT obtained results were verified by conventional test results and are agreed well.

Influence of the Precipitation in Nimonic-263 by Ultrasonic and Ball Indentation Techniques

---**G.V.S Murthy**, Sabitha Ghosh, Mouasami Das, Goutam Das, R. N. Ghosh, Materials Science and Technology Division, National Metallurgical Laboratory, Jamshedpur-831007, Jharkhand, India

---The microstructure of a poly crystalline material is a key factor in its technological applications as it determines a wide variety of properties including mechanical strength, toughness, corrosion resistance and hardness. Precipitation takes place during processing and on prolonged exposure to service at high temperatures. Consequently, knowledge about the precipitation phases and their influence on the various properties is of fundamental interest not only for its intrinsic interest, but also for its technological significance. Ultrasonic testing is being looked upon as an alternative technique for microstructural characterization, and the use of various small specimen techniques to determine the mechanical properties holds great promise. The purpose of the present investigation is to explore the possibility of using ultrasonic velocity measurements and ball indentation techniques for studying and correlating them for a complete characterization of the precipitation behavior in a nickel based super alloy Nimonic-263. In the present study, a set of Nimonic 263 specimens of dimensions 20mmx20mmx10mm was solutionised at 1423K for 1 hour followed by quenching. Ageing was carried out at 923K for 1,2,4,6 and 8 hours and at 1073K for times varying from 1 hour to 75 hours. Ultrasonic velocity measurements were carried out using a 15MHz longitudinal and 5MHz shear wave transducers. Ball indentation tests have been carried out in the laboratory scale set-up on the same specimens. A table top mechanical testing machine of 10kN capacity with a 5kN load cell has been used. The present study reveals that both these techniques can be used for monitoring the strengthening process as a result of the precipitation.

Session 33

SESSION 33

NEW TECHNIQUES AND SYSTEMS

J. Bamberg, Chairperson

Ballroom B

8:30 AM **EMAT Measurements of In- and Out-of-Plane Ultrasonic Signals**
---**R. S. Edwards**, S. Dixon, Y. Fan, and X. Jian, University of Warwick, Department of Physics, Coventry CV4 7AL, United Kingdom

8:50 AM **The Correspondence Between Elastic and Plastic Anisotropy in Nominally Pure and AA3104 Aluminum Sheets**
---**J. Morrison**, S. M. Dixon, M. D. G. Potter, and S. Essex, University of Warwick, Department of Physics, Coventry, West Midlands, CV4 7AL, United Kingdom; C. Davis, The University of Birmingham, School of Engineering, Metallurgy and Materials, Birmingham, B15 2TT, United Kingdom

9:10 AM **Optimal Probe Arrangement for Ultrasonic Inspection of Turbine Engine Spin Test Disks**
---**J. Bamberg**, MTU Aero Engines GmbH, 80995 Munich, Germany; M. Spies, Fraunhofer IZFP, Physical Basics Department, 66123 Saarbruecken, Germany

9:30 AM **Integration of Different Scanning Modalities for Real-Time Dual-Channel Ultrasonic Inspection of Aircraft Structures**
---**I. Komsky** and S. Krishnaswamy, Northwestern University, Center for Quality Engineering and Failure Prevention, Evanston, IL 60208; B. Lasser, Imperium Inc., Silver Spring, MD 20903

9:50 AM **MOSAIC: A Scalable Reconfigurable 2D Array System for NDE**
---**S. Triger** and J. Wallace, University of Glasgow, Microsystem Technology Group, Department of Electronic & Electrical Engineering, Glasgow, Scotland, United Kingdom; L. Wang, Formerly of Microsystem Technology Group, University of Glasgow, now at Imperial College London, London, United Kingdom; S. Cochran, J.-F. Saillant, and F. Afroukh, University of Paisley, Microscale Sensors Group, School of Engineering, Paisley, Scotland, United Kingdom; D. R. S. Cumming, University of Glasgow, Microsystem Technology Group, Department of Electronic & Electrical Engineering, Glasgow, Scotland, United Kingdom

10:10 AM ***Break***

10:30 AM **Prototype Demonstrator for an Inspection Qualification Multi-Agent System (IQMAS)**
---**N. McLean**, A. Gachagan, and G. Hayward, Centre for Ultrasonic Engineering, University of Strathclyde, Glasgow, United Kingdom; S. McArthur, Institute for Energy and the Environment, University of Strathclyde, Glasgow, United Kingdom

10:50 AM **An Advanced Flaw-Response Modelling Approach for Inspection Qualification Using A Multi-Agent System Software Platform**
---**J. P. McKenna**, A. Gachagan, and G. Hayward, Centre for Ultrasonic Engineering, Department of Electronic and Electrical Engineering, University of Strathclyde, Glasgow, G1 1XW, United Kingdom; S. McArthur, Institute for Energy and Environment, Department of Electronic and Electrical Engineering, University of Strathclyde, Glasgow, G1 1XW, United Kingdom

11:10 AM **An Integrated Ultrasonic Correlation Spectrometer**
---**A. P. Y. Phang**, R. E. Challis, V. G. Ivchenko, and A. N. Kalashnikov, The University of Nottingham, School of Electrical and Electronic Engineering, Nottingham, Nottinghamshire, NG7 2RD, United Kingdom

11:30 AM ***Adjourn***

EMAT Measurements of In- and Out-of-Plane Ultrasonic Signals

---**Rachel S. Edwards**, Steve Dixon, Yichao Fan, and Xiaoming Jian, University of Warwick, Department of Physics, Coventry CV4 7AL, United Kingdom

---Ultrasonic testing using electro-magnetic acoustic transducers (EMATs) is becoming a more well known technique for defect detection in electrically conducting and/or magnetic samples. Recent improvements to EMAT design have been possible through modelling of the EMAT behavior, with the combination of experiments and modelling explaining measurement results and suggesting new applications. Rayleigh waves generated on thick samples are of particular interest for detection and characterization of surface-breaking defects, for example rolling contact fatigue on the railhead, and such cracks often propagate at an angle to the surface normal. Measurements of both the in- and out-of-plane components are useful for characterizing such cracking. Typical EMAT systems detect predominantly in-plane signals, with out-of-plane signals measurable using a much more expensive interferometer system. We have developed EMATs to measure predominantly in- or out-of-plane signals, and these detection EMATs have been used to measure the behavior of Rayleigh waves close to defects, in order to understand the signal enhancement close to the crack opening. Measurements and modelling of closely spaced slots and angled defects identify the benefits of using both in- and out-of-plane signals for defect characterization.

The Correspondence Between Elastic and Plastic Anisotropy in Nominally Pure and AA3104 Aluminum Sheets

---**J. Morrison**, S. M. Dixon, M. D. G. Potter, and S. Essex, University of Warwick, Department of Physics, Coventry, West Midlands, CV4 7AL, United Kingdom; C. Davis, The University of Birmingham, School of Engineering, Metallurgy and Materials, Birmingham, B15 2TT, United Kingdom

---Texture information derived by non-destructive means has been used with limited success to determine formability parameters of sheet metals in a number of specific metallic alloys. Ultrasonic measurement of the zero order symmetric (S0) lamb wave velocity as a function of angle to the rolling direction reveals a metal sheets elastic anisotropy. With knowledge of the behaviour of the single crystal elastic properties in the polycrystalline aggregate, the sheets crystalline texture may be determined. Evaluation of orientation distribution coefficients which sufficiently describe a sheets texture is therefore achieved and can be useful for the non-destructive prediction of formability parameters. EMATs (Electromagnetic Acoustic Transducers) perform this ultrasonic measurement without contact which allows relatively efficient generation of the in plane wavepacket as compared to piezoelectric transducers, whilst allowing for operation on a moving sample. Most importantly, because the S0 wavepacket employed for ultrasonic testing measures the bulk elastic anisotropy it, easily, samples a statistically significant number of grains through the entire thickness of the sheet. It therefore avoids spurious results which may be obtained when local texture is assumed to provide an indication of a samples global texture as is likely to be the case when diffraction techniques such as XRD (x-ray diffraction) EBSD (electron backscatter diffraction) are used to determine texture at the samples surface. In order to achieve the level of sampling as that achieved ultrasonically with diffraction the sheet must be destroyed in a relatively time consuming measurement. A comparison of textures obtained by EBSD and ultrasonic methods has been performed and the use of this texture information to provide formability parameters, determined by mechanical testing, has been investigated for a number of nominally pure aluminium sheets and commercial can body stock sheets of AA3104 aluminium.

Optimal Probe Arrangement for Ultrasonic Inspection of Turbine Engine Spin Test Disks
---**Joachim Bamberg**, MTU Aero Engines GmbH, 80995 Munich, Germany; Martin Spies, Fraunhofer IZFP, Physical Basics Department, 66123 Saarbruecken, Germany

---Non-destructive ultrasonic detection of flaws in turbine engine disk components is essential for the acceptance of manufactured parts as well as for the extension of the life of parts after a period of service. Therefore, inspection systems have to be implemented to evaluate components both during production and at periodic intervals after delivery. As an example for such a technique, the inspection of spin test disk components from the inner bore using immersion technique is presented. In the specific case under concern, concurrent experimental and simulation studies have been employed to elaborate an efficient inspection procedure to detect small cracks of radial orientation. In a first step, a selection has been made on the transducer to be operated in transmit-receive mode to ensure a proper coverage of the inspection area. In the second part of the study, an appropriate model has been derived and implemented to optimize the inspection parameters, such as angle of insonification, water path and frequency. Here, emphasis has been on the maximization of the scattering amplitude of a ‘small’ penny-shaped crack in a depth from 1 mm to 10 mm below the surface. Experimental and simulation results will be presented to illustrate the methodology and the efficiency of the elaborated inspection procedure.

Integration of Different Scanning Modalities for Real-Time Dual-Channel Ultrasonic Inspection of Aircraft Structures
---**Igor Komsky** and Sridhar Krishnaswamy, Northwestern University, Center for Quality Engineering and Failure Prevention, Evanston, IL 60208; Bob Lasser, Imperium Inc., Silver Spring, MD 20903

---Modern airplanes require real-time three-dimensional information about the condition of aircraft multi-layered structures. This kind of information can only be provided when several ultrasonic scanning modalities are combined. A dual-channel ultrasonic inspection system is under development for real-time three-dimensional evaluation of large area aircraft structures. The system consists of two integrated data acquisition channels that are utilized for concurrent in-plane and in-depth real-time evaluation of structures. High resolution imaging (“horizontal”) channel with an ultrasonic CCD camera presents large (1square inch) real-time planar (X-Y plane) images of the structures while another (“vertical”) acquisition channel analyzes in-depth (Z-axis) ultrasonic scans presenting data in an A-scan format. The highest resolution and quality of the ultrasonic images are usually achieved at or close to the focal plane of the imaging device. Full coverage ultrasonic inspections of thick or multi-layered aircraft structures with unknown depth of potential deficiencies would require continuous real-time refocusing of the imaging system. This very challenging imaging procedure will, in turn, necessitate development of complex and expensive hardware and software modules. On the other hand, the dual-channel imaging system provides “on demand” refocusing of the imaging plane. Initially, the ultrasonic data are collected and analyzed by the “vertical” acquisition channel. Without any defect indications the “horizontal” imaging channel remains focused at pre-selected depth. Any ultrasonic signal that can be qualified by the “vertical” channel as a defect indication will result in real-time automatic refocusing of the imaging channel and acquisition of the high resolution defect images at the desired depth. Applications of the dual-channel real-time ultrasonic imaging system on metallic and composite aircraft structures will be presented.

MOSAIC: A Scalable Reconfigurable 2D Array System for NDE

---**Simon Triger** and John Wallace, University of Glasgow, Microsystem Technology Group, Department of Electronic & Electrical Engineering, Glasgow, Scotland, United Kingdom; Lei Wang, Formerly of Microsystem Technology Group, University of Glasgow, now at Imperial College London, London, United Kingdom; Sandy Cochran, Jean-Francois Saillant, and Farid Afroukh, University of Paisley, Microscale Sensors Group, School of Engineering, Paisley, Scotland, United Kingdom; David R. S. Cumming, University of Glasgow, Microsystem Technology Group, Dept. of Electronic & Electrical Engineering, Glasgow, Scotland, United Kingdom

---Ultrasound imaging relies on data collection from transducer arrays with greater sample area or enhanced resolution obtainable by increasing the number of elements. However, scaling difficulties exist due to corresponding increases in quantity and complexity of transmission and reception electronics. This paper presents an alternative approach via the construction of 2D array modules which can be tessellated to form reconfigurable arrays of any size and shape. The ability to form ultrasound systems in this way from generic building blocks which are physically identical for manufacturing purposes yet functionally unique via programming to suit the application has the potential to transform NDE. Such systems require full integration of transducer and electronics whereas previously only front end analogue electronics have been integrated with piezoelectric transducers. Close coupling permits excitation voltages down to 3.3V utilizing coded excitation. This has been demonstrated to provide viable pulse-echo results, with insertion loss of 40dB on reflection from an aluminum back wall at 75mm achieved using 2D arrays without decoding. This generic, compact, portable system occupies a 16mm x 16mm footprint and is in-field programmable for any target application and thus represents a departure from almost all previous work in ultrasound which has traditionally been highly application-specific.

Prototype Demonstrator for an Inspection Qualification Multi-Agent System (IQMAS)

---**Neil McLean**, Anthony Gachagan, and Gordon Hayward, Centre for Ultrasonic Engineering, University of Strathclyde, Glasgow, United Kingdom; Stephen McArthur, Institute for Energy and the Environment, University of Strathclyde, Glasgow, United Kingdom

---Inspection Qualification under the ENIQ methodology uses a Technical Justification combining a mixture of physical reasoning and modeling linked to limited experimental trial data from identified worst-case defects. This process can be costly and time-consuming, requiring extensive work by an experienced NDE engineer. At QNDE 2006, the design of a novel Multi-Agent system (MAS) for NDE was presented, allowing integration and automation of new and existing inspection qualification software tools for generating, collating and presenting data supporting inspection qualification. This paper gives an account of the development of the system to the point of a working prototype, demonstrating the application of the system to a practical inspection qualification scenario. A description is given of a user interface for the system, allowing a user to submit inspection qualification scenarios to be operated upon by the various agents, including worst case defect analysis, in an intuitive and consistent manner. In addition, an account is given of the development and integration into the system of a new case-based reasoning agent for identifying, retrieving and reporting on test block trial data most relevant to a given inspection qualification scenario.

An Advanced Flaw-Response Modelling Approach for Inspection Qualification Using a Multi-Agent System Software Platform

---**James P. McKenna,** Anthony Gachagan, and Gordon Hayward, Centre for Ultrasonic Engineering, Department of Electronic and Electrical Engineering, University of Strathclyde, Glasgow, G1 1XW, United Kingdom; Stephen McArthur, Institute for Energy and Environment, Department of Electronic and Electrical Engineering, University of Strathclyde, Glasgow, G1 1XW, United Kingdom

---This paper describes the application of a Multi-Agent System used in the design and qualification of ultrasonic NDT inspections using theoretical ultrasonic flaw-response modelling. Flaw-response models provide a fast and cheap alternative to test-piece trials but their use requires prior knowledge about the model's theory and application, necessitating the use of an experienced NDT engineer. Selection of the most appropriate model for a given inspection scenario becomes time-consuming as the disparate nature of the numerous software models prevents integration with other NDT software tools. A Multi-Agent System approach creates an extensible software environment that permits the integration of software tools that are capable of autonomous behavior, enabling collaboration and data sharing between these tools despite their heterogeneous nature. A prototype Inspection Qualification Multi-Agent System has been developed which incorporates a rule-based software system (model facilitator agent) to perform the flaw-response model selection procedure. Importantly, the design and implementation of this software system has utilized expert knowledge elucidated from senior NDT engineers. The performance of the model facilitator agent will be analyzed through case studies which illustrate the benefits of employing this approach with regard to computational speed and accuracy over conventional techniques used in the ultrasonic qualification process.

An Integrated Ultrasonic Correlation Spectrometer

---**Albert P. Y. Phang**, Richard E. Challis, Vladimir G. Ivchenko, and Alexander N. Kalashnikov, The University of Nottingham, School of Electrical and Electronic Engineering, Nottingham, Nottinghamshire, NG7 2RD, United Kingdom

---Measurements of ultrasonic wave attenuation and phase velocity as functions of frequency can provide important information on the dynamics of chemical reactions and the state of chemical products in-process. To overcome the problem of low SNR in the signal pathway, many ultrasonic spectrometers employ high voltage excitations, which may not be feasible in plant environments where limits are imposed on the working voltages of equipment due to fire and explosion hazards. In this work we present an integrated spectrometer system based on correlation techniques. High SNRs in the captured signal records were achieved using 1V complementary Golay sequence excitations combined with cross-correlation for signal detection, all of which were implemented on a single FPGA chip. Implementation on a reconfigurable hardware platform provides a basis for development of more robust and low-cost systems in the future. The system design model and supporting experiments show that its performance is equivalent to a conventional high-voltage pulsed transmission system.

Session 34

SESSION 34
PROCESS CONTROL
B. Larson, Chairperson
Ballroom C

8:30 AM **Infrared Flash Thermography Applied to the External Defect Detection on HTR Fuel Particles During the Manufacturing Process**
---**S. Hermosilla-Lara**, and M. Piriou, NDE Technical Center, AREVA Nuclear Plant, and AREVA and Siemens Company – Services Sector – BP13 – 71380 St Marcel – France; P. Levesque, Département Mécanique du Solide et de l'Endommagement (DMSE) de l'Office National d'Etudes et de Recherches Aérospatiales (ONERA) – 29 avenue de la Division Leclerc BP72, 92322 Chatillon, France

8:50 AM **Quantitative Homogeneity and In-Contact Particles of High Temperature Reactors (HTR) Compacts Determination Via X-Ray Tomography**
---G. Lecomte, J.-M. Létang; CNDRI INSA-Lyon, 69621 Villeurbanne, France; D. Tisseur and **J. Banchet**, AREVA NP, NDE Technical Center, 71380 St. Marcel, France; M.-P. Vitali, CERCA, 26104 Romans sur Isère, France

9:10 AM **Infrared Monitoring of the Powder-Metallurgy Process**
---**S. Benzerrouk**, R. Ludwig and D. Apelian, Worcester Polytechnic Institute, Department of Electrical and Computer Engineering, 100 Institute Road, Worcester, MA 01609-2280; S. Benzerrouk and R. Ludwig, Department of Electrical and Computer Engineering, Worcester Polytechnic Institute, Worcester, MA 01609-2280

9:30 AM **Dual-Mode Combined Infra Red and Ultrasonic Technique for Real-Time Industrial Process Control with Special Reference to the Food Industry**
---**P. Pallav**, D. A. Hutchins, and G. G. Diamond, University of Warwick, School of Engineering, Coventry, W. Mids, CV4 7AL, United Kingdom

9:50 AM **Ultrasonic Characterization of Glass Beads**
---I. Lassila and **E. Haeggström**, University of Helsinki, Department of Physical Sciences, Electronics Research Unit, Helsinki, Finland; S. Siiriä, University of Helsinki, Division of Pharmaceutical Technology, Helsinki, Finland

10:10 AM ***Break***

Infrared Flash Thermography Applied to the External Defect Detection on HTR Fuel Particles During the Manufacturing Process

---**S. Hermosilla-Lara** and M. Piriou, NDE Technical Center, AREVA Nuclear Plant, an AREVA and Siemens Company - Services Sector - BP13 - 71380 St Marcel - France; P. Levesque, Département Mécanique du Solide et de l'Endommagement (DMSE) de l'Office National d'Etudes et de Recherches Aérospatiales (ONERA) - 29 avenue de la Division Leclerc BP72, 92322 Chatillon, France

---In most of High Temperature Reactor (HTR) designs, elementary fuel components are in the form of 1 mm multilayered particles, called TRISO particles. The manufacturing process is divided in several steps, each of the latter corresponding to a chemical vapor layer deposit. At each step, it is necessary to ensure that the deposit is exempt of defects, such as open cracks, detachments between layers. The authors propose the use of an adapted flash thermography method to perform the online detection of open cracks on each layer. The method consists, via an infrared camera, in the measurement of the particle temperature increase produced by a heating pulse on the external surface of the particle. Study is performed on laser notches and real cracks located in the different layers of the particle, and includes the influence of the defect relative position with respect to the heating source, as well as the influence of operating conditions. It is shown that this technique is able to yield good discrimination between sound and flawed particles at a rate that meets the production constraints.

Quantitative Homogeneity and In-Contact Particles of High Temperature Reactors (HTR) Compacts Determination Via X-Ray Tomography

---Gwenaelle Lecomte and Jean-Michel Létang, CNDRI INSA-Lyon, 69621 Villeurbanne, France; David Tisseur and **Julien Banchet**, AREVA NP, NDE Technical Center, 71380 St Marcel, France; Marie-Pierre Vitali, CERCA, 26104 Romans sur Isère, France

---In AREVA NP's High temperature reactor (HTR) design program called ANTARES, fuel consists in compacts, composed of few thousands of TRISO particles, i.e. millimetric quasi-spherical particles containing a uranium-based kernel and four layers of pyrocarbon and silicon carbide of few tens of microns thickness, embedded in a graphite matrix. To obtain a compact, TRISO particles should be dispersed in the graphite matrix prior to compaction. It is this process that conditions compact acceptance criterion, based on the homogeneous spatial distribution of TRISO particles in the graphite matrix, as well as the possibility of obtaining no particle in contact. Both effects need to be assessed since they condition the thermo-mechanical behavior of the nuclear fuel under irradiation. After discarding conventional X-ray radiography, X-ray tomography inspection was then performed on compacts with different dispersion parameters. Data and image processing algorithms were then developed and applied to 3D reconstructions in order to yield a quantitative criterion for homogeneity determination as well as the detection and determination of the number of particles in contact. For both parameters, a sensitivity study was conducted and the feasibility of simultaneous inspection of several compacts assessed.

Infrared Monitoring of the Powder-Metallurgy Process

---**Souheil Benzerrouk**, Reinhold Ludwig and Diran Apelian, Worcester Polytechnic Institute, Department of Electrical and Computer Engineering, 100 Institute Road, Worcester, MA 01609-2280; Souheil Benzerrouk and Reinhold Ludwig, Department of Electrical and Computer Engineering, Worcester Polytechnic Institute, Worcester, MA 01609-2280

---Quality-control for powder metallurgy components proves to be a major challenge since standard non-destructive evaluation techniques are not applicable for the pre-sintered state. Due to high production speeds, low strength and delicate material compositions the testing approach of powder metallurgy compacts should ideally be one hundred percent contact-less, real time, and reliable. This paper describes an inspection approach for the detection of surface cracks and subsurface defects in the important, early-stage manufacturing process of powder metallic compacts. Our thermographic detection system is configurable to be passive for online testing where we have to rely on residual heating emanating from the parts when they exit the high pressure compaction machine. A second configuration is active thermography that utilizes induction heating as an external heat source for more comprehensive evaluation. This second approach proves to be very useful and practical for the detection of subsurface defects and small surface cracks. We will discuss the theoretical basis for the detection system, including the analytically predicted, transient temperature behavior in the part with simulated subsurface defects to assess the defect /energy interaction. We will then present results from practical tests carried out in a production environment.

Dual-Mode Combined Infra Red and Ultrasonic Technique for Real-Time Industrial Process Control with Special Reference to the Food Industry

---**P. Pallav**, D. A. Hutchins, and G. G. Diamond, University of Warwick, School of Engineering, Coventry, W. Mids, CV4 7AL United Kingdom

---Non contact, air-coupled ultrasound and through-transmission infrared (sub-micron NIR) were used in a complementary fashion for real-time industrial process control. This study was performed in collaboration with major industrial partners to demonstrate the capabilities of air-coupled ultrasound and through transmitted infrared for online inspection of food materials in production environments. Air-coupled ultrasound is highly suitable for real-time process control and permits the characterization of diverse food materials such as chocolate and cheese and is also capable of performing rapid measurements upon fast-moving, sealed metal cans. Infrared was shown to be a powerful and very useful complimentary technique to measure certain food materials on a production line in cases where air-coupled ultrasound was highly attenuated and in some cases completely obstructed by foreign material. Comparisons are presented between the two techniques and methodology.

Ultrasonic Characterization of Glass Beads

---Ilkka Lassila and **Edward Hæggström**, University of Helsinki, Department of Physical Sciences, Electronics Research Unit, Helsinki, Finland; Simo Siiriä, University of Helsinki, Division of Pharmaceutical Technology, Helsinki, Finland

---We aim at estimating size distribution of spherical glass beads (1- 10 mm diameter) residing in a container. We investigate the feasibility to use a nonlinear ultrasonic through transmission setup for the task. Furthermore, we try to estimate the elastic modulus of the beads as well as the contacts between them. The beads are packed in a cubic PVC box featuring integrated transmit and receive Pz-27 elements embedded in opposing container walls. The simulations are based on the discrete element method. Interactions between particles are handled as spring forces separating particles from each other's. Frictional forces between particles are taken into account. Time is handled as small steps, during which all forces are considered constant. The simulations are compared with the experimental results by using the same transmitted signals and comparing the outputs. The results can help to interpret experiments and check theoretical predictions. This work is a first step towards inline monitoring of granulation processes in pharma, chemical, and food industry.

Session 35

SESSION 35

THERMOELASTIC AND THERMOGRAPHIC NDE

S. Holland, Chairperson

Ballroom C

10:30 AM **Thermoelastic Stress Analysis of a Cantilever Beam**

---**S. Lee**, M. Choi, K. Kang, and Y. Kwan, Korea Research Institute of Standards and Science, Safety Measurement Group, 1 Doryong-dong, Yuseong-gu, Daejeon, Korea 305-340; W. Kim, Kongju National University, Major of Bio-mechanical Engineering, Yesan, Chungnam, Korea

10:50 AM **Thermo-Elastic Non-Contact Nondestructive Evaluation of Accumulated Fatigue Damage in Ti-6Al-4V**

---**S. Sathish**[1], K. V. Jata[2], J. T. Welter, N. Schell, and T. Boehilne, [1]University of Dayton Research Institute, 300 College Park, Dayton, OH 45469-0127; [2]Air Force Research Laboratory, AFRL/MLLP, 2230 Tenth Street, Wright-Patterson Air Force Base, OH 45433-7816

11:10 AM **Use of Lock-In Thermography in Shearing Magnitude in Determining the Defect Size**

---**W. Kim**, Kongju National University, Major of Bio-mechanical Engineering, 1 Daehye-ri, Yesan, Chungnam 340-702, Korea; K. Kang, J. Park, and Y. Hur, Korea Research Institute of Standards and Science, Safety Measurement Group, Daejeon, Korea; K. Kim, Chosun University, Department of mechanical Engineering, Gwangju, Korea

11:30 AM **Thermal Non-Destructive Testing of CFRP Impact Damage and Metal Porous Filters**

---**L. Feng**, N. Tao, W. Xu, and Y. Li, Capital Normal University, Department of Physics, Beijing, China

11:50 AM **Development of the Reference Block for Lock-In Photo-Infrared Thermography**

---**M. Choi**, K. Kang, J. Park, B. Ahn, Korea Research Institute of Standards and Science, Safety Measurement Group, Daejeon, Korea; W. Kim, Kongju National University, Major of Bio-mechanical Engineering, Yesan, Chungnam, Korea

12:10 PM ***Adjourn***

Thermoelastic Stress Analysis of a Cantilever Beam

---**S. Lee**, M. Choi, K. Kang, and Y. Kwan, Korea Research Institute of Standards and Science, Safety Measurement Group, 1 Doryong-dong, Yuseong-gu, Daejeon, Korea 305-340; W. Kim, Kongju National University, Major of Bio-mechanical Engineering, Yesan, Chungnam, Korea

---Structural components subjected to high frequency vibrations, such as those used in vibrating parts of gas turbine engines, are usually required to avoid resonance frequencies. Generally, the operating frequency is designed at more than resonance frequencies. When a vibrating structure starts or stops, the structure has to pass through a resonance frequency, which results in large stress concentration. This paper investigates the transient thermoelastic stress analysis of vibrating cantilever beam using infrared thermography. In experiment, the finite element modal (FEM) analysis of a cantilever beam (Euler-Bernoulli beam) was performed to generate natural frequencies and mode shapes. Stress distributions between 2nd and 3rd vibration mode are investigated with thermography and also dynamic stress concentration factors according to the change of vibration amplitude are estimated at resonance frequency.

Thermo-Elastic Non-Contact Nondestructive Evaluation of Accumulated Fatigue Damage in Ti-6Al-4V

---**Shamachary Sathish**[1], Kumar V. Jata[2], John T. Welter, Norm Schell, and Thomas Boehilne, [1]University of Dayton Research Institute, 300 College Park, Dayton, OH 45469-0127; [2]Air Force Research Laboratory, AFRL/MLLP, 2230 Tenth Street, Wright-Patterson Air Force Base, OH 45433-7816

---Cyclic loads lower than the elastic limit of the materials cause fatigue damage leading to mechanical failure. This incipient damage is difficult to detect, until it appears as slip bands or microcracks on the surface of the material. While major research effort has been focused on the development of techniques for detection of cracks, there is little effort on the development of techniques for detection of incipient fatigue damage. This paper presents the development of a non-contact thermoelastic technique to detect the accumulated fatigue damage in Ti-6Al-4V. A specimen in a fatigue machine is subjected to a high amplitude acoustic signal and the temperature change in the insonified region is monitored with a high-resolution infrared camera. The measurement of temperature change is performed at fixed number cyclic loads until the sample fails. The results show that the material becomes more efficient in converting the acoustic energy as the fatigue damage is accumulated. The instrumentation and the results of the measurements are described and the applicability of the methodology for nondestructive evaluation of accumulated incipient fatigue damage is discussed. The role of the changing microstructure during cyclic loading and its effect in the conversion of acoustic energy into heat is examined to understand the basic mechanism leading to the increased efficiency of the material to convert acoustic energy into heat.

Use of Lock-In Thermography in Shearing Magnitude in Determining the Defect Size

---**W. Kim,** Kongju National University, Major of Bio-mechanical Engineering, 1 Daehye-ri, Yesan, Chungnam 340-702, Korea; K. Kang, J. Park, and Y. Hur, Korea Research Institute of Standards and Science, Safety Measurement Group, Daejeon, Korea; K. Kim, Chosun University, Department of Mechanical Engineering, Gwangju, Korea

---In this paper, the shearing-phase technique is proposed for the quantitative determination of size and location of an inside defect by lock-in thermography. A phase (or temperature) difference between the defect area and the healthy area indicates the qualitative location and size of the defect. To accurately estimate these parameters, the shearing-phase technique has been employed, where the inspected image is shifted by a certain number of pixels (shearing amount) to obtain a shifted image while subtraction of one image from the other gives the shearing-phase distribution. The shearing-phase distribution has maximum, minimum, and zero points that help determine quantitatively the size and location of the subsurface defect. Since the shearing amount of proposed technique has influence on determining defect size and location, the influence of shearing amount in determining the defect size and location by lock-in thermography will be presented in this work. The dependency according to the change of shearing amount is analyzed and an optimum range of shearing amount is proposed. Experimental results, compared with actual values, shows good agreement within the optimum range. Also, it is described that errors in the estimation of defect location can be compensated with the newly proposed equation.

Thermal Non-Destructive Testing of CFRP Impact Damage and Metal Porous Filters

---**Lichun Feng**, Ning Tao, Weichao Xu, and Yanhong Li, Capital Normal University, Department of Physics, Beijing, China

---Pulse thermography and pulse phase thermography methods were applied for non-destructive testing of carbon fiber reinforced plate after low velocity impact and metal porous filters. 10 pieces of CFRP were used in the experimental study by QMW test method. Results from PT and PPT methods both show the validity of active thermography for CFRP impact damage inspection. Metal porous filters which are used for gas-liquid separation are difficult to test by traditional non-destructive testing methods due to its instinctive porosity and requirement for non-contact test. Thermal non-destructive method shows its superiority after adequate surface treating.

Development of the Reference Block for Lock-In Photo-Infrared Thermography

---**M. Choi**, K. Kang, J. Park, and B. Ahn, Korea Research Institute of Standards and Science, Safety Measurement Group, Daejeon, Korea; W. Kim, Kongju National University, Major of Bio-mechanical Engineering, Yesan, Chungnam, Korea

---Thermographic NDT techniques have been receiving increasing attentions as one of the effective NDT techniques, because of its non-contact, remote sensing, time-saving, and cost-saving vision techniques. However, infrared thermography basically depends on environmental disturbances such as surrounding temperature, humidity, and emissivity, which has influence on the detection ability in non-destructive testing and the influence would be more serious in field testing. In order to evaluate the detection reliability of thermography, this paper proposes the reference block of lock-in photo-infrared thermography. The reference block, with known defects of different depths, shapes, and sizes, can help how to evaluate the reliability of an inspection system and the detection range of a defect from given environmental condition. In this paper, the design condition of the block will be described in details and the system evaluation technique will be proposed from inspection data of the reference block. As conclusion, it might be considered that the reference block will improve the reliability of thermography in nondestructive testing.

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