Abstracts

Review of Progress in Quantitative NDE

University of Rhode Island - Kingston (URI)
Kingston, Rhode Island
July 26 – 31, 2009

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

Army Research Laboratory

Federal Aviation Administration

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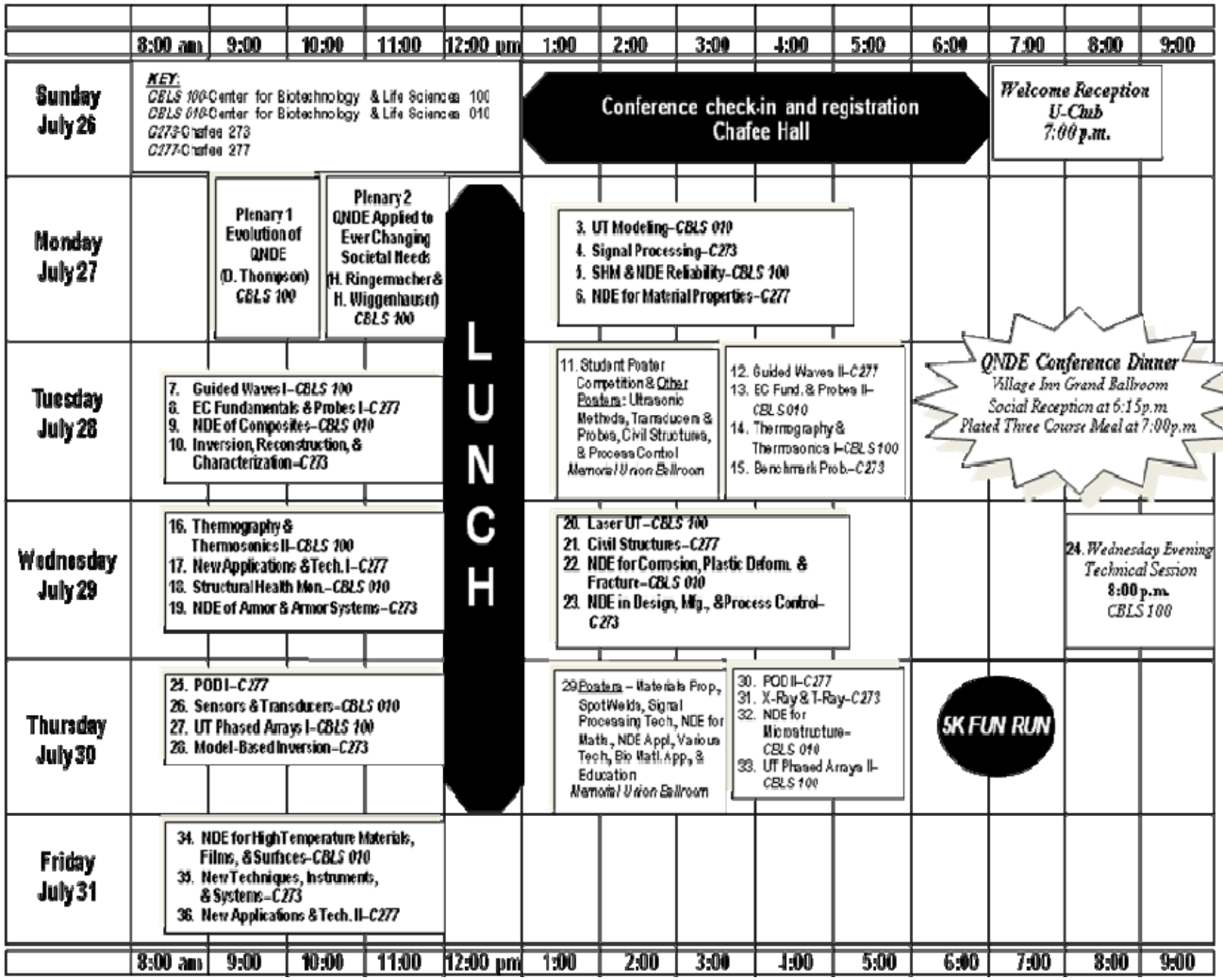
National Science Foundation
Industry/University Cooperative Research Centers

2009 Review of Progress in Quantitative NDE Program Summary



MONDAY

MONDAY AFTERNOON, JULY 27, 2009

This grid is provided for planning purposes. As you go through your abstract book to decide which talks/sessions you would like to attend, you can mark them on this grid for a one shot look at where you would like to go and when on each day of the conference.

	Session 3 **UT Modeling** ***CBLS 010***	**Session 4** **Signal Processing** ***Chafee 273***	**Session 5** **Structural Health Monitoring and NDE Reliability** ***CBLS 100***	**Session 6** **NDE for Material Properties** ***Chafee 277***
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Plenary Sessions 1 and 2

REVIEW OF PROGRESS IN QUANTITATIVE NDE
University of Rhode Island (URI)
Kingston, Rhode Island

July 26 – 31, 2009

PROGRAM

Monday, July 27, 2009

PLENARY SESSION 1
EVOLUTION OF QNDE
R. B. Thompson, Chairperson
CBLS 100

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

9:15 AM **Evolution of QNDE's Core Interdisciplinary Science and Engineering Base**
---**D. O. Thompson**, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

10:10 AM ***Break***

PLENARY SESSION 2
QNDE APPLIED TO EVER CHANGING SOCIETAL NEEDS
D. E. Chimenti, Chairperson
CBLS 100

10:30 AM **NDE: Surfing the Electromagnetic Spectrum**
---**H. I. Ringermacher**, GE Research Center, KW D254, 1 Research Circle, Schenectady, NY 12309

11:20 AM **NDT in Civil Engineering: Experience and Results of the FOR 384 Research Group**
---**H. Wiggenhauser**, BAM, Federal Institute for Materials Research and Testing, Division VIII.2, Non-destructive Damage Assessment and Environmental Measurement Methods, Unter den Eichen 87, D-12205, Berlin, Germany; I. H. W. Reinhardt, Universität Stuttgart, Institut für Werkstoffe im Bauwesen und Otto-Graf-Institut, Pfaffenwaldring 4, 70440 Stuttgart

12:10 PM ***Lunch***

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

Evolution of QNDE's Core Interdisciplinary Science and Engineering Base
---**Donald O. Thompson**, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---Nondestructive testing (NDT) for flaws in materials and structures has undergone an evolutionary change over the past 50 years. In the U.S. it has moved from a testing strategy (nondestructive testing) with a zero defects requirement to a test and evaluate technology (NDE) based upon damage tolerant design considerations. Here it is assumed that the part will always contain defects but those greater than a critical size, specified by fracture mechanics, will be removed by NDE inspection thereby resetting the part's service clock. In this talk, significant events will be identified that were critical in promoting this paradigm shift. A number of major research programs were initiated to upgrade NDT to meet the new requirements; principal attention in this talk will be given to research highlights initiated in the first of these programs, the DARPA/AFML Interdisciplinary Program for Quantitative Flaw Definition that was established 35 years ago. Its purpose was threefold: to develop a new core science/people base for inspection technology that could meet the new requirements, to set the stage for new field - adaptable engineering tools, and to initiate the current continuing series of QNDE meetings. Advances initiated in this program and pursued by many over the years have resulted in a scientific core structure for QNDE based on a linkage of fundamental models of the various measurement processes that are involved in any inspection and/or technology. These models and their linkage will be discussed and the core structure defined. A new and powerful set of engineering tools - i.e. simulation programs for UT, X-ray, and EC technologies –have also been developed using these models. Applications of these tools will be highlighted and their role in other advanced programs including Structural Health Monitoring and Condition-Based Maintenance will be noted. Finally, a discussion of visions of future opportunities and directions for QNDE will be given.

NDE: Surfing the Electromagnetic Spectrum

---**Harry Ringermacher**, Sr. Research Physicist, NTL, GE Research Center, KW D254, 1 Research Circle, Schenectady, NY 12309

---Advances in Nondestructive Evaluation demand an arsenal of techniques. This was as true twenty years ago as it is today. As materials and their associated technologies progress, so must the strategy for evaluating the quality of the product. Nondestructive Evaluation is a constant struggle to extract, from classical and quantum physics, the quintessential elements that will optimally address an inspection requirement, apart from purely academic interest. It must work to be useful and thereby advance the field. The electromagnetic spectrum, from Röntgen to Maxwell/Hertz, lies at the foundation of both classical and quantum physics. Not only has NDE plucked pearls form every nook of the spectrum ranging from X-rays to T-rays but also has managed to utilize virtually every known coupling of the spectrum to the classical mechanics of heat and sound. I will “surf” the spectrum to provide a sampling of what NDE has extracted past and present as well as try to couple to its future.

NDT in Civil Engineering: Experience and Results of the FOR 384 Research Group
---**Herbert Wiggenhauser**, BAM, Federal Institute for Materials Research and Testing, Division VIII.2, Non-destructive Damage Assessment and Environmental Measurement Methods, Unter den Eichen 87, D-12205, Berlin, Germany; I. H. W. Reinhardt, Universität Stuttgart, Institut für Werkstoffe im Bauwesen und Otto-Graf-Institut, Pfaffenwaldring 4, 70440 Stuttgart

---The Research Group FOR 384 was funded by the Deutsche Forschungsgemeinschaft (German Research Foundation) between 2001 and 2007, it evolved from an initiative which started much earlier, in 1994 on a spontaneous basis. The group made an combined effort to research "Non-destructive evaluation of concrete structures using acoustic and electro-magnetic echo-methods". Seven research groups from universities, Fraunhofer Foundation and Material Testing Institutes all over Germany formed this group under the speaker Professor HW Reinhardt (University of Stuttgart). The research focused on ultrasonic echo, impact echo, ground penetrating radar, signal analysis, reconstruction and modeling. Performance demonstrations were also included in the work plan. The lessons learned from the history of this group, their operational phase and in the exploitation of the results are presented and discussed.

Session 3

SESSION 3
UT MODELING
M. Hinders, Chairperson
CBLS 010

1:30 PM **Modeling Elastodynamic Scattering Using Finite Elements**
---**A. Velichko** and P. D. Wilcox, Department of Mechanical Engineering, University of Bristol, Queen's Building, University Walk, Bristol, BS8 1TR, United Kingdom

1:50 PM **Analytical Model for the Scattering of an Obliquely Incident Plane Shear Wave from a Cylindrical Cavity**
---**J. C. Aldrin**, Computational Tools, Gurnee, IL 60031; M. Blodgett, G. Steffes, and E. A. Lindgren, U.S. Air Force Research Laboratory, Wright Patterson AFB, OH 45433

2:10 PM **Ultrasonic Measurement Models, Beam Models, and Flaw Scattering Models for Surface Wave and Plate Wave Inspections**
---**L. W. Schmerr, Jr**., Iowa State University, Center for NDE and Department of Aerospace Engineering, Ames, IA 50011

2:30 PM **A 2D Model of Ultrasonic Testing for Cracks Near a Non-Planar Surface**
---J. Westlund and A. Boström, Department of Applied Mechanics, Chalmers University of Technology, Goteborg, Sweden

2:50 PM **Nonlinear Behavior of Ultrasonic Wave at Crack**
---N.-Y. Kim, Department of Mechatronic Engineering, Korea University of Technology and Education, Chunan, South Korea; T.-H. Lee, Graduate School of Hanyang University, Seoul, South Korea; **K.-Y. Jhang**, School of Mechanical Engineering, Hanyang University, Seoul, South Korea; I.-K. Park, Department of Mechanical Engineering, Seoul National University of Technology, Seoul, South Korea

3:10 PM ***Break***

3:30 PM **Modeling of Wave Propagation and Defect Detection in Rectangular Bar Specimens**
---**M. J. Guers** and B. R. Tittmann, The Pennsylvania State University, Department of Engineering Science and Mechanics, 212 Earth Engineering Science Building, University Park, PA 16802

3:50 PM **Inhomogeneous Interface Waves in a Thin Layer Between Half Spaces and Their Relationship to Lamb Waves**
---H. Kannajosyula, C. J. Lissenden, and J. L. Rose, Department of Engineering Science and Mechanics, The Pennsylvania State University, 212 Earth Engineering Sciences Building, University Park, PA 16802

4:10 PM **Analysis of Wave Structure of Guide Wave Which Propagates Along Pipes Filled with Fluid**
---**H. Sato**, National Institute of Advanced Industrial Science and Technology (AIST), Tsukuba, Japan

4:30 PM **Evaluation for Defect Detection by Guided Wave Over the Bend Zone in Piping**
---M. Miki, Y. Nagashima, and M. Endou, Energy and Environmental Systems Laboratory, Hitachi, Ltd., Hitachi City, Ibaraki Pref., Japan; K. Kodaira, M. Koike, and M. Odakura, Hitachi Works, Hitachi-GE Nuclear Energy Ltd., Hitachi City, Ibaraki Pref., Japan

4:50 PM **High-Resolution 3D EFIT Simulations of Guided Waves in Complex Structures**
---**M. K. Hinders** and J. P. Bingham, Department of Applied Science, College of William and Mary, Williamsburg, VA 23187-8795

Modeling Elastodynamic Scattering Using Finite Elements

---**Alexander Velichko** and Paul D. Wilcox, Department of Mechanical Engineering, University of Bristol, Queens Building, University Walk, Bristol, BS8 1TR, United Kingdom

---To model ultrasonic array data it is necessary to efficiently predict the behavior of a scatterer for many combinations of incident and scattering directions. Although analytical models exist for many canonical problems, the general case of scattering from an arbitrarily-shaped defect requires direct numerical methods such as finite elements (FE). Even today, the execution of such models is very computationally demanding. This paper presents a robust and efficient technique for predicting the complete scattering behavior for an arbitrarily-shaped defect and that can be implemented in a commercial FE package. The goal is to make the spatial size of the modeling domain around the defect as small as possible to minimize computational expense. The underlying principle is to contain the defect wholly within a closed surface on which the Kirchhoff-Helmholtz integral is evaluated for both incident and scattered fields. Conceptually, this allows a incident plane wave to be injected onto the defect from a specified direction and the scattered field to be decomposed into plane waves in different directions. Example results for 2D scattering in isotropic material will be presented and the method of generalizing the technique to anisotropic materials, 3D and guided wave scattering will be discussed.

Analytical Model for the Scattering of an Obliquely Incident Plane Shear Wave from a Cylindrical Cavity

---**John C. Aldrin**, Computational Tools, Gurnee, IL 60031; Mark Blodgett, Gary Steffes, and Eric A. Lindgren, U.S. Air Force Research Laboratory, Wright-Patterson AFB, OH

---Ultrasonic angle-beam shear wave inspections have been developed to address crack detection in multilayer structures without fastener removal. Although techniques for crack detection are typically based on corner reflection and diffraction signals, a complimentary method of generating and detecting spiral creeping waves at a fastener site has been proposed. Benefits of this approach include greater sensitivity to cracks of varying angular location and improved sensitivity to skewed cracks not perpendicular to the hole. A 3D analytical model was developed for the propagation and scattering of an obliquely incident plane shear wave from a cylindrical cavity. Good agreement was found with both a 2D analytical model and experimental results. The generation and decay of the spiral creeping waves was found to be dependent on both the angle of incidence and polarization of the plane shear wave. The local displacement profile of the propagating spiral creeping wave on a cylinder was found to be oriented at an angle consistently less than the angle of incidence, but independent of the angle of polarization. An extension of the model using an image method was derived to also study a special case of plane wave scattering by a truncated cylinder with an infinite crack.

Ultrasonic Measurement Models, Beam Models, and Flaw Scattering Models for Surface Wave and Plate Wave Inspections
---**Lester W. Schmerr Jr.,** Center for NDE and the Department of Aerospace Engineering, Iowa State University, Ames, IA 50011

---Ultrasonic measurement models have been developed and widely applied for bulk wave inspections. The foundations for such models are well known. Here, we will examine the implementation of measurement models for surface wave and plate wave tests and the underlying ultrasonic beam models and flaw scattering models needed to describe such inspections, including a new multi-Gaussian beam model for angle beam surface wave setups.---This work was supported by the NSF Industry/University Cooperative Research Center at Iowa State University.

A 2D Model of Ultrasonic Testing for Cracks Near a Non-planar Surface
---**Jonathan Westlund** and Anders Boström, Department of Applied Mechanics, Chalmers University of Technology, Göteborg, Sweden

---2D P-SV elastic wave scattering by a crack near a non-planar surface is investigated. The solution method employed is based on a reformulation of the wave scattering problem as two coupled boundary integral equations (BIE): a traction BIE for the crack opening displacement (COD) and a displacement BIE for the back surface displacement. The two coupled integral equations are solved using a combination of the boundary element method (BEM) for the back surface and a series expansion of the COD in Chebyshev functions. To model an ultrasonic contact probe in transmission, the traction on the surface beneath the probe is prescribed. The action of the receiving ultrasonic probe is modeled using a reciprocity relation. The model is completed by applying an inverse temporal Fourier transform to obtain the time traces. Applications of the model include simulation of ultrasonic nondestructive testing of objects featuring non-planar surfaces, e.g. pipe connections and pipes with diameter transitions. The ultrasonic testing of these objects is complicated by the fact that the signal response from a crack near a non-planar back surface may be masked by the signal response from the back surface. A few numerical examples illustrating this effect are given.

Nonlinear Behavior of Ultrasonic Wave at Crack

---Noh-Yu Kim, Department of Mechatronic Engineering, Korea University of Technology and Education, Chunan, South Korea; Tae-Hun Lee, Graduate School of Hanyang University, Seoul, South Korea; **Kyung-Young Jhang**, School of Mechanical Engineering, Hanyang University, Seoul, South Korea; Ik-Keun Park, Department of Mechanical Engineering, Seoul National University of Technology, Seoul, South Korea

---A nonlinear model for the contact acoustic nonlinearity (CAN) at a closed crack is proposed and analyzed by using Coulomb damping to investigate the characteristics of reflection and transmission waves for harmonic waves at the contact interface. Closed crack is modeled as an imperfectly jointed interface that has nonlinear discontinuity condition in displacement across its boundary. Based on contact interfacial stiffness of contact interface, the nonlinear parameter defined as the ratio of second harmonic component to first harmonic is determined by deriving reflection and transmission waves in terms of discontinuous displacements across the interface. It is found that the amplitude of second order harmonic wave is highly dependent on interfacial stiffness. This was verified by experiments for a real crack. For this, we prepared CT fatigue specimens of Al6061 with V-notch to initiate the crack, and the amplitude of second order harmonic was measured by scanning along the crack direction. From results of pre-test to evaluate the contact condition of crack interfaces by monitoring the amplitudes of echo and through transmission the crack was regarded as gradually closed, and we could see that the harmonic amplitude had good correlation with the crack and results agreed well with the theoretical expectation.

Modeling of Wave Propagation and Defect Detection in Rectangular Bar Specimens

---**Manton J. Guers** and Bernhard R. Tittmann, The Pennsylvania State University, Department of Engineering Science and Mechanics, 212 Earth-Engineering Science Building, University Park, PA 16802

---In previous papers, a technique utilizing a remote magnetostrictive transducer has been proposed for in-situ measurements of specimens in research reactors. The work presented in this paper examines efforts to model and characterize the technique's ability to detect defects in a rectangular bar specimens. A finite element model was used to simulate waveforms recorded in the remote monitoring setup. Since defect detection is of interest, the accuracy of predicted signal amplitudes must be considered and compared to experiments. The effects of material properties and the representation of the transducer in the model are explored to improve accuracy of the simulated waveforms.

Inhomogeneous Interface Waves in a Thin Layer between Half Spaces and Their Relationship to Lamb Waves

---**Haraprasad Kannajosyula**, Cliff J. Lissenden, Joseph L. Rose, Department of Engineering Science and Mechanics, The Pennsylvania State University, 212 Earth-Engineering Sciences Building, University Park, PA 16802

---We consider inhomogeneous guided interface waves in a thin isotropic elastic layer embedded between two half spaces (A). Dispersion curves corresponding to true or propagating modes in such a configuration are known to exist only below the shear velocity of the half space. These modes coincide with some Lamb wave dispersion curves in adhesively bonded plates (B) depending on the dimensions of the plates and adhesive layer (thin elastic layer). The corresponding Lamb waves have a wave structure that is dominant in the adhesive region. It is shown that inhomogeneous dispersion curves in configuration A also coincide with some true modes of configuration B. These curves exist in a region above the shear velocity of the half spaces (plates). The corresponding Lamb wave structures are also shown to have predominant displacement in the adhesive region. Finite Element analysis is discussed as a means to explain the phenomena involved.

Analysis of Wave Structure of Guide Wave Which Propagates Along Pipes Filled With Fluid

---**Harumichi Sato**, National Institute of Advanced Industrial Science and Technology (AIST), Tsukuba, Japan

---Cylindrical pipes are widely used in industries such as nuclear power plants and micro total analysis systems (uTAS), and it is important to monitor their health. Bulk wave is mainly used for an ultrasonic inspection of the pipes. Since the frequency of bulk wave is high, only the area close to the transducer can be inspected. Then, it takes a long time to inspect wide areas. In order to overcome the problem, long-range inspection using a guide wave is being developed. Its target is mainly a hollow pipe now. However, pipes are used to carry gas or liquid, and are normally filled with fluid. The properties of the guide wave which propagates along the pipes filled with liquid differ from those that propagate along a hollow pipe. In order to apply to nondestructive evaluation, it is required to know its wave structure. Therefore, I analyzed its dispersion and wave structure, and verified its result by the finite element method. The results revealed that the wave structure depends strongly on its mode and frequency. This technique and results will be guide to nondestructive evaluation.

Evaluation for Defect Detection by Guided Wave Over the Bend Zone in Piping

---**Masahiro Miki**, Yoshiaki Nagashima, and Masao Endou, Energy and Environmental Systems Laboratory, Hitachi Ltd., Hitachi City, Ibaraki Pref., Japan; Kojiro Kodaira, Masahiro Koike, and Mitsuru Odakura, Hitachi Works, Hitachi-GE Nuclear Energy Ltd., Hitachi City, Ibaraki Pref., Japan

---The guided wave inspection technique is effective for detecting defects like corrosion in piping. Effectiveness for the straight parts in piping by the guided wave inspection has been clarified by many researchers. However, the inspection performance by the guided wave decreases due to distortion when there is a bend part in the inspection area. We thought that the inspection performance could be improved if the guided wave was transmitted from many circumferentially-set sensors, similar to the arrangement in a phased-array method. Then, we confirmed the effectiveness by experiments using piping with a bend. The virtual reflected wave was transmitted from a local defect, and the wave transmitted by the phased-array method was determined from the reflected wave based on time reversal theory. This transmitted wave was confirmed by experiment as the guided wave focused over the bend zone. Thus, the distortion caused in the bend zone could be suppressed. In addition, signal processing that considered the higher-order modes was examined in the reflected wave evaluation. By combining this transmission control with the reflected signal processing, we determined that the detection performance for local defects over the bend zone could be improved.

High-Resolution 3D EFIT Simulations of Guided Waves in Complex Structures

---**Mark K. Hinders** and Jill P. Bingham, Department of Applied Science, College of William and Mary, Williamsburg, VA 23187-8795

---In order to understand guided wave propagation through the real structures containing flaws, a parallel processing, 3D elastic wave simulation using the finite integration technique (EFIT) has been developed. This full field, numeric simulation technique easily examines models too complex for analytical solutions, and is developed to handle built up 3D structures as well as layers with different material properties and complicated surface detail. The simulations produce informative visualizations of the guided wave modes in the structures as well as the output from sensors placed in the simulation space to mimic experiment.

Session 4

SESSION 4
SIGNAL PROCESSING
L. Jacobs, Chairperson
Chafee 273

1:30 PM **Enhanced Signal Processing and Characterization Using Guided Waves**
---**P. Catton**[1], A. Haig[2], R. Sanderson[1], P. Mudge[1], and W. Balachandran[2], [1]TWI Ltd., Granta Park, Great Abington, Cambridge CB21 6AL, United Kingdom; [2]School of Engineering & Design, Brunel University, Uxbridge, Middlesex UB8 3PH, United Kingdom

1:50 PM **Automatic Multi-Mode Guided Wave Feature Extraction Using Wavelet Fingerprints**
---**M. K. Hinders** and J. P. Bingham, Department of Applied Science, College of William and Mary, Williamsburg, VA 23187-8795

2:10 PM **Wavelet and Short Time Fourier Transform Analysis for Understanding Frequency Dependent Scattering**
---G. K. Sharma, A. Kumar, C. B. Rao, **T. Jayakumar**, and B. Raj, Indira Gandhi Centre for Atomic Research, Non Destructive Evaluation Division, Kalpakkam, Tamil Nadu, 603102 India

2:30 PM **Application of Wavelets in Damage Detection of Annular Components**
---**Z. Li**, Y. Liu, and K. Gong, LTCS & Department of Mechanics and Engineering Science, Peking University, Beijing 100871, China

2:50 PM **Defect Feature Extraction Using Surface Wave Interactions and Time-Frequency Behavior**
---**B. Dutton**, R. S. Edwards, and M. H. Rosli, University of Warwick, Department of Physics, Coventry, CV4 7AL United Kingdom

3:10 PM ***Break***

3:30 PM **POD Based Image Infusion Methodology for Enhancing Eddy Current Images of Defects in Stainless Steel Welds**
---B. Sasi, B. Purna, C. Rao, **T. Jayakumar**, and B. Raj, Indira Gandhi Centre for Atomic Research, Non Destructive Evaluation Division, Kalpakkam, Tamil Nadu, 603102 India

3:50 PM **The Choice of Optimal Structure of Artificial Neural Network Classifiers Intended for Classification of Welding Flaws**
---**R. Sikora**, T. Chady, P. Baniukiewicz, and M. Caryk, West Pomeranian University of Technology, Department of Electrical Engineering, Szczecin, Poland; B. Piekarczyk, Technic-Control, Szczecin, Poland

4:10 PM **NDE of Concrete Bridge Deck Delamination using Enhanced Acoustic Method**
---**G. Zhang** and R. S. Harichandran, Michigan State University, Department of Civil and Environmental Engineering, East Lansing, MI 48824-1226; P. Ramuhalli, Michigan State University, Department of Electrical and Computer Engineering, East Lansing, MI 48824

4:30 PM **Thermoelastic Waves in a Transversely Isotropic Cylinder**
---H. Bai, Lakehead University, Department of Mechanical Engineering, Thunder Bay, Ontario, P7B 5E1, Canada; **S. K. Datta**, University of Colorado, Department of Mechanical Engineering, Boulder, CO 80309-0427; A. H. Shah, The University of Manitoba, Department of Civil Engineering, Winnipeg, Manitoba, R3T 5V6, Canada

4:50 PM **Advanced Image Processing Techniques for Precise Estimation of Defect Features in Radiography Images**
---T. Saravanan, S. Bagavathiappan, K. Arunmuthu, J. Philip, **T. Jayakumar**, and B. Raj, Indira Gandhi Centre for Atomic Research, Non Destructive Evaluation Division, Kalpakkam, Tamil Nadu, 603102 India

Enhanced Signal Processing and Characterization Using Guided Waves

---**Phil Catton**[1], Alex Haig[2], Ruth Sanderson[1], Peter Mudge[1], Wamadeva Balachandran[2], [1]TWI Ltd., Granta Park, Great Abington, Cambridge CB21 6AL, United Kingdom; [2]School of Engineering & Design, Brunel University, Uxbridge, Middlesex UB8 3PH, United Kingdom

---In the past, pipeline inspection by ultrasonic guided waves (also called 'Long Range Ultrasonic Testing', or LRUT) has been used as a tool for rapidly screening components for the presence of corrosion, where a loss to the original cross sectional area of greater than around 9% can be detected, and located with an axial resolution of a few inches. Recent advances have shown that this qualitative screening method has the potential to be transformed into a more quantitative NDT technique. This is achieved by using a phased-array technique to focus guided waves at areas of interest identified by an initial screening test, and allows the ability of estimating the circumferential extent and position of localized defects. It is possible to sequentially focus the guided waves at incremental positions along the length of the pipe as well as around the circumference, but the inspection time increases with the number of required focus positions. To address this practical limitation, the present work investigates techniques to greatly reduce the inspection duration. Full matrix capture and broadband excitation approaches are discussed and initial results are presented, illustrating the feasibility of such methods.

Automatic Multi-Mode Guided Wave Feature Extraction Using Wavelet Fingerprints

---**Mark K. Hinders** and Jill P. Bingham, Department of Applied Science, College of William and Mary, Williamsburg, VA 23187-8795

---The development of automatic guided wave interpretation for detecting corrosion in aluminum aircraft structural stringers is described. The Dynamic Wavelet Fingerprint Technique (DWFT) is used to render the guided wave mode information in two-dimensional binary images. Automatic algorithms then extract DWFT features that correspond to the distorted arrival times of the guided wave modes of interest, which give insight into changes of the structure in the propagation path. To better understand how the guided wave modes propagate through real structures, parallel-processing elastic wave simulations using the finite integration technique (EFIT) has been performed. 3D simulations are used to examine models too complex for analytical solutions. They produce informative visualizations of the guided wave modes in the structures, and mimic the output from sensors placed in the simulation space. The 3D EFIT results are compared directly to their experimental counterparts.

Wavelet and Short Time Fourier Transform Analysis for Understanding Frequency Dependent Scattering

---Govind Kumar Sharma, Anish Kumar, Chelamchala Babu Rao, **Tammana Jayakumar**, and Baldev Raj, Indira Gandhi Centre for Atomic Research, Non Destructive Evaluation Division, Kalpakkam, Tamil Nadu, 603102 India

---Signal processing techniques are used to understand the ultrasonic wave scattering in highly anisotropic/dispersive media such as large grain size stainless steel. The back-scattered noise generated during ultrasonic wave propagation is coherent and hence cannot be eliminated using spatial averaging techniques. Various studies have been made to correlate ultrasonic back-scatter energy and attenuation with grain size. In this study, wavelet transform and short time Fourier transform (STFT) have been used for analyzing the frequency content of the back-scatter noise and back-wall echoes obtained from various grain size specimens of austenitic stainless steel. Ultrasonic pulse echo technique was used with 20 MHz normal beam transducer to obtain the ultrasonic signals used for analysis. As the grain size increases, the back-scatter signal increases whereas the peak frequency of the back wall echo decreases. The back-scatter signal is found to contain predominantly higher frequencies. The time domain signals from large grain size austenitic stainless steel specimens showed only one clear back wall echo and the remaining were masked in the high frequency noise. Using 'Morlet' wavelet at higher scales, it is possible to clearly obtain up to four back wall echoes from the same data. The lower scale wavelet showed only high frequency noise. For each grain size, the optimum wavelet scales were obtained based on the best signal to noise ratio criterion. Further, the optimum wavelet scales were correlated with grain size in austenitic stainless steel.

Application of Wavelets in Damage Detection of Annular Components

---**Zheng Li**, Yu Liu, and Kezhuang Gong, LTCS & Department of Mechanics and Engineering Science, Peking University, Beijing 100871, China

---Thin tube is one of the familiar structural components in engineering applications, but fatigue cracks usually have been found to initiate and grow in the radial direction inside many annulus-shaped components, which makes it difficult to detect the cracks. Here, a damage detection method to an annular component with an interior radial crack is developed by extracting stress wave signals by means of continuous wavelet transform. A circular annulus model with a radial crack on its inner surface is considered in this paper, and it is subjected to an impact load on outer surface to inspire circumferential guided waves. A certain point outside the annulus is set to catch the dynamic strain signals. Since the continuous wavelet transform can effectively solve the frequency dispersion problem for waves propagating in the circular annulus, it can extract the arrival times and amplitudes of each frequency from dynamic strain signals at an arbitrary point on the surface of the circular annulus. Considering the interaction on the crack and the mode conversions of these circumferential guided waves, the location of the interior radial crack in the annulus can be identified quantificationally by the wavelet results, and the crack extent can also be estimated.

Defect Feature Extraction Using Surface Wave Interactions and Time-Frequency Behavior

---**Benjamin Dutton**, Rachel S. Edwards, and Mohd H. Rosli, University of Warwick, Department of Physics, Coventry, CV4 7AL United Kingdom

---The scope of this paper is to exploit the interaction of ultrasonic surface waves with surface cracks in order to extract defect characteristics, such as depth and the angle they make with the surface. A computer model has been developed to simulate laser generated surface waves interacting with defects of several depths and at a range of angles to the surface, and experimental measurements are used to validate the model. Rayleigh waves are monitored across the defect region and their properties probed to extract defect features. Rayleigh reflection and transmission coefficient behaviours are compared to look at the effect that crack angle and depth have on surface waves. We also consider the frequency behaviour at the defect interface in aluminium samples. Image processing of the phase component of the FFT is used to extract similar information, and more information is gained by looking at the frequency behaviour of acquired waveforms. A frequency enhancement has been observed previously using a magnitude FFT, but the spectral fluctuation information in time is not available when using this transformation. Therefore the use of wavelets and Wigner transforms is investigated.

POD Based Image Infusion Methodology for Enhancing Eddy Current Images of Defects in Stainless Steel Welds

---Balakrishnan Sasi, Bhagi Purna, Chandra Rao, **Tammana Jayakumar**, and Baldev Raj, Indira Gandhi Centre for Atomic Research, Non Destructive Evaluation Division, Kalpakkam, Tamil Nadu, 603102 India

---This paper discusses probability of detection (POD) based fusion methodology developed for fusing eddy current (EC) images of weld regions in austenitic stainless steel for reliable detection of defects. EC images are obtained at two different frequencies using transmit-receive type probe that exhibits directional sensitivity. As the images are influenced by variations in microstructures and associated changes in electrical conductivity and magnetic permeability in the weld regions, wavelet transform based denoising is performed and the resulting images are fused following the Dempster Schafer theory. This methodology has been validated on images of EDM notches (length 6 mm, width 0.5 mm and varying depths of 0.3 mm, 1 and 2 mm) in austenitic stainless steel welds (thickness 12 mm), obtained at 320 kHz and 750 kHz. After wavelet denoising, the images obtained at the two frequencies have been combined based on the curve of acceptance and curve of rejection. This methodology could reliably detect 0.3 mm deep longitudinal notch and also resulted in significant improvement in signal-to-noise ratio. This paper discusses the details of the proposed methodology and its applications to automated detection and imaging of defects in stainless steel welds.

The Choice of Optimal Structure of Artificial Neural Network Classifiers Intended for Classification of Welding Flaws

---**Ryszard Sikora**, Tomasz Chady, Piotr Baniukiewicz, and Marcin Caryk, West Pomeranian University of Technology, Department of Electrical Engineering, Szczecin, Poland; Bogdan Piekarczyk, Technic-Control, Szczecin, Poland

---Nondestructive testing and evaluation are under continuous development. Currently researches are concentrated on three main topics: advancement of existing methods, introduction of novel methods and development of artificial intelligent systems for automatic defect recognition (ADR). Automatic defect classification algorithm comprises of two main tasks: creating a defect database and preparing a defect classifier. Here, the database was built using defect features that describe all geometrical and texture properties of crack. Almost thirty carefully selected features calculated for flaws extracted from real radiograms were used. The radiograms were obtained from shipbuilding industry and they were verified by qualified operator. There were compared two weld defect's classifiers based on artificial neural networks. First model consisted of one neural network model, where each output neuron corresponded to different defect group. The second model contained five neural networks. Each neural network had one neuron on output and was responsible for detection of one defects' group. In order to evaluate the effectiveness of the neural networks classifiers, the mean square errors were calculated for test radiograms and compared.

NDE of Concrete Bridge Deck Delamination using Enhanced Acoustic Method

---**Gang Zhang** and Ronald S. Harichandran, Michigan State University, Department of Civil and Environmental Engineering, East Lansing, MI 48824-1226; Pradeep Ramuhalli, Michigan State University, Department of Electrical and Computer Engineering, East Lansing, MI 48824

---Delamination of the concrete above the upper reinforcing bars is a common problem in bridge decks. The delamination is initiated by corrosion of the upper reinforcing bars and promoted by traffic loading. The detection of delamination is important for bridge maintenance and acoustic non-destructive evaluation (NDE) is widely used due to advantages of low cost, speed, and easy implementation. In traditional acoustic approaches, the inspector sounds the surface of the deck by hammer or bar impact, or chain drag, and assesses delamination by the "hollowness" of the sound. The acoustic signals are affected by traffic noise at the site and the detection is highly subjective. The performance of acoustic NDE methods can be improved by employing a suitable noise-reduction algorithm and a reliable detection algorithm that eliminates subjectivity. Since the noise is non-stationary and unpredictable, the algorithm has to be adaptive. In this paper, a blind source separation algorithm using a modified independent component analysis (ICA) was used to separate the sounding signals from recordings of the noisy environment. The filtered signals were then fed into a detection algorithm where Mel-frequency Cepstral Coefficients (MFCC) were extracted and used as features for detection. The performance of the algorithm is validated by comparing the detection rates under different conditions. The results show that the algorithm can improve the detection rate, especially in highly noisy conditions.

Thermoelastic Waves in a Transversely Isotropic Cylinder

---Hao Bai, Lakehead University, Department of Mechanical Engineering, Thunder Bay, Ontario, P7B 5E1, Canada; **Subhendu K. Datta**, University of Colorado, Department of Mechanical Engineering, Boulder, CO 80309-0427; Arvind H. Shah, The University of Manitoba, Department of Civil Engineering, Winnipeg, Manitoba, R3T 5V6, Canada

---An exact analysis of the propagation of harmonic thermoelastic waves in a transversely isotropic, infinite cylinder has been presented here using the Lord-Shulman generalized theory of thermoelasticity. In the study, the symmetry axis of the materials is assumed to be parallel to the cylinder axis. The displacement field is represented by three scalar potentials. The stresses are expressed in terms of these potential functions. Subsequently, homogenous traction – free and thermally insulated boundary conditions are imposed to obtain dispersion relations. A refinement procedure is employed here to obtain the frequency spectra. To validate the analytical results, some comparisons with available published results for isothermal propagation in a transversely isotropic cylinder and thermoelastic propagation in an isotropic cylinder are presented.

Advanced Image Processing Techniques for Precise Estimation of Defect Features in Radiography Images

---Thangavelu Saravanan, Subramanian Bagavathiappan, Krishnan Arunmuthu, John Philip, **Tammana Jayakumar**, and Baldev Raj, Indira Gandhi Centre for Atomic Research, Non Destructive Evaluation Division, Kalpakkam, Tamil Nadu, 603102 India

---In the last few years, we have developed several new image processing techniques to enhance defect features in radiography images. A histogram concavity-based thresholding approach has been used for segmenting porosities, voids and inclusions from digitized radiography images. Small reference defects were fabricated in cylindrical tubes and flat plates to show that histogram concavity-based thresholding approach is better than automatic thresholding techniques for quantitative sizing of defects. The developed segmentation procedure is optimized by filtering the abrupt noise with low-pass median filtering, followed by grey-level global thresholding. This procedure has resulted in excellent segmentation of pores and voids present in the radiography images and their sizes could be estimated with an accuracy of ±1pixel (65 microns). Fourier space filters have been employed for enhanced detectability of defect features on the digitized radiography images of the tube-to-tube sheet welds. The Butterworth band-pass filter is found to have maximum signal-to-noise ratio (SNR) compared to other spatial filters like Sobel, Prewitt, Laplacian, Robert and Fourier filters such as ramp filter and Butterworth high-pass. The sizes of the defects could be estimated with an accuracy of ±1pixel (8 microns). Using the above approach, pores as small as 60 microns and lack of fusion having width as small as 35microns could be estimated.

Session 5

SESSION 5
STRUCTURAL HEALTH MONITORING AND NDE RELIABILITY
A. Broz, Chairperson
CBLS 100

1:30 PM **In Situ Detection of Surface-Mounted PZT Transducer Defects Using Linear Reciprocity**
---**S.–J. Lee**, Carnegie Mellon University, Department of Civil and Environmental Engineering, Pittsburgh, PA 15213; H. Sohn, Korea Advanced Institute of Science and Technology, Department of Civil and Environmental Engineering, Daejeon, Republic of Korea; J. E. Michaels and T. E. Michaels, Georgia Institute of Technology, School of Electrical and Computer Engineering, Atlanta, GA 30332-0250

1:50 PM **Phased Array Probe Optimization for the Inspection of Titanium Billets**
---**E.-M. Rasselkorde** and I. Cooper, TWI NDT Validation Center Wales, %ECM2, Heol Cefn Gwrgan, Margam, Port Talbot SA13 2EZ, United Kingdom

2:10 PM **Identification of Dormant Thermally Stimulated Defect in Optical Fiber Using Raman Sensor**
---C. Pandian, S. Sosamma, C. B. Rao, **T. Jayakumar** and B. Raj, Indira Gandhi Centre for Atomic Research, Non Destructive Evaluation Division, Kalpakkam, Tamil Nadu, 603102 India

2:30 PM **Investigation of the Effects of Notch Width on Eddy Current Response and Comparison of Signals from Notches and Cracks**
---**B. F. Larson**, C. C. H. Lo, and N. Nakagawa, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

2:50 PM **Portable Ultrasonic Guided Wave Inspection with Macro Fiber Composite Actuators**
---**A. G. Haig** and W. Balachandran, Brunel University, School of Engineering and Design, Uxbridge, Middlesex, UB8 3PH, United Kingdom; P. J. Mudge and P. Catton, TWI Ltd, Granta Park, Great Abington, Cambridge, Cambridgeshire, CB21 6AL, United Kingdom

3:10 PM ***Break***

3:30 PM **Quantifying and Improving the Reliability of NDE Through Modeling Manual Ultrasonic Inspections**
---**A.-H. Ali**, D. Balint, and P. Leevers, Imperial College London, Department of Mechanical Engineering, Mechanics of Materials Group, England, United Kingdom; A. Temple, Imperial College London, Department of Mechanical Engineering, England, United Kingdom

3:50 PM **Reliable Radiographic Inspection of Flexible Risers for the Oil Industry**
---R. M. Almeida and **J. M. A. Rebello**, Federal University of Rio de Janeiro - Department of Metallurgical and Materials Engineering - COPPE/UFRJ - Rio de Janeiro/RJ, Brazil; M. A. Vaz, Federal University of Rio de Janeiro - COPPE/UFRJ - Rio de Janeiro/RJ, Brazil

4:10 PM **Monitoring Crack Propagation in Turbine Blades Caused by Thermosonic Inspection**
---**G. Bolu**, A. Gachagan, and G. Pierce, University of Strathclyde, Centre for Ultrasonic Engineering, Glasgow, United Kingdom; G. Harvey, Rolls Royce, East Kilbride, United Kingdom; W. L. Choong, Vibrant NDT Ltd., Smithfield, Sheffield, United Kingdom

4:30 PM **An FAA Quantified Inspection Success Story**
---**A. L. Broz**, Federal Aviation Administration, ANE-105N, 12 New England Executive Park, Burlington, MA 01803-5213

4:50 PM **Aging Management Using Proactive Management of Materials Degradation (PMMD)**
---**L. J. Bond**[1], S. R. Doctor[1], S. E. Cumblidge[1], S. Bruemmer[1], B. Taylor[1], G. Carpenter[2], A. B. Hull[2], and S. N. Malik[2], [1]PNNL and [2]NRC

In Situ Detection of Surface-Mounted PZT Transducer Defects Using Linear Reciprocity
---**Sang-Jun Lee**, Carnegie Mellon University, Department of Civil and Environmental Engineering, Pittsburgh, PA 15213; Hoon Sohn, Korea Advanced Institute of Science and Technology, Department of Civil and Environmental Engineering, Daejeon, Republic of Korea; Jennifer E. Michaels and Thomas E. Michaels, Georgia Institute of Technology, School of Electrical and Computer Engineering, Atlanta, GA

---Guided waves generated by Lead Zirconate Titanate (PZT) transducers are widely used to detect structural damage for nondestructive evaluation (NDE) and structural health monitoring (SHM) applications. It is generally assumed that the surface-mounted PZT transducers are both undamaged and properly bonded to the host structure during usage. However, this assumption may not be valid, particularly under realistic operating conditions. In this study, a methodology for PZT transducer diagnosis is developed to identify abnormal transducers using linear reciprocity of guided wave propagation between pairs of surface-mounted transducers on metallic structures. The advantage of the proposed technique is that transducer bonding problems and PZT defects can be detected even when the system being monitored is subjected to varying operational, environmental or structural conditions. In addition, the complexity of the boundary conditions and geometry of the structure do not affect performance. The effectiveness of this diagnostic technique is evaluated via numerical simulations and experiments with PZT transducers instrumented on an aluminum plate.

Phased Array Probe Optimization for the Inspection of Titanium Billets
---**El-Mahjoub Rasselkorde** and Ian Cooper, TWI NDT Validation Center Wales, % ECM2, Heol Cefn Gwrgan, Margam, Port Talbot SA13 2EZ, United Kingdom

---The manufacturing process of titanium billets can produce multiple sub-surface defects that are particularly difficult to detect during the early stages of production. Failure to detect these defects can lead to subsequent in-service failure. A new and novel automated quality control system for the inspection of titanium billet, destined for use in aerospace applications, is being developed. The sensors will be deployed by an automated system to minimize the use of manual inspections which should improve the quality and reliability of these critical inspections early on in the manufacturing process. This paper presents the first part of the work which is the design and the simulation of the phased array ultrasonic inspection of the billets. A series of phased array transducers were designed to optimize the ultrasonic inspection of a ten inch diameter billet made from Titanium 6Al-4V. A comparison between different probes including a Fermat type transducer, equal and unequal element surface area type probes was performed. The final transducer design was validated using simulation tools.

Identification of Dormant Thermally Stimulated Defect in Optical Fiber Using Raman Sensor

---Chelliah Pandian, Samvel Sosamma, Chelamchala Babu Rao, **Tammana Jayakumar** and Baldev Raj, Indira Gandhi Centre for Atomic Research, Non Destructive Evaluation Division, Kalpakkam, Tamil Nadu, 603102 India

---Various kinds of defects may be present in optical fibers. These defects arise at various stage of fiber sensor development, viz. perform fabrication, fiber drawing and fiber laying. The defects can be due to presence of dopants, OH ions, residual stresses and cracks developed at different stages of fiber fabrication. We present a case study of a defect, which is dormant at ambient temperature and surfaces at higher temperature. We bring out the details of detection of a defect in a 62.5μm/125μm polyamide coated fiber, using a Raman scattering based distributed temperature sensor. The fiber is divided into three zones of lengths 34m, 30m and 36m and the central zone is heated to 200ºC. Nd-YAG laser (wavelength 1.06micron, pulse width 5ns) is launched into the fiber. The backscattered anti-Stokes light is monitored for temperature measurement. Typically, the amplitude of the anti-Stokes line of a material increases with temperature. Using the anti-Stokes scattering coefficient and the pulse width of the laser, the expected response is simulated. In the fiber under test, however at higher temperatures, the intensity of the anti-Stokes light is found to decrease with increase in the temperature, beyond a specific location in the fiber section being heated. On cooling, the intensity returned back to the expected simulated result at room temperature. The drop in the intensity of the backscattered signal with temperature infers that the defect gets stimulated thermally.

Investigation of the Effects of Notch Width on Eddy Current Response and Comparison of Signals From Notches and Cracks

---**B. F. Larson**, C. C. H. Lo, and N. Nakagawa, Center for NDE, Iowa State University, 1915 Scholl Road, Ames, IA 50011

---This paper reports on work conducted to investigate the effect that EDM notch width has on the eddy current (EC) signal, and to compare EC signals from notches to those from laboratory-grown fatigue cracks. Additionally, the effect of crack closure was investigated since this affects the correlation between the EC responses from cracks and those from notches. Both aerospace engine (titanium- and nickel-base alloys) and airframe (aluminum) materials were included in the study. This study builds upon previous work with Ti and Inconel materials where the signal amplitude was shown to decrease, as expected, as the notch width decreases. The trend was captured well by numerical results and this allowed estimates to be made about the signals from idealized “zero-width” notches. The results indicated that the signal reduction factor from a 0.127mm (0.005 inch) wide, rectangular notch to a theoretical zero-width semi-elliptical notch of the same size ranged from 25 to 42% for low conductivity materials. This study sought to answer whether a zero-width notch yielded approximately the same EC signals as a fatigue crack of the same size and whether trends held true for aluminum, which has much higher conductivity and different surface oxide conditions.---This material is in part based upon work supported by the Air Force Research Laboratory under contract # FA8650-04-C-5228 at Iowa State University Center for NDE.

Portable Ultrasonic Guided Wave Inspection with Macro Fiber Composite Actuators

---**Alexander G. Haig** and Wamadeva Balachandran, Brunel University, School of Engineering and Design, Uxbridge, Middlesex, UB8 3PH, United Kingdom; Peter J Mudge and Phil Catton, TWI Ltd, Granta Park, Great Abington, Cambridge, Cambridgeshire, CB21 6AL, United Kingdom

---The development of portable ultrasonic guided wave transducer arrays that utilize Macro Fiber Composite actuators (MFCs) is described. Portable inspection equipment can make use of ultrasonic guided waves to rapidly screen large areas of many types of engineering structures for defects. The defect finding performance combined with the difficulty of application determines how much the engineering industry makes use of this non-destructive, non-disruptive technology. The developments with MFCs have the potential to make considerable improvements in both these aspects. MFCs are highly efficient because they use interdigital electrodes to facilitate the extensional, d_{33} displacement mode. Their fiber composite design allows them to be thin, lightweight, flexible and durable. The flexibility affords them conformance with curved surfaces, which can facilitate good mechanical coupling. The suitability of a given transducer for Long Range Ultrasonic Testing is governed by the nature and amplitude of the displacement that it excites/senses in the contact area of the target structure. This nature is explored for MFCs through directional sensitivity analysis and empirical testing. Housing methods that facilitate non-permanent coupling techniques are discussed. Finally, arrangements of arrays of MFCs for the guided wave inspection of plates and pipes are considered and some broad design criteria are given.

Quantifying and Improving the Reliability of NDE through Modeling Manual Ultrasonic Inspections

---**Abdul-Hannan Ali**, Daniel Balint, and Pat Leevers, Imperial College London, Department of Mechanical Engineering, Mechanics of Materials Group, England, United Kingdom; Andrew Temple, Imperial College London, Department of Mechanical Engineering, England, United Kingdom

---The overarching objective of this work is to develop a general model for fault tree analysis (FTA) of a range of NDE inspection techniques, which will predict the probability of missing critical defects, misclassifying harmless defects as critical and sizing errors. This paper presents a first-generation model specialized for ultrasonic testing (UT) of V-butt welds, implemented in spreadsheets. The measurement of defects in UT inspection procedures have been related to ten key factors (including human factors); each factor contributes to the final measured value with a systematic error and a random error, where random errors can lead to either oversizing or undersizing of a defect. The model is based on physical equations for the UT process, logic for how errors combine and triangular probability distributions for both the occurrence of errors and the resulting errors in sizing. Constructing the probabilities has required extensive data gathering from round-robin test results, industrial reports, academic journals and UT inspector feedback. An overview of the model will be given, followed by select example calculations to demonstrate how it can be used to draw conclusions about the relative importance of various sources of error.

Reliable Radiographic Inspection of Flexible Risers for the Oil Industry

---Romulo M. Almeida and **Joao M. A. Rebello**, Federal University of Rio de Janeiro - Department of Metallurgical and Materials Engineering - COPPE/UFRJ - Rio de Janeiro/RJ, Brazil; Murilo A. Vaz, Federal University of Rio de Janeiro - COPPE/UFRJ - Rio de Janeiro/RJ, Brazil

---Flexible risers are composite tubular structures manufactured by the concentric assemblage of cylindrical polymeric and helically wound metallic layers employed to convey pressurized fluids such as oil, gas and water in the ocean environment. The metallic layers account for the flexible riser's structural strength and are dimensioned according to the static and dynamic loads. They are usually installed in a free hanging catenary configuration and are subjected to the direct action of waves and marine currents and wave induced motions from the oil production platform. The fatigue rupture of wire armours in the end fitting or within the riser segment protected by the bend stiffener is an object of major concern. Integrity models have been developed, however inspection techniques are mandatory to ensure that failure is detected. Gammagraphy have been used as a usual technique of inspection in all regions of the flexible riser, mainly with the single wall-single view method. On the other side, there aren´t any radiographic procedures qualified to this kind of structure. The aim of this work is to, exactly, show the power of this technique, related to its defect detectability in other inspection geometries as the double wall-single view method. The following methodology was adopted: radiographic simulation and its validation with real gammagraphies and establishment of radiographic parameters to complex radiation geometries. The first task to be done was to develop a virtual solid ("NURBS"–Non Uniform Rational B-Spline) representing the flexible riser on the simulation environment. The multi-layers were reliably represented by the solid developed and mainly the helically wound metallic layers, know as wired armours, needed special attention because of the difficulty on the development of the virtual model. Results show the viability of the radiographic inspection analyzing the wired armours rupture and the displacement between wires.

Monitoring Crack Propagation in Turbine Blades Caused by Thermosonic Inspection

---**Gabriel Bolu**, Anthony Gachagan, and Gareth Pierce, University of Strathclyde, Centre for Ultrasonic Engineering, Glasgow, United Kingdom; Gerald Harvey, Rolls Royce, East Kilbride, United Kingdom; Wei Liang Choong, Vibrant NDT Ltd., Smithfield, Sheffield, United Kingdom

---High power acoustic excitation of components during a thermosonic (or Sonic IR) inspection may further propagate existing cracks. Monitoring such changes through destructive or non-destructive means is no trivial task. Process Compensated Resonance Testing (PCRT) technology offers the capability to monitor the growth of fatigue-induced cracks (and other progressive defects) through statistical analysis of changes in a components resonant spectra over time. This technique can be used to detect changes in material properties by comparing a components spectra to itself at regular intervals after systematic exposure to high power excitation associated with thermosonic inspection. In this work, the resonant spectra of 6 cracked and 6 uncracked turbine blades are captured prior to batch of inspections. Next, these spectra are analysed using proprietary software for changes in resonant behaviour. Results from this work indicate that a typical thermosonic inspection of a turbine blade for crack detection does not cause crack propagation or degrade a blades structural integrity.

An FAA Quantified Inspection Success Story
---**Alfred L. Broz**, Federal Aviation Administration, ANE-105N, 12 New England Executive Park, Burlington, MA 01803-5213

---Over a decade ago, the Federal Aviation Administration (FAA), Engine and Propeller Directorate launched a program aimed at reducing the number of Uncontained Engine Failures. That program started out with the title of An Enhanced Engine Inspection Program and transitioned to the Uncontained Engine Failure Program. The premise of that effort was to simply inspect the critical portions of engines more often. The program required intensive interaction between the FAA to mandate the inspections and the engine manufacturers to identify those engines and areas that would profit from the additional effort to reduce the risk of failure. No new inspections were developed. Only existing inspection technology was implemented. Through required inspections, reporting and analysis of each inspection find, was a five fold reduction in the rate accomplished. Historical details leading to the program, and its management will be shared.

Aging Management Using Proactive Management of Materials Degradation (PMMD)
---**L. J. Bond**[1], S. R. Doctor[1], S. E. Cumblidge[1], S. Bruemmer[1], Boyd Taylor[1], G. Carpenter[2], A. B. Hull[2], and S. N. Malik[2], [1]PNNL and [2]NRC

---The Nuclear Regulatory Commission (NRC) has undertaken a program to lay the technical foundations for defining proactive actions to manage degradation of materials in light water reactors (LWRs). The current focus is existing plants, however, if applied to new construction there is potential to better monitor and manage plants throughout their life cycle. This paper discusses the U.S. Nuclear Regulatory Commission's Proactive Management of Materials Degradation (PMMD) program and its application to nuclear power plant structures, systems and components (SSC). The PMMD program is examining the materials and materials degradation phenomena that affect them, and examines these issues in an attempt to predict and prevent problems developing. All parts of a nuclear power plant are subject to the continuous time-dependent degradation of materials due to normal service conditions, which include normal operation and transient conditions; postulated accident and post-accident conditions are excluded. As some forms of degradation, such as stress corrosion cracking, are characterized by a long initiation time followed by a rapid growth phase, new inspection or monitoring technologies may be required. New NDE techniques that may be needed include techniques to find SCC precursors, on-line monitoring techniques to detect cracks as they initiate and grow, and advance in current NDE technologies. Also, many reactor components may or may not have insufficient NDE programs in place to prevent failures in reactors operating well beyond the age range originally intended for the current NDE programs. A review of the reactor components will be needed to determine if new inspection regimes may be required to deal with new degradation mechanisms that may emerge over time. Also, as reactors lifetimes are expanded, degradation mechanisms previously considered too long-term to be of consequence (such as concrete and wiring insulation degradation) may become more important. The paper concisely explains the US NRC program in PMMD, the basic principles of PMMD and its relationship to in-service inspection, condition based maintenance and advanced diagnostics and prognostics. It then provides an assessment of the state of maturity for diagnostic and prognostic technologies, including NDE and related technologies for damage assessment. his development in technology requires advances sensors; better understanding of what and how to measure within a nuclear power plant; enhanced data interrogation, communication and integration; new prediction models for damage/aging evolution; system integration for real-world deployments and quantification of uncertainties in what are inherently ill-posed problems.

Session 6

SESSION 6
NDE FOR MATERIAL PROPERTIES
C.-H. Yang, Chairperson
Chafee 277

1:30 PM **On the Influence of Cold Work on Electrical Resistivity Changes Caused by Thermal Exposure in Nickel-base Superalloys**
---**E. Madhi** and P. B. Nagy, University of Cincinnati, Department of Aerospace Engineering, 745 Baldwin Hall, ML 0070, Cincinnati, OH 45221

1:50 PM **Nondestructive Evalution of Microstructurally Graded Nickel Base Super Alloy Turbine Disk**
---**M. P. Blodgett**, R. W. Martin, and S. Sathish, NDE, Branch, Materials and Manufacturing Directorate, AFRL/WPAFB, Dayton, OH 45433; Structural Integrity Division, University of Dayton Research, Dayton, OH 45469-0121

2:10 PM **Accounting for Structural Noise and Attenuation in the Modeling of the Ultrasonic Testing of Polycrystalline Materials**
---**V. Dorval** and F. Jenson, CEA, LIST, F-91191 Gif-sur-Yvette, France; G. Corneloup and J. Moysan, Université de la Méditerranée, IUT Aix-en-Provence, Avenue Gaston Berger, 13625 Aix en Provence, France

2:30 PM **Microstructure and Thermal Aging Characterization Using Reversible Permeability**
---**C. S. Kim**, Pennsylvania State University, Engineering Science and Mechanics, University Park, PA 16802

2:50 PM **Use of Absolute Amplitude of the Backscattered Signal in the Gimbal-X Technique**
---**D. Enyart**, F. Margetan, and R. B. Thompson, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

3:10 PM ***Break***

3:30 PM **Evaluation of Mechanical Properties in Nimonic-263 by Ball Indentation Technique**
---**G. V. S. Murthy**, M. Das, P. Dubey, and G. Das, Materials Science and Technology Division, National Metallurgical Laboratory, Jamshedpur 831 007, India

3:50 PM **Model-Based Material Characterizations Using Fourier Transform Infrared Spectroscopy**
---**C.-P. Chiou** and R. B. Thompson, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

4:10 PM **Detection of Thermal Damage in X2M Gear Steel Using Barkhausen Noise Analysis**
---**V. Champagne**, P. Sincebaugh, M. Pepi, and D. Snoha, U.S. Army Research Laboratory, Aberdeen Proving Ground, MD 21005

4:30 PM **C-Scan Ultrasonic Evaluation of Al/Ti Brazed Joint**
---**G. V. S. Murthy**, G. Sridhar, Materials Science and Technology Division, National Metallurgical Laboratory, Jamshedpur-831 007, India; A. Kumar and T. Jayakumar, NDE Division, Indira Gandhi Center for Atomic Research, Kalpakkam 603102, India

4:50 PM **Characterization of Material Properties in Solid Oxide Fuel Cells Using a Laser Ultrasound Technique**
---S.-W. Tang and **C.-H. Yang**, Institute of Manufacturing Technology, National Taipei University of Technology, Taipei, Taiwan

On the Influence of Cold Work on Electrical Resistivity Changes Caused by Thermal Exposure in Nickel-base Superalloys

---**Elhoucine Madhi** and Peter B. Nagy, University of Cincinnati, Department of Aerospace Engineering, 745 Baldwin Hall, ML 0070, Cincinnati, OH 45221

---In nickel-base superalloys, irreversible electrical conductivity changes occur above a transition temperature where thermally-activated microstructural evolution initiates. The electrical conductivity first decreases above about 450°C then increases above 600°C. However, the presence of plastic deformation results in accelerated microstructure evolution at an earlier transition temperature. It was recently suggested that this well-known phenomenon might explain the notable conductivity difference between the peened near-surface part and the intact part at sufficiently large depth in surface-treated specimens. The influence of cold work on the electrical conductivity change with thermal exposure offers a probable answer to one of the main remaining questions in eddy current residual stress assessment, namely unusually fast and occasionally even non-monotonic decay of the apparent eddy current conductivity change that was observed at temperatures as low as 400°C. To validate this explanation, the present study investigates the influence of cold work on low-frequency Alternating Current Potential Drop (ACPD) resistivity variations with thermal exposure. In-situ resistivity monitoring was conducted throughout various heating cycles using the ACPD technique. IN-718 nickel-base superalloy specimens with different levels of cold work were exposed to gradually increasing peak temperatures from 400°C to 800°C. The results indicate that the initial rise in irreversible resistivity is approximately one order of magnitude higher and occurs about 50°C earlier in temperature in cold-worked samples of 30% plastic strain than in the intact material.

Nondestructive Evalution of Microstructurally Graded Nickel Base Super Alloy Turbine Disk

---**M. P. Blodgett**, R. W. Martin[1], S. Sathish[1] and J-K. Na[1], NDE Branch, Materials and Manufacturing Directorate, AFRL/WPAFB, Dayton, OH 45433; [1]Structural Integrity Division, University of Dayton Research Institute, Dayton, OH 45469-012

---In high temperature gas turbine engines, the bore region of the disk experience relatively high stress and low temperatures, while the rim region experiences relatively low stress and higher temperatures. The material for the bore region should have high yield strength, high fatigue strength and a high crack growth resistance. On the other hand, the rim region should posses very high creep resistance. It is challenging to develop a disk that requires having competing in the bore and rim. When turbine disks are manufactured with a single microstructure some of the properties are compromised. To achieve optimized properties current turbine engine disks are manufactured by joining two components with two different microstructures. Although this methodology has produced optimized properties, the region of joining has always been a great concern. Recently new disks have been developed that have graded microstructures by combining developments in nickel base super alloys and innovative Dual Microstructure Heat Treatment (DMHT) methods. These new turbine disks have appropriate microstructures and material properties required in the bore and the rim sections of the disk. The new nickel base alloys are multiphase materials with refractory elements intended to strengthen the alloys at high temperatures. The DMHT produced disk has fine grain microstructure in the bore region to enhance the yield strength, fatigue strength and the crack-growth resistance and a coarse grain microstructure in the rim to maximize the creep resistance. Currently there are no standard NDE methods to evaluate the new turbine disks. This paper presents results of conventional NDE methods of ultrasonics, eddy current, x-ray diffraction measurements to evaluate material properties and microstructure variation in the disk. The results will be discussed in the light of the importance of development of appropriate NDE techniques and the challenges to NDE in the evaluation of DMHT nickel base super alloy disks.

Accounting for Structural Noise and Attenuation in the Modeling of the Ultrasonic Testing of Polycrystalline Materials

---**Vincent Dorval** and Frederic Jenson, CEA, LIST, F-91191 Gif-sur-Yvette, France ; Gilles Corneloup and Joseph Moysan, Université de la Méditerranée, IUT Aix-en-Provence, Avenue Gaston Berger, 13625 Aix en Provence, France

---Structural noise and attenuation can cause significant losses in detection performances in the ultrasonic non destructive testing of diffusive metals, such as some austenitic steels. Being able to predict these phenomena can help in designing better testing procedures. In this purpose, a computational method has been developed to take into account both structural noise and attenuation in the simulation of an ultrasonic testing. The method makes use of a single scattering model based on the Born approximation, accounting for anisotropic scattering and for mode conversions. It assumes that scattering is due to the variations in the orientations of anisotropic crystals. Attenuation effects are accounted for by convoluting a computed ultrasonic field with a filter issued from a scattering model. The backscattered noise is predicted by computing the response of a set of point-like scatterers randomly distributed in the inspected volume. The parameters of the statistical distribution of scatterers are determined from the characteristics of the metallurgical structure, using the above scattering model. This ensures that it generates a fully developed speckle equivalent to the speckle caused by a polycrystalline medium. In this communication, the computational method is described and comparisons between its predictions and experimental results are shown.

Microstructure and Thermal Aging Characterization Using Reversible Permeability

---**Chung Seok Kim**, Pennsylvania State University, Engineering Science and Mechanics, University Park, PA 16802

---The recent trend toward the utilization of clean energy to protect the global environment has accelerated the application of ultra supercritical pressure boilers. Such boilers operate for power generation, at higher efficiencies than conventional boilers, and thus release less carbon dioxide. Unfortunately, when these steels are exposed to high temperatures for long durations of time, they undergo a softening of the matrix as a result of precipitate coarsening and dislocation recovery. The objective of this work is to measure the reversible permeability nondestructively from a specimen surface, and experimentally investigate the effects of microstructure on the reversible permeability in thermally aged USC steel, which is the next generation of power plant. Thermal aging was observed to coarsen the as-tempered carbide (Cr23C6), generate the Laves (Fe2W) phase, and decrease the dislocation density. The peak position of the reversible permeability drastically decreased during the initial 1000 h aging period, and was then observed to decrease only slightly thereafter. The variation in peak position of reversible permeability is closely related to the decrease in the number of pinning sites, such as dislocations; fine precipitates; and the martensite lath/subgrain.

Use of Absolute Amplitude of the Backscattered Signal in the Gimbal-X Technique

---**D. Enyart**, Frank Margetan, and R. B. Thompson, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---In the Gimbal-X technique, one insonifies a sample in an immersion configuration and observes the rms ultrasonic backscattered noise as a function of the angle of incidence θ. Based on the hypothesis that the noise peaks when θ is the critical angle for Rayleigh wave generation, θ_{cr}, this provides a single transducer technique for determining the Rayleigh wave velocity. That determination is based on Snell's Law and the experimental measurement of θ_{cr}. This paper extends the understanding of the Gimbal-X technique to the interpretation of the absolute amplitude of the noise, as is complementary to its angular dependence. A theory is presented for the dependence of the absolute amplitude of the rms backscattered noise on the depth dependence of microstructural parameters and the frequency of the measurement. Supporting experiments on case hardened samples are presented. Approaches for inverting experimental data as a function of frequency to estimate depth dependence of the microstructural parameters are then discussed.

---This work was supported by the NSF Industry/University Cooperative Research Program.

Evaluation of Mechanical Properties in Nimonic-263 by Ball Indentation Technique

---**G.V.S. Murthy**, Mousumi Das, Paritosh Dubey, and Goutam Das, Materials Science and Technology Division, National Metallurgical Laboratory, Jamshedpur 831 007, India

---Consideration for mechanical properties of any material/component is a key factor in its technological design, as it degrades as result of the high temperature service exposure. It is also helpful in predicting the remaining life of the component under test and its evaluation in-situ is of utmost importance. Among the various techniques to determine mechanical properties of materials, ball indentation technique (BIT) plays an important role. The BIT has some unique features and it has certain advantages over the conventional mechanical test. This technique requires small amount of test materials. Precipitation takes place during processing and on prolonged exposure to service at elevated temperatures. Consequently, knowledge about the precipitation phases and their influence on the various properties is of fundamental interest not only for its intrinsic study, but also for its technological significance. The purpose of the present study is to explore the possibility of using ball indentation technique (BIT) for investigating and correlating them with microstructure in a nickel-based super alloy Nimonic 263. Yield strength (YS), ultimate tensile strength (UTS), strength co-efficient (K), strain hardening exponent (n), Young Modulus (E), fracture toughness (KJC) and hardness (BHN) can be determined through BIT. The present investigation reveals that this technique can be used effectively for monitoring the strengthening process as a result of the precipitation on ageing at different times and temperatures.

Model-Based Material Characterizations Using Fourier Transform Infrared Spectroscopy

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

---Recently, considerable research efforts have been made towards determining material properties from variable-angle reflectance data by using Fourier transform infrared spectroscopy. The suitability of several modeling and analysis approaches was studied. Variable-angle reflectance data were first simulated for materials of U. S. Air Force's interest in the half-space configuration. The simulation was carried out via semi-quantum oscillator models with parameters closely matching experimental observation. These reflectance data were then used to determine the feasibility of a best-fit algorithm involving Fresnel equations in a non-linear least squares formulation. Particular attention was paid to the Fresnel fit method's stability of inverting the complex refractive indices in the strong bands. Next, material, system and environmental noises were introduced into the simulated data to see if the fitting results could be significantly affected over the entire frequency range. In this project, other conventional techniques such as the Kramers-Kronig transformation as well as other experimental configurations will also be considered. The outcome of this work would provide more insight into the true radiation-matter interactions such as phonon eigen-frequencies and lifetimes. The ultimate goal is to make best fits using oscillator models based on the lattice dynamics of the material in question. The most suitable methods (or their combinations) will be applied towards the tracking of material changes in relevant Air Force materials subject to various stresses, e.g. cyclical heating.---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.

Detection of Thermal Damage in X2M Gear Steel Using Barkhausen Noise Analysis

---**Victor Champagne**, Patrick Sincebaugh, Marc Pepi, and Daniel Snoha, U.S. Army Research Laboratory, Aberdeen Proving Ground, MD 21005

---Vasco X2M steel, in the heat treated and carburized condition is used to produce critical U.S. Army rotorcraft power train components. Grinding is performed to achieve the required dimensional tolerances for precision components while shot peening is performed afterward for the purpose of inducing compressive residual stresses to enhance fatigue resistance. Improper grinding can result in high surface transient temperatures that can reduce the beneficial compressive stresses, or even result in the presence of tensile stresses in the surface layers. If the condition is severe enough it can lead to grinding burns, which reduce wear resistance and fatigue strength, potentially causing premature failure of the component. This paper describes the development and implementation of Barkhausen Noise Analysis (BNA) techniques for detecting thermal damage in X2M steel components. BNA is a nondestructive inspection method that has been shown to be sensitive to microstructural and residual stress variations in ferromagnetic materials. BNA data will be presented for X2M samples with various degrees of thermal damage, prior to and subsequent to shot peening. X-Ray Diffraction residual stress measurements and microstructural analysis results will also be presented. The effect of the microstructure, in this case the percentage of carbides present, is a complex phenomena and warrants further study. The goal of this effort was to determine whether BNA techniques could be used to differentiate between two different heat treatments. The BNA data clearly demonstrates that it is feasible to use BNA methods to differentiate between the two heat treatments used on the X2M steel samples in this study.

C-Scan Ultrasonic Evaluation of Al/Ti Brazed Joint

---**G.V.S. Murthy**, G. Sridhar, Materials Science and Technology Division, National Metallurgical Laboratory, Jamshedpur-831 007, India; Anish Kumar and T. Jayakumar, NDE Division, Indira Gandhi Center for Atomic Research, Kalpakkam 603102, India

---A brazed joint of Al/Ti was characterized by ultrasonic C-scan method. The study revealed certain debond locations in the brazed joint suggesting metal and air interface. These debond locations would have resulted due to the failure of filler material's joining ability. In spite of certain amount of load applied on the braze base metals, the above debonding happened. The debond locations further confirm that the pressure was not sufficient and therefore the debonds are present at exactly the same location where there were gaps in the fixture. Further analysis revealed that these debonds were present at the interface between the braze material and Al-plate. It is concluded that ultrasonic C-scan can be effectively used to evaluate the bond characteristics in a brazed joint between dissimilar metals.

Characterization of Material Properties in Solid Oxide Fuel Cells Using a Laser Ultrasound Technique

---Sheng-Wei Tang and **Che-Hua Yang**, Institute of Manufacturing Technology, National Taipei University of Technology, Taipei, Taiwan

---Solid oxide fuel cell (SOFC) has attracted much attention as a promising source of electrical power generation because of its high efficiency in converting chemical energy to electrical power. The main structure of SOFC is a three-layered structure with the electrolyte sandwiched by anode and cathode. The ceramic materials make the SOFC capable of operating at elevated temperatures in the range 500-1000℃. However, the ceramic structure also suffers the difficulties in the control of geometrical and mechanical properties. For example, thickness of the electrolyte is desired to be controlled within 15 micros with good uniformity. Other mechanical properties also subject to substantial variations during the manufacture process. Therefore, monitoring of anode and electrolyte material properties is an important issue. This research is aimed at the nondestructive characterization of anode and electrolyte properties. An ultrasonic nondestructive procedure employing a laser ultrasound technique (LUT) together with an inversion algorism is used to characterize the ceramic SOFC layer properties. By investigating the dispersion spectra of Lamb waves propagating in the layered structure followed by a simplex algorism, thicknesses and mechanical properties of the SOFC anode and electrolyte are obtained. The obtained material properties are compared with those in the literature where destructive methods are employed.

TUESDAY

TUESDAY, JULY 28, 2009

	Session 7 **Guided Waves I** ***CBLS 100***	**Session 8** **EC Fundamentals and Probes I** ***Chafee 277***	**Session 9** **NDE of Composites** ***CBLS 010***	**Session 10** **Inversion, Reconstruction, and Characterization** ***Chafee 273***
8:30 AM				
8:50				
9:10				
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9:50				
10:10	COFFEE BREAK			
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11:30				
11:50				
12:10 PM	LUNCH			
Session 11 – POSTERS – 1:30 – 3:10 PM – Memorial Union Ballroom				
	Session 12 **Guided Waves II** ***Chafee 277***	**Session 13** **EC Fundamentals and Probes II** ***CBLS 010***	**Session 14** **Thermography and Thermosonics I** ***CBLS 100***	**Session 15** **Benchmark Problems** ***Chafee 273***
3:10	COFFEE BREAK			
3:30				
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5:10				
5:30	ADJOURN			

Session 7

SESSION 7
GUIDED WAVES I
D. Chimenti, Chairperson
CBLS 100

8:30 AM **Born Inverse Scattering Analysis of SH Guided Waves for Plate Thinning**
---**S. Hirose** and K. Kudo, Tokyo Institute of Technology, Department of Mechanical and Environmental Informatics, 2-12-1, W8-22 O-okayama, Meguro-ku, Tokyo, Japan

8:50 AM **Feasibility of Guided Wave Diffraction Tomography within the Born Approximation**
---**P. Belanger** and P. Cawley, Imperial College, Mechanical Engineering, London, United Kingdom

9:10 AM **Directionality of the Scattering of the A0 Lamb Wave Mode at Cracks**
---**P. Fromme**, University College London, Department of Mechanical Engineering, London, WC1E 7JE, United Kingdom

9:30 AM **Characterization of Surface Treated Aero Engine Alloys by Rayleigh Wave Velocity Dispersion**
---**B. Koehler** and M. Barth, Fraunhofer IZFP, Dresden Branch, Dresden, Germany; J. Bamberg, and H.-U. Baron, MTU Aero Engines GmbH, Nondestructive Testing (TEFP), Munich, Germany

9:50 AM **Model-Based In Situ Parameter Estimation of Ultrasonic Guided Waves in an Isotropic Plate**
---**J. S. Hall** and J. E. Michaels, Georgia Institute of Technology, School of Electrical and Computer Engineering, Atlanta, GA 30332-0250

10:10 AM ***Break***

10:30 AM **Leak Location in Spacecraft Using Structure-Borne Noise**
---**R. Reusser**, S. Holland, D. Chimenti, and R. Roberts, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

10:50 AM **Damage Detection in a Real Complex Structure with a Guided Wave SHM Sparse Array System**
---**T. Clarke** and P. Cawley, Research Centre in Non-Destructive Evaluation, Mechanical Engineering Department, South Kensington Campus, Exhibition Road, London SW72AZ, United Kingdom

11:10 AM **Simulation of Inspections of Elastic Waveguides of Arbitrary Section Containing Arbitrary Local Discontinuities or Defects**
---**A. Lhémery**, V. Baronian, and K. Jezzine, CEA, LIST, Gif-sur-Yvette, France; V. Baronian and A.-S. Bonnet-BenDhia, ENSTA, POEMS, Paris, France

11:30 AM **Modelling Propagation of Ultrasonic Guided Waves in the Asymmetric Layered Steel/Grout/Steel Structures**
---V. Zernov and **L. Fradkin**, London South Bank University, Department of Electrical, Computer and Communications Engineering, 103 Borough Road, London SE1 0AA, United Kingdom

11:50 AM **Axial Higher Order Modes Cluster (HOMC) Guided Wave for Pipe Inspection**
---C. Jayaraman, C. V. Krishnamurthy, and **K. Balasubramaniam**, Indian Institute of Technology-Madras, Department of Mechanical Engineering,Chennai, India

12:10 PM ***Lunch***

Born Inverse Scattering Analysis of SH Guided Waves for Plate Thinning

---**Sohichi Hirose** and Kei Kudo, Tokyo Institute of Technology, Department of Mechanical and Environmental Informatics, 2-12-1, W8-22 O-okayama, Meguro-ku, Tokyo, Japan

---Recently, ultrasonic guided waves are of interest for nondestructive testing and structural health monitoring of large structures. For the purpose of quantitative evaluation, scattering problems of guided waves have been solved by using various numerical methods. Among them, the mode-exiting method, proposed by Hirose and his colleagues, provides an efficient tool to obtain the amplitude of each reflected wave mode in a plate or pipe. In this paper, the Born inverse scattering analysis is developed to reconstruct the shape of plate thinning from the reflected amplitudes of SH guided waves. The integral formula for reflected SH guided waves is obtained in conjunction with the Green's function of SH waves in a plate. Introducing the Born approximation into the integral formula, the amplitudes of reflected SH guided waves can be expressed in terms of the Fourier transform of the shape function of plate thinning. Thus the shape of plate thinning is reconstructed by taking the inverse Fourier transform of the reflected amplitudes of SH guided waves. Numerical simulation is presented to show the efficiency of the proposed inverse scattering method.

Feasibility of Guided Wave Diffraction Tomography within the Born Approximation

---**Pierre Belanger** and Peter Cawley, Imperial College, Mechanical Engineering, London, United Kingdom

---Detection and sizing of corrosion in pipelines and pressure vessels over large partially accessible areas is of growing interest in the petrochemical industry. Low-frequency guided wave diffraction tomography is a potentially attractive technique to rapidly evaluate the thickness of large sections of partially accessible structures. The diffraction tomography algorithms were developed in ultrasonic medical and geophysical imaging and are here adapted to guided wave inspection of plates and pipes in the context of full view imaging. The reconstruction of a map of the remnant thickness is produced from the amplitude and phase of the scattered field generated by the defects in the area of inspection. Finite element simulations of a 64 element circular array on a plate have shown that when the scattered field is perfectly separated from the incident field the reconstruction of the thickness is very accurate provided that the phase difference between the incident and scattered fields is within the validity of the Born approximation. The practical implementation is however more challenging because the incident field is not known. Hence the frequency response function of each transducer in the array as well as the wavelength in the plate must be measured in order to simulate the incident field. Experimental results show that ultimately the scattering from the array of transducer is the major source of error in the isolation of the scattered field in the total field, and consequently in the tomographic reconstruction.

Directionality of the Scattering of the A0 Lamb Wave Mode at Cracks

---**Paul Fromme**, University College London, Department of Mechanical Engineering, London, WC1E 7JE, United Kingdom

---Localized and distributed array systems for guided ultrasonic waves offer an efficient way for the long-term monitoring of the structural integrity of large structures. However, the detection sensitivity for fatigue cracks depends on the orientation of the crack relative to the position of the transducer elements. Finite Element (FE) simulations show that for cracks and slots no energy is scattered in certain directions from the defect. Crack-like defects have a directionality pattern of the scattered field depending on the angle of the incident wave relative to the crack orientation and on the ratio of the characteristic defect size and depth to wavelength. Simulation predictions are compared to laser measurements of the scattered wave field at machined part-through and through-thickness notches. Good agreement is found and the directionality pattern can be predicted accurately. These results provide the basis for the quantification of the detection sensitivity for defects in plate structures using guided wave sensors and arrays.

Characterization of Surface Treated Aero Engine Alloys by Rayleigh Wave Velocity Dispersion

---**Bernd Koehler** and Martin Barth, Fraunhofer IZFP, Dresden Branch, Dresden, Germany; Joachim Bamberg, and Hans-Uwe Baron, MTU Aero Engines GmbH, Nondestructive Testing (TEFP), Munich, Germany

---In aero engines mechanically high stressed components made of high-strength alloys like IN718 and Ti6Al4V are usually surface treated by shot-peening. Other methods, e.g. laser-peening, deep rolling and low plasticity burnishing are also available. All methods introduce compressive residual stress desired for minimize sensitivity to fatigue or stress corrosion failure mechanisms, resulting in improved performance and increased life of components. Beside that, also cold work is introduced in an amount varying from method to method. To determine the remaining life time of critical aero engine components, a quantitative non-destructive determination of compressive stresses is required. It has been shown that high frequency eddy current techniques are able to characterize shot peened IN718 alloys but not as well Ti6Al4V alloys. Investigations to separate the influence of stress and cold work to the eddy current signals are presented in another contribution to this conference. This paper deals with the potential of the Rayleigh wave velocity and its dispersion for getting the desired information. The Rayleigh waves are excited by conventional probes and detected by a laser vibrometer. This method determines not only the velocity at a single frequency but its dispersion over a wide frequency range. It could be shown that the surface treatment can be characterized by Rayleigh wave dispersion. The separation of the influence of compressive stress and cold work is subject to ongoing work. Besides a pure Rayleigh wave approach also a combination of ultrasonic Rayleigh wave and high frequency eddy current measurements is considered.

Model-Based In Situ Parameter Estimation of Ultrasonic Guided Waves in an Isotropic Plate

---**James S. Hall** and Jennifer E. Michaels, Georgia Institute of Technology, School of Electrical and Computer Engineering, Atlanta, GA 30332-0250

---Most ultrasonic systems employing guided waves for flaw detection require information such as dispersion curves, transducer locations, and expected propagation loss. Degraded system performance may result if assumed parameter values do not accurately reflect the actual environment. By characterizing the propagating environment in situ at the time of test, potentially erroneous a priori estimates are avoided and performance of ultrasonic guided wave systems can be improved. A five-part model-based algorithm is proposed to estimate parameters of an assumed propagation model to best match the received signals. This approach leverages the inherent constraints of the assumed model to estimate dispersion curves, propagation loss, transducer distances, transmitted signal, and mode weighting coefficients. Performance is demonstrated on signals obtained from theoretical dispersion curves, finite element modeling, and experimental data. Quantitative performance curves are also presented that show parameter estimation accuracy as a function of the signal-to-noise ratio.

Leak Location in Spacecraft Using Structure-Borne Noise

---**R. Reusser**, S. D. Holland, D. Chimenti, and R. Roberts, Center for NDE, Iowa State University, 1915 Scholl Road, Ames, IA 50011

---Guided ultrasonic waves, generated by air escaping through a small hole, have been measured with an 8x8 piezoelectric phased-array detector. Rapid location of air leaks in a spacecraft skin, caused by high-speed collisions with small objects, is essential for astronaut survival. Cross correlation of all 64 elements, one pair at a time, on a diced PZT disc combined with synthetic aperture analysis determines the dominant direction of wave propagation. The leak location is triangulated by combining data from two or more sensors. To optimize the frequency band selection for the most robust direction finding, noise-field measurements of a plate with integral stiffeners have been performed using laser Doppler velocimetry. In this talk, we will compare optical and acoustic measurements to analyze the influence of the PZT sensor and its mechanical coupling to the plate.

Damage Detection in a Real Complex Structure with a Guided Wave SHM Sparse Array System

---**Thomas Clarke** and Peter Cawley, Research Centre in Non-Destructive Evaluation, Mechanical Engineering Department, South Kensington Campus, Exhibition Road, London Sw72AZ, United Kingdom

---A sparse array SHM system based on guided waves was applied to the door of a commercial shipping container. The door comprised a corrugated steel panel approximately 2.4 m by 2.4 m surrounded by a box beam frame and testing was performed in a non-laboratory environment. A 3D finite element model of the corrugations was used to obtain incidence angle-dependent transmission coefficients for the A0 and S0 modes, in order to evaluate which provided better coverage of the structure. It was found that the S0 mode transmission across the corrugations was substantially stronger and this mode was used in the main test series. A sparse array with 9 transducers was attached to the structure and signals from the undamaged structure were recorded at periodic intervals over a three week period and the resulting signal database was used for temperature compensation of subsequent signals. Defects in the form of holes whose diameter was increased incrementally from 1 to 10 mm were introduced at two different points of the structure and signals were taken for each condition. Direct analysis of subtracted signals allowed understanding of the defect detection capability of the system. Comparison of signals transmitted between different transducer pairs before and after damage was used to give an initial indication of defect detectability. Signals from all combinations of transducers were then used in imaging algorithms and good localization of holes with 5mm diameter or above was possible in the 2.4m square structure.

Simulation of Inspections of Elastic Waveguides of Arbitrary Section Containing Arbitrary Local Discontinuities or Defects

---**Alain Lhémery**, Vahan Baronian, and Karim Jezzine, CEA, LIST, Gif-sur-Yvette, France; Vahan Baronian and Anne-Sophie Bonnet-BenDhia, ENSTA, POEMS, Paris, France

---In waveguides, flaws or variations of guide shape (discontinuities) cause scattering. Incident modes reflect or are converted into new modes; their transmission through discontinuities is similarly affected. Guided waves (GW) NDT methods rely on the analysis of reflected or transmitted modes relatively to what happens in a sound guide. Simulation tools are essential to handle the inherent complexity of GW propagation and scattering; they help to optimize configurations, to interpret measurements. As GW analysis always refers to mode amplitudes, it is advantageous to exploit the modal nature of GW in the simulation itself. This simplifies the interpretation of overall or partial results (considering the various phenomena involved); this avoids developing post-processing techniques and running their time-consuming computations as required if results are calculated with no reference to modes. Two modal formulations (previously presented in this series) to simulate NDT-GW measurements (pitch-catch, pulse-echo) are used to link a semi-analytic finite element code for the modal solution in arbitrary guides, a model of radiation and reception by transducers and a specific finite element model for GW scattering by arbitrary discontinuities. The paper reviews these simulation tools. Examples of interest for NDT illustrate their capabilities to address complex configurations and to help interpretation.

Modelling Propagation of Ultrasonic Guided Waves in the Asymmetric Layered Steel/Grout/Steel Structures

---Victor Zernov and **Larissa Fradkin**, London South Bank University, Department of Electrical, Computer and Communications Engineering, 103 Borough Road, London SE1 0AA, United Kingdom

---Ultrasonic guided waves are widely used for inspecting industrial structures at long range. One of the challenges facing the technology is the control of inspection range: the engineers to be able to predict whether and under which conditions enough wave energy is delivered to the area containing possible damage. We study propagation of guided waves along a tubular monopile constituting the support of a wind turbine tower. A monopile of a large radius can be modelled as a couple of overlapping grouted steel plates immersed or partially immersed in water: The waves are excited by a transducer installed on the joint's butt-end. The model allows for the energy losses caused by the radiation into water. We split the construction into several simple waveguides and represent the displacement field in each as a sum of the Rayleigh-Lamb modes. These are chosen to satisfy the appropriate boundary conditions. The solution of the resulting system of linear equations allows us to calculate the reflection and transmission coefficients on the waveguide boundaries. The coefficients display an interesting beating or pass band/stop band behavior that can be used to choose the carrier frequency that focuses the ultrasonic energy on the prescribed portions of the structure. The modelling has been carried out for symmetric and asymmetric structures. The results indicate the presence of the beating effect in both cases, but it is less pronounced for the asymmetric configuration due to the absence of purely symmetric and antisymmetric modes. The inspection of an asymmetric structure is also complicated by the presence of high attenuation for all modes, when the structure is immersed in water, whereas in a symmetric configuration some advantageous regimes can be found to make energy losses in water practically negligible.

Axial Higher Order Modes Cluster (HOMC) Guided Wave for Pipe Inspection

---Chandrasekaran Jayaraman, C. V. Krishnamurthy, and **Krishnan Balasubramaniam**, Indian Institute of Technology-Madras, Department of Mechanical Engineering,Chennai, India

---This paper reports the potential of Higher Order Modes Cluster Guided Waves (HOMC-GW) which are highly non-dispersive for axial testing in pipe over a couple of meters. The HOMC-GW is a recently explored phenomena which is found to occur at very high frequency-thickness product i.e. 15 MHz.mm to 35 MHz.mm. 2D ABAQUS finite element simulations were used to decide the optimal wedge angle which facilitates the generation of the HOMC-GW. Experiments were carried out on a 6 inch diameter mild steel pipe with machined pin hole type defects of various diameter and depth. A commercial 2.25 MHz, 1 inch diameter transducer mounted on a machined acrylic wedge was used. The potential of axially propagating HOMC-GW on pipe like structures is being brought into light.

Session 8

Tuesday, July 28, 2009

SESSION 8

EC FUNDAMENTALS AND PROBES I

J. Bowler, Chairperson
Chafee 277

8:30 AM **Innovative Eddy Current Probe for Micro Defects**
---**T. Santos**, P. Vilaça, and L. Quintino, IDMEC, Institute of Mechanical Engineering, Av. Rovisco Pais, 1049-001 Lisbon, Portugal; J. dos Santos, GKSS Forschungszentrum Geesthacht GmbH, Institute of Materials Research, WMP, Max-Planck-Street 1, D-21502 Geesthacht, Germany

8:50 AM **Characterizing and Modeling Ferrite-Core Probes**
---**H. A. Sabbagh**, R. K. Murphy, and E. H. Sabbagh, Victor Technologies, LLC, PO Box 7706, Bloomington, IN 47407-7706; J. C. Aldrin, Computational Tools, Gurnee, IL 60031

9:10 AM **Experimental Based Discussion for Separation of Residual Stress and Cold Work in Shot Peened IN718 with High Frequency Eddy Current Spectroscopy**
---**S. Hillmann**, H. Heuer, A. Robbert, and N. Meyendorf, Fraunhofer Inst. for Non-Destructive Testing, Dresden, Germany; H.-U. Baron and J. Bamberg, MTU Aero Engines GmbH, Munich, Germany

9:30 AM **A Novel Boundary Integral Equation for the Surface Crack Model**
---H. Xie, **J. Song**, and M. Yang, Iowa State University, Department of Electrical and Computer Engineering, Ames, IA 50011; N. Nakagawa, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

9:50 AM **Limitations of Eddy Current Residual Stress Profiling in Surface-Treated Engine Alloys of Various Hardness Levels**
---B. A. Abu-Nabah, General Electric Aviation, Cincinnati, OH 45221; W. T. Hassan, Rolls-Royce Corporation, Indianapolis, IN 46241; M. P. Blodgett, Air Force Research Laboratory, WPAFB, Dayton, OH 45433; **P. B. Nagy**, University of Cincinnati, 745 Baldwin Hall, ML 0070, Cincinnati, OH 45221

10:10 AM ***Break***

10:30 AM **Finite Element Modeling of Pulsed Eddy Current Signals from Aluminum Plates Having Defects in the Presence of Ferrous Fastener**
---**V. K. Babbar**, D. D. Harlley, and T. W. Krause, Royal Military College of Canada, Department of Physics, Kingston, Ontario, Canada

10:50 AM **Flexible and Array Eddy Current Probes for Fast Inspection of Complex Parts**
---**M. Marchand**, M. Decitre, and M. Casula, CEA, LIST, Batiment 611, Point Courrier 120, Saclay, F-91191 Gif-sur-Yvette, France

11:10 AM **A Hybrid Volume Integral-Finite Elements Approach for the Simulation of Eddy Current Inspection of Steam Generator Tubes in the Region of Quadrifoiled Support Plate**
---A. Skarlatos, C. Gilles-Pascaud, and **G. Pichenot**, CEA, LIST, F-91191 Gif-sur-Yvette, France; G. Cattiaux and T. Sollier, IRSN, B.P. 17, 92262 Fontenay-aux-Roses, France

11:30 AM **Development of a Field Concentrator Coil by Finite Element Modeling to Optimize Power Efficiency in Eddy Current Thermography Inspection**
---**M. Grenier**, C. Ibarra-Castanedo, and X. Maldague, Electrical and Computing Engineering Department, Université Laval, Quebec City, QC, Canada

11:50 AM **Eddy Current Testing and Four-Point Probe Measurement of Nano/Macro Materials Enhanced Polymeric Composites**
---**R. Ko**, T. Gibson, and J. Fielding[1], [1]Air Force Research Laboratory, WPAFB, Dayton, OH 45433; University of Dayton Research Institute, 300 College Park Drive, Dayton, OH 45469

12:10 PM ***Lunch***

Innovative Eddy Current Probe for Micro Defects

---**Telmo Santos**, Pedro Vilaça, Luísa Quintino, IDMEC, Institute of Mechanical Engineering, Av. Rovisco Pais, 1049-001 Lisbon, Portugal; Jorge dos Santos, GKSS Forschungszentrum Geesthacht GmbH, Institute of Materials Research, WMP, Max-Planck-Street 1, D-21502 Geesthacht, Germany

---Solid state welding processes, e.g. Friction Stir Welding (FSW) and Friction Stir Spot Welding (FSpW), frequently originate micro defects of less than 75 micron. The morphology and location of these defects lead to a high loss of mechanical properties of the joints under fatigue. Moreover, actual NDT reliability in characterizing and sizing these defects still remains a challenge. This paper reports the development of an innovative eddy current (EC) probe, and its application to these defects. The new EC probe presents innovative concept issues, allowing 3D induced current in the material, a lift-off independence, and an easy interpretation of the signal based on a comprehensible qualitative change. A dedicated algorithm was computational implemented to quantify the signal features allowing defects sizing. Analytical and numerical simulation tools were developed. The theoretical results fully agree with experiments and it helps on defects characterization. Validation experiments were performed on aluminum alloys processed by FSW and FSpW. The probe was also tested on standard defects and in Fiber Metal Laminate composites. All results were compared with conventional helicoidally and planar spiral EC probes. The results clearly show that the new EC probe is able to detect and sizing surface defects about 50 micros depth.

Characterizing and Modeling Ferrite-Core Probes

---**Harold A. Sabbagh**, R. Kim Murphy, and Elias H. Sabbagh, Victor Technologies, LLC, PO Box 7706, Bloomington, IN 47407-7706; John C. Aldrin, Computational Tools, Gurnee, IL 60031

---Accurate models of the subsystems that go into eddy-current nondestructive evaluation (NDE) are required if progress is to be made through the disciplines of model-assisted probability of detection (MAPOD) and model-based inversion (MBI). Perhaps the most crucial subsystem in eddy-current NDE is the probe, and in this paper we accurately and carefully characterize a ferrite-core probe that is widely used in the US Air Force. The characterization starts with the development of a model that can be executed using the proprietary volume-integral code, VIC-3D(c), and then the model is fitted to measured multifrequency impedance data taken with the probe in freespace and over samples of Ti-6Al-4V and aluminum. The agreement between the VIC-3D(c) model and experimental data for both aluminum and titanium was quite good, even through the resonance regime. The foundations of the VIC-3D(c) model of the ferrite core probe will be discussed.

Experimental Based Discussion for Separation of Residual Stress and Cold Work in Shot Peened IN718 with High Frequency Eddy Current Spectroscopy

---**Susanne Hillmann**, Henning Heuer, Alexander Robbert, Norbert Meyendorf, Fraunhofer Institute for Non-Destructive Testing, Dresden, Germany; Hans-Uwe Baron and Joachim Bamberg, MTU Aero Engines GmbH, Munich, Germany

---Typical aero engine-alloys like IN718 can be surface-treated by use of shot peening to induce the compressive strain near the surface. To calculate the remaining time of operation for those critical aero engine components, a quantitative non-destructive determination of strain gradients near the surface has to be developed. We could show in the past, that it is possible by use of high frequency eddy current techniques to obtain a characteristic depth profile of the electrical conductivity in the surface of the shot peened specimen. The measured conductivity profile is a resultant from residual stresses, cold work, surface roughness and the microstructure of the material. The aim is to measure separately only the residual stress in the components after a defined life time. It can be assumed, that the roughness and the microstructure are not changing in the IN718 during lifetime, but the cold work and residual stresses are changing both simultaneous. So there is a need to separate information from both material properties in the signal of the eddy current conductivity to get only information from the residual stress. This paper presents results of different experiments which try to separate both effects by use of the eddy current technique on shot peened IN718. We present different physical approaches and the experiments to solve them. We will show that there is a need to use other additional techniques like ultrasonic time of flight measurements to separate the effect of residual stresses from the mixed signal with the cold work.

A Novel Boundary Integral Equation for the Surface Crack Model

---Hui Xie, **Jiming Song**, and Ming Yang, Iowa State University, Department of Electrical and Computer Engineering, Ames, IA 50011; Norio Nakagawa, Iowa State University, Center FOR NDE, 1915 Scholl Road, Ames, IA 50011

---Boundary element method is one of the widely used numerical approaches for solving eddy-current nondestructive evaluation (EC NDE) problems due to its high efficiency and the ability to handle complex geometries. The key part of this method is to find appropriate boundary integral equation (BIE). A novel BIE is developed for the EC NDE problems with surface crack under a uniform applied field. Once the field and its normal derivative are obtained for the structure in the absence of cracks, the normal derivative of scattered field on the surface can be calculated by solving this equation with the aid of the method of moments. This equation is more efficient than the conventional BIE because of a smaller computational domain. Two kinds of 2D EC NDE problems are solved numerically through applying this proposed BIE. The first problem is that of a surface crack in the half-space conductor. To verify the equation and implementation, our results are compared with the published data and there is a good agreement between them. The second problem is that of a surface crack in the quarter-space conductor. Some new results for this problem will be presented.

Limitations of Eddy Current Residual Stress Profiling in Surface-Treated Engine Alloys of Various Hardness Levels

---Bassam A. Abu-Nabah, General Electric Aviation, Cincinnati, OH 45221, Waled T. Hassan, Rolls-Royce Corporation, Indianapolis, IN, Mark P. Blodgett, Air Force Research Laboratory, WPAFB, Dayton, OH and **Peter B. Nagy**, University of Cincinnati, 745 Baldwin Hall, ML 0070, Cincinnati, OH 45221

---Recent research results indicate that eddy current conductivity measurements can be exploited for nondestructive evaluation of subsurface residual stresses in surface-treated nickel-base superalloy components. According to this approach, first the depth dependent electric conductivity profile is calculated from the measured frequency-dependent apparent eddy current conductivity spectrum. Then, the residual stress depth profile is calculated from the conductivity profile based on the piezoresistivity coefficient of the material, which is determined separately from calibration measurements using known external applied stresses. This paper presents new results that indicate that in some popular nickel-base superalloys the relationship between the electric conductivity profile and the sought residual stress depth profile is more tenuous than previously thought. In particular, it is shown that in IN718 the relationship is very sensitive to the state of precipitation hardening and could render this technique unsuitable for eddy current residual stress profiling in components of 36 HRC or harder, i.e., in most critical engine applications.

Finite Element Modeling of Pulsed Eddy Current Signals from Aluminum Plates Having Defects in the Presence of Ferrous Fastener

---**Vijay K. Babbar**, David D. Harlley, and Thomas W. Krause, Royal Military College of Canada, Department of Physics, Kingston, Ontario, Canada

---Pulsed eddy current technology is being developed for detection of flaws located at depth in airplane wing structures. The defects, such as cracks, present near a ferrous fastener are difficult to detect because of the strong signal produced by high permeability fastener material. The magnitude and resolution of the output defect signal can be improved by varying probe design parameters and also by appropriate positioning of the probe over the sample. The present work investigates the effect of some of these parameters on the output signal by using three-dimensional finite element modeling employing COMSOL Multiphysics package. The model incorporates a reflection-type probe consisting of driver, pickup coil and ferrite core, which is placed on a multilayer aluminum structure having a defect. Models were produced to investigate the effect of changing number of turns of the driver, length of the ferrite core, and permeability of the core on current distribution and penetration depth within the multilayer structure. A probe of a particular configuration was also used to model the effect of changing probe position over the multilayer structure embracing a hole. The modeled results were validated against experimental observations. The results are discussed on the basis of existing theory.

Flexible and Array Eddy Current Probes for Fast Inspection of Complex Parts

---**M. Marchand**, M. Decitre, and M. Casula, CEA, LIST, batiment 611, point courrier 120, Saclay, F-91191 Gif-sur-Yvette, France

---The inspection of complex geometry parts requires lift-off minimization. In this purpose, flexible eddy-current probes are particularly well adapted. Different sensor technologies have been investigated at CEA LIST in the aim of detecting surface flaws and buried flaws. A first technology based on magnetic sensor embedded into silicone has been developed to detect flaws buried into complex parts. These sensors show great interest because of their high sensitivity and large bandwidth and make the probe efficient. For the detection of small surface breaking flaws, a second technology has been adopted, based on micro-coils etched on kapton film which is set on a silicone roll. Its shape can be designed to fit to the part and reduce lift-off variations. On the other hand, high spatial fast scanning is a real challenge in Non-Destructive-Testing, especially for aeronautical industry. Consequently, probes with high density large arrays of micro-coils (up to 256 coils) or magnetic sensors (up to 96 sensors) have been designed. Compared to conventional probes, pitch is reduced (100µm) in order to make possible the detection of very small surface notches (200µm). In this communication we describe the different probes. Their performances of detection are shown on experimental results and discussed.

A Hybrid Volume Integral-Finite Elements Approach for the Simulation of Eddy Current Inspection of Steam Generator Tubes in the Region of Quadrifoiled Support Plate

---A. Skarlatos, C. Gilles-Pascaud, and **G. Pichenot**, CEA, LIST, F-91191 Gif-sur-Yvette, France ; G. Cattiaux and T. Sollier, IRSN, B.P. 17, 92262 Fontenay-aux-Roses, France

---The accumulated experience from the operational performance of various steam generators give evidence that the parts of the primary circuit tubes situated near the tube support plates (TSP) are prone to corrosion and stress cracking. The successful detection of such material flaws near the TSP is thus a non-negligible request for the applied inspection procedure. A simulation tool which allows the accurate modelling of the TSP influence to the measured signals is thus beneficial for the validation and the optimization of existing industrial nondestructive testing procedures and may offer an important aid to the development of future techniques. In this context and in the framework of a CEA - IRSN collaboration, a hybrid volume integral method-finite elements approach has been developed in the CIVA plateform to simulate eddy current inspection near TSP with trifoil or quadrifoil shaped holes. With this coupled method, the primary field is calculated using a finite elements so lver (namely Flux3D) for the tube-support plate ensemble whereas the flaw response is calculated via the volume integral method already implemented in CIVA. The results of the proposed hybrid technique has been validated using experimental results with tubes containing electro eroded notches. In addition, some simple signal processing techniques based in frequency mixing has been tested for the suppression of the plate signal and recovering the flaw signal.

Development of a Field Concentrator Coil by Finite Element Modeling to Optimize Power Efficiency in Eddy Current Thermography Inspection

---**Marc Grenier**, Clemente Ibarra-Castanedo, and Xavier Maldague, Electrical and Computing Engineering Department, Université Laval, Quebec City, QC, Canada

---Eddy current thermography is a relatively new inspection technique that takes advantage of the electromagnetic induction phenomenon to generate heat in electro conductive materials during inspection. An interesting advantage of eddy current heating compared to classical optical or ultrasonic heating is that the excitation source is smaller and can be conveniently shaped in order to provide energy efficient localized heating. Such excitation source is more suitable for the development of portable instruments and to perform field inspections. In this paper, finite element modeling (FEM) is used to optimize the eddy current coil configuration in terms of heating power efficiency. The performances of air-core coils, normally used in eddy current thermography, and a new field concentrator coil are compared and discussed. FEM results demonstrate that the proposed field concentrator coil improves the magnetic coupling with the inspected material and requires less energy than air-core coils to generate the same temperature variation. Experimental results show good agreement with finite element simulations and confirm the improvement in power efficiency.

Eddy Current Testing and Four-Point Probe Measurement of Nano/Macro Materials Enhanced Polymeric Composites

---**Ray Ko**, Thao Gibson, Jennifer Fielding[1], [1] Air Force Research Laboratory, Wright-Patterson Air Force Base, Dayton, Ohio 45433; University of Dayton Research Institute, 300 College Park Drive, Dayton, Ohio 45469

---Nano and macro materials are being engineered into polymeric composites to enhance the electrical conductivity for lightning strike protection purposes. These materials have certain advantageous characteristics that can enhance the bulk properties of components to which they are added. Traditional nondestructive evaluation (NDE) methods cannot realistically be expected to monitor individual nano material in such components. However, NDE techniques can possibly detect and quantify the macroscopic physical properties that are being designed into these advanced materials. In the above examples, electrical conductivity can be measured using electromagnetic techniques. Bulk electric conductivity can be simply determined by measuring the resistance based on four-point probe measurements. Eddy current methods can provide a more localized measure of conductivity on the surface of a component. In this study, engineered components containing both marco/nano materials have been fabricated. Eddy current measurements were made on these specimens to quantify the sensitivity of this method to the relevant variables and to sources of noise. Preliminary results from eddy current evaluation and four-point probe measurement of enhanced polymeric composites containing nano/marco materials will be presented.

Session 9

Tuesday, July 28, 2009

SESSION 9
NDE OF COMPOSITES
S. K. Brady, Chairperson
CBLS 010

8:30 AM **Exploiting Changes in Dielectric Dissipation to Detect Thermal Degradation in Polymers and Composites**
---**S. K. Brady,** The Boeing Company, P. O. Box 3707, Seattle, WA 98124-2207

8:50 AM **Finite Element Model for Guided Wave Damage Detection in a Composite Plate**
---**K. Qi** and G. Zhao, Intelligent Automation, Inc., Rockville, MD 20855; K. Qi and J. L. Rose, The Pennsylvania State University, Department of Engineering Science and Mechanics, University Park, PA 16802

9:10 AM **Porosity Detection in CFRP Specimens - Thermal Measurements and 3D Numerical Simulations for Quantitative Evaluation of Effective Thermal Diffusivity Models**
---**G. Mayr**, G. Hendorfer, and B. Plank, Upper Austria University of Applied Sciences, Research and Development, Wels, Austria; J. Sekelja, FACC AG, Advanced Composite Components, Ried, Austria

9:30 AM **Use of Acoustic Emission to Monitor Progressive Damage Accumulation in Kevlar® 49 Composites**
---**J. M. Waller** and R. L. Saulsberry, NASA-JSC White Sands Test Facility, Laboratories Department, Las Cruces, NM 8004-0020; E. Andrade UTEP, Department of Metallurgical and Materials Engineering, TX

9:50 AM **Evaluation of Visco-Elastic Properties and Fibers Dispersion in Natural Fiber Reinforced Composites with Acoustic Microscopy and Depth Sensing Indentation Methods**
---E. Y. Maeva and **I. Severina**, NSERC Industrial Research Chair in Applied Solid State Physics and Material Characterization, Physics Department, University of Windsor, Windsor, ON Canada

10:10 AM ***Break***

10:30 AM **On Field Inspection of Composite Pipes Using Pulsed Phase Thermography**
---**M. P. V. Souza**[1], R. M. Almeida[1], J. M. A. Rebello[1], and S. D. Soares[2]; [1]Metallurgy and Materials Department. COPPE/UFRJ – Federal University of Rio de Janeiro, P.O. Box 68505, Rio de Janeiro RJ, 21941-972, Brazil; [2] PETROBRAS R&D Center, 950 Horacio Macedo Av., Rio de Janeiro RJ, 21941-915, Brazil

10:50 AM **NDE of Adhesive Bond Failure and Degradation in Aluminum and Composite Honeycomb Sandwiches**
---**D. K. Hsu**, V. Dayal, and D. J. Barnard, Iowa State University, Center for NDE, Ames, IA 50011

11:10 AM **Defect Detection in Composite Coatings by Computational Simulation Aided Thermography**
---**R. M. Almeida**, M. P.V. Souza and J. M. A. Rebello, Federal University of Rio de Janeiro - Department of Metallurgical and Materials Engineering - COPPE/UFRJ - Rio de Janeiro/RJ, Brazil

11:30 AM **Guided Wave Subsurface Damage Detection for a Composite on a Half-Space Structure**
---**K. Qi** and J. L. Rose, The Pennsylvania State University, Department of Engineering Science and Mechanics, University Park, Pennsylvania 16803; K. Qi, Intelligent Automation, Inc., Rockville, MD 20855; E. Smith, The Pennsylvania State University, Department of Aerospace Engineering, University Park, PA 16803

11:50 PM ***Lunch***

Exploiting Changes in Dielectric Dissipation to Detect Thermal Degradation in Polymers and Composites

---**Steven K. Brady,** The Boeing Company, P. O. Box 3707, Seattle, WA 98124-2207

---Thermally overexposed, polymer-matrix composite laminates can exhibit strength loss even at exposure levels insufficient to cause inter-ply delamination. This is referred to as incipient heat damage. As polymers and composites see ever broader use in critical applications, reliable nondestructive testing methods to detect heat damage in them are vital to safety. Various methods are emerging presently, including infrared spectroscopy, ultrasonic lamb wave measurements, microwave inspections, and dielectric property measurements. This talk will focus on the dielectric dissipation changes which occur in some polymers as they experience thermal damage, even in the incipient damage regime. Inspection methods, devices, and results will be discussed, as well as some underlying theory. Strengths and weaknesses of dielectric dissipation NDT will also be addressed.

Finite Element Model for Guided Wave Damage Detection in a Composite Plate

---**Kevin Qi** and George Zhao, Intelligent Automation, Inc., Rockville, MD 20855 ; Kevin Qi and Joseph L. Rose, The Pennsylvania State University, Department of Engineering Science and Mechanics, University Park, PA 16802

---A hybrid method is presented to characterize defects in a composite plate. Finite element (FE) models are developed to simulate guided wave propagation in a damaged composite laminate. Scattered waves, carrying information about defect severity and position, are analyzed with a normal mode expansion method. The comparison of results from different guided wave modes and frequencies provides features for mode selection. Source influence is considered by simulating the behavior of piezoelectric sensors in the FE model. Experiments are conducted to verify the numerical result. This technique is shown to be useful for transducer design in nondestructive testing for composites.

Porosity Detection in CFRP Specimens - Thermal Measurements and 3D Numerical Simulations for Quantitative Evaluation of Effective Thermal Diffusivity Models

---**G. Mayr**, G. Hendorfer, and B. Plank, Upper Austria University of Applied Sciences, Research and Development, Wels, Austria; J. Sekelja, FACC AG, Advanced Composite Components, Ried, Austria

---Pulsed thermography (PT) has proved to be a powerful method for non-destructive characterization of heterogeneous materials like carbon fiber reinforced plastics (CFRP). In particular, thermal diffusivity imaging has the potential to reflect the existence of inhomogeneous material properties which correlate with increased volume porosity. The test specimens examined in this study were a large number of CFRP panels with porosity values from 0.5% to 8%. For calibration of the thermal diffusivity values, the absolute porosity volumes of these panels were measured using a 3D Computed Tomography (CT), which yields data on the porosity as well as on the distribution of the size and shape of pores. The investigations are accompanied by 3D numerical simulations of the experiments performed, which allows us to evaluate the influence of the size and shape of the pores, as well as the orthogonal material parameters of the CFRP-matrix on the effective thermal diffusivity. The experimental and numerical data from the described methods verify the results of the thermal diffusivity models like the “Dethermalization-Theory” from Ringermacher and models from Kerrisk. As a result of our investigations we show how to combine measured thermal diffusivity with statistical pore parameters, obtained from CT data to calculate volume porosity.

Use of Acoustic Emission to Monitor Progressive Damage Accumulation in Kevlar® 49 Composites

---**Jess M. Waller** and Regor L. Saulsberry, NASA-JSC White Sands Test Facility, Laboratories Department, Las Cruces, NM 8004-0020; E. Andrade, UTEP, Department of Metallurgical and Materials Engineering, TX

---Acoustic emission (AE) data acquired during tensile loading of epoxy impregnated Kevlar® 49 (K/Ep) composite strands were analyzed to monitor progressive damage accumulation during the approach to tensile failure. K/Ep test materials were chosen due to their similarity to the material-of-construction in composite overwrapped pressure vessels (COPVs) used on the NASA Space Shuttle Orbiter. Insight into the progressive microstructural degradation of K/Ep strands was gained by monitoring AE event rate and energy. Source location based on energy attenuation and arrival time data was used to discern between significant AE attributable to microstructural damage accumulation, and spurious AE attributable to grip and background noise. One of the significant findings was the observation of increasing violation of the Kaiser effect (Felicity ratio < 1.0) with damage accumulation. The efficacy of three different intermittent load hold stress schedules that allowed the Felicity ratio to be determined is discussed in detail. Potential use of such stress schedules for qualification testing, in-service inspection, and structural health monitoring of COPV composite materials, including carbon-epoxy, is discussed. Future work whereby additional information about damage accumulation is extracted using the modal AE signatures, specifically AE event frequencies and velocities, is discussed, along with the relevance of anticipated findings.

Evaluation of Visco-Elastic Properties and Fibers Dispersion in Natural Fiber Reinforced Composites with Acoustic Microscopy and Depth Sensing Indentation Methods

---E. Yu. Maeva and **I. Severina**, NSERC Industrial Research Chair in Applied Solid State Physics and Material Characterization, Physics Department, University of Windsor, Windsor, ON Canada

---Natural fiber-reinforced composites are relatively new class of materials which nowadays is gaining acceptance in various industries and are aimed to replace synthetic fibers in composite materials. As bio-composites significantly differ from synthetic materials in microstructure and morphology, necessity for intensive study of their morphology and mechanical properties of new materials is obvious. Acoustic methods are effective non-destructive tool for visualization of bulk structure of the materials and quantitative evaluation of the material's parameters. In this paper, ultrasonic wave propagation was studied in wheat straw/soy flakes-reinforced polypropylene with transmission and reflection methods with 5-10 MHz frequency. The effect of the coupling agent, fiber size and content on acoustic sound velocity and attenuation were investigated. The obtained results are compared elastic moduli obtained by depth sending indentation technique. The microstructure of the composites, its relation to material composition and distribution of the filler phase in the polymer matrix is investigated as well as the acoustic and elastic parameters of the composites are measured scanning acoustic microscopy. Obtained results have shown that the acoustic microscopy is able to analyze the microstructure of the new materials, its homogeneity and detect all major defects and damages in the green composites.

On Field Inspection of Composite Pipes Using Pulsed Phase Thermography

---**Marcos P. V. Souza**[1], Romulo M. Almeida[1], Joao Marcos A. Rebello[1], and Sergio D. Soares[2]; [1]Metallurgy and Materials Department. COPPE/UFRJ – Federal University of Rio de Janeiro, P.O. Box 68505, Rio de Janeiro RJ, 21941-972, Brazil; [2] PETROBRAS R&D Center, 950 Horacio Macedo Av., Rio de Janeiro RJ, 21941-915, Brazil

---The pulsed phase thermography (PPT) is becoming a valuable tool on the detection and dimensioning of defects on composite materials. Although, the most of the works that adopt the PPT needs very sophisticated equipment to thermal excitation of the specimen and data acquisition. This work uses the concepts of the PPT to inspect sections of fiberglass reinforced epoxy pipes used on adhesively bonded joints applied on the oil industry on extraction and transportation of fluids, using low cost and simple equipment to thermal excitation. A MatLab routine to data processing was used intending to achieve a fast and reliable non-destructive method to be performed on field. Amplitude and phase images are generated from the infrared images without any pre-processing technique revealing simulated defects that were impossible to be detected on the original data. A study of how deep the thermal wave can reach along the thickness of this kind of material is also performed trying to estipulate the limits of the technique. Computational simulation is also applied to show the thermal distribution along the specimen and the thermal response to excitation on the defective areas. Results support the possibility of implementing a reliable and low cost method of inspection on field to various values of pipe thicknesses found on many plants of the oil industry.

NDE of Adhesive Bond Failure and Degradation in Aluminum and Composite Honeycomb Sandwiches

---**David K. Hsu**, Vinay Dayal, and Daniel J. Barnard, Iowa State University, Center for NDE, Ames, IA 50011

---Adhesively bonded honeycomb sandwiches with a variety of metallic and composite skin and core materials are widely used on aircraft, space structures, and boats. One of the main inspection needs of such structures is the detection of skin-to-core disbond. We report here a study of the failure mechanism of heat-induced disbond in aluminum and composite honeycomb sandwiches. Controlled heating is also pursued as a way to create disbond of desired size for NDE testing and to induce degradation of the adhesive bond. On a section of Boeing 757 slat wedge, heat-induced disbond and degradation were introduced and a number of NDE imaging methods were used to verify the flaws. Work is underway to correlate the degree of heat damage and the remaining strength of the adhesive bond.---This work was supported by the IUCRC program at Center for NDE of Iowa State University.

Defect Detection in Composite Coatings by Computational Simulation Aided Thermography

---**Romulo M. Almeida**, Marcos P.V. Souza and Joao M. A. Rebello, Federal University of Rio de Janeiro - Department of Metallurgical and Materials Engineering - COPPE/UFRJ - Rio de Janeiro/RJ, Brazil

---Thermography is based on the measurement of superficial temperature distribution of an object inspected subjected to tension, normally thermal heat. This measurement is performed with a thermographic camera that detects the infrared radiation emitted by every object. Nowadays, the thermography is applied on various fields. On the oil industry it is used to inspect composite materials in order to detect delaminations and other kinds of discontinuities revealed as hot spots on the thermal images. However, to achieve good results on the detection and dimensioning of defects on composite materials by this technique, a study of the inspection setup must be carried out in order to lower interferential radiations. Then, the computational simulation became a modern tool with great power on the thermography study. By means of the COMSOL Multiphysics simulation software, this work intends to evaluate the benefits that this kind of study can generate on the improvement of inspection parameters. A multi-layer composite inspection with a steel substrate covered with two layers of different kinds of corrosion protective resin was used as specimen. Defects like voids and lack of adhesion between layers were simulated based on characteristics of the real specimen and the parameters of the inspection setup tested trying to achieve the most favoring thermal distribution to defect detection. The setup obtained by simulation leading to the most reliable defect detection was used in real thermographic inspections.

Guided Wave Subsurface Damage Detection for a Composite on a Half-Space Structure

---**Kevin Qi** and Joseph L. Rose, The Pennsylvania State University, Department of Engineering Science and Mechanics, University Park, Pennsylvania 16803; Kevin Qi, Intelligent Automation, Inc., Rockville, MD 20855; Edward Smith, The Pennsylvania State University, Department of Aerospace Engineering, University Park, PA 16803

---Guided waves are applied for subsurface damage detection in the structure of a composite skin on a half-space, as an example modeling an aircraft skin on a honeycomb core. The global matrix method with a 2D root search is used to determine the complex wave numbers. The dispersion relations and wave structures are obtained for both propagating and attenuating modes in which the attenuation is caused by the leakage from the waveguide to the half-space. The scattering of leaky waves by skin-substrate debonding is analyzed by a finite element model, in which infinite elements simulate a silent boundary of the semi-infinite substrate. As a sample application, waves in the trailing edge of a helicopter rotor blade, a composite laminate on a honeycomb half-space, is analyzed. Theoretically driven experiments are conducted on a composite rotor blade section to detect the debonding between skin and substrate.

Session 10

SESSION 10
INVERSION, RECONSTRUCTION, AND CHARACTERIZATION
A. Dogandzic, Chairperson
Chafee 273

8:30 AM **A Bayesian Approach to the Inversion of NDE and SHM Data**
---**R. B. Thompson**, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

8:50 AM **Using a Bayesian Model to Jointly Estimate the Flaw Size Distribution and the POD Function**
---**W. Q. Meeker**, M. Li, and P. Hovey, Iowa State University, Ames, IA 50011

9:10 AM **Sparse-Signal Reconstruction from Noisy NDE Measurements**
---K. Qiu and **A. Dogandzic**, ECpE Department, Iowa State University, 3119 Coover Hall, Ames, IA 50011

9:30 AM **The Application of Guided Wave Travel Time Tomography to Bends**
---**A. Volker**, E. Luiten, and J. Bloom, TNO Science and Industry, Stieltjesweg 1, P. O. Box 155, 2600 AD Delft, Netherlands

9:50 AM **Eddy Current Tomography Based on a Finite Difference Forward Model with Additive Regularization**
---**A. Trillon**, A. Girard, S. Dubost, and N. Paul, Electricite de France, Research and Development Division, Chatou, France; A. Trillon and J. Idier, IRCCyN, Nantes, France; A. Trillon, Y. Goussard, and F. Sirois, École Polytechnique de Montréal, Montréal, Québec, Canada

10:10 AM ***Break***

10:30 AM **Imaging Cracks by Laser Excited Thermography**
---**J. Schlichting**, G. N. Kervalishvili, C. Maierhofer, and M. Kreutzbruck, BAM Federal Institute for Materials Research and Testing, Division VIII.4, Acoustical and Electrical Methods, 12205 Berlin, Germany

10:50 AM **Two Novel ACM (Active Contour Model) Methods for Ultrasound Intravascular (IVUS) Image Segmentation**
---**C. H. Chen**, L. Potdat, and R. Chittineni, University of Massachusetts Dartmouth, Electrical and Computer Engineering, 285 Old Westport Road, N. Dartmouth, MA 02747-2300

11:10 AM **Parameter Estimation of Guided-Wave Reflection Signal for Quantitative Characterization of Defect in Pipeline**
---**X. Wang** and P. W. Tse, Smart Engineering Asset Management Laboratory (SEAM), Department of Manufacturing Engineering & Engineering Management, City University of Hong Kong, Hong Kong

11:30 AM **Finite Element Based Hybrid Models for Ultrasonic NDE, Using Commercial Packages**
---**P. Rajagopal** and M. J. S. Lowe, Imperial College, UK Research Centre in NDE, Mechanical Engineering, London, United Kingdom; E. Skelton and R. Craster, Imperial College, Mathematics, London, United Kingdom

11:50 PM ***Lunch***

A Bayesian Approach to the Inversion of NDE and SHM Data

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

---As structural design and life management strategies moved from safe life to damage tolerant approaches, the information expected from inspection changed. Safe life is based on an initiation criterion; the existence of any observed flaw is grounds for rejection of the part. Hence, the sole goal of inspection was to detect flaws, with any detected flaw being grounds for rejection. There are a number of well documented challenges with this approach, including the inefficient use of potential lives in parts because of the need to remove all from service at a conservative design life and the possibility of premature failures if manufacturing processes did not produce pristine material analogous to that used in fatigue tests. A further negative implication of this approach is that, as NDE techniques become more sensitive, smaller flaws are detected indicating an earlier end to useful life according to the initiation criterion, even though actual life is unchanged. Damage tolerance approaches overcome these objections based on giving credit for crack propagation as well as initiation. It now becomes important to obtain size related information from the NDE technique. POD curves, as a function of size, are one way of quantifying this information, and strategies for inspections at fixed service intervals a consequence. Current development of condition based maintenance strategies are driven by the desire to reduce the costs of these fixed time interval inspections, which generally would not be expected to find flaws based on the conservatism required to assure safety. One wishes to flag those components in which things are starting to go wrong for further interrogation without the need for inspection of all components at a fixed interval. Structural Health Monitoring (SHM) is a continuous monitoring technology that has evolved in response to this goal. In this paper, the use of Bayes' theorem as a way of interpreting NDE and SHM data in a unified way is presented. It is argued that this approach provides a rational strategy for establishing accept/reject criteria in SHM and for combining the information contained in NDE and SHM measurements. Numerical examples are provided illustrating the properties of the approach. A comparison is given to how lifing calculations would be made based on this approach as compared to approaches typically used in structural integrity programs.---This work was supported by the NSF Industry/University Cooperative Research program.

Using a Bayesian Model to Jointly Estimate the Flaw Size Distribution and the POD Function

---W. Q. Meeker[1], M. Li[1] and P. Hovey[2], [1]Center for NDE and Department of Statistics, Iowa State University, Ames, IA 50011; [2]Department of Mathematics, University of Dayton, Dayton, OH 45469

---In this paper we extend previous work by the authors to jointly estimate the flaw-size distribution and the POD function from field inspection data. Similar to our previous work, we assume that when a crack is above a detection limit, both the signal amplitude and the flaw size are recorded. For a signal that is above the noise floor, but below the detection limit, the amplitude is recorded. At all other locations we know only that the signal is below the noise floor. We use a noise-interference model that allows for the fact that some recorded amplitudes are really the result of noise artifacts, which others are from real cracks. Our model also allows different aircraft to have different crack-growth rates, the distribution of which is to be estimated from the data. To estimate the parameters of the model, we use a Bayesian formulation that provides a convenient structure for estimating the plane-to-plane differences. The Bayesian formulation also allows the use of prior information based on knowledge of physics or previous experience with similar inspection situations. For example, there may be useful information about crack growth rates and about the slope in the crack-size/amplitude relationship. Use of such information can importantly improve precision of estimation.

Sparse-Signal Reconstruction from Noisy NDE Measurements

---Kun Qiu and **Aleksandar Dogandzic**, ECpE Department, Iowa State University, 3119 Coover Hall, Ames, IA 50011

---We propose an expansion-compression variance-component based method for reconstructing sparse or compressible signals from noisy measurements. The measurements follow an underdetermined linear model, with noise covariance matrix known up to a constant. To impose sparse or compressible signal structure, we define high- and low-signal coefficients, where each high-signal coefficient is assigned its own variance, all low-signal coefficients are assigned a common variance, and all the variance components are unknown. Our expansion-compression scheme approximately maximizes a generalized maximum likelihood (GML) criterion, providing an approximate GML estimate of the high-signal coefficient set and an empirical Bayesian estimate of the signal coefficients. The proposed method will be compared with existing approaches and applied to experimental NDE measurements, such as sparse projections in computerized tomography. Our goal is to demonstrate successful reconstruction from fewer projections (than traditionally used), which will lead to considerable savings in acquisition time and storage.---This work was supported by the NSF Industry University Cooperative Research Program, Center for Nondestructive Evaluation (CNDE), Iowa State University.

The Application of Guided Wave Travel Time Tomography to Bends

---**Arno Volker**, Erik Luiten, and Joost Bloom, TNO Science and Industry, Stieltjesweg 1 P. O. Box 155, 2600 AD Delft

---The concept of predictive maintenance using permanent sensors that monitor the integrity of an installation is an interesting addition to the current method of periodic inspections. The method should be capable of providing quantitative wall thickness information for both straight pipes and bends. The wave propagation in bends is far more complicated than in straight pipes because natural focusing occurs due to geometrical path differences. Numerical simulations clearly show this effect. Travel time tomography requires accurate modeling of travel times that can be translated to spatial wall thickness variations. Therefore, a ray tracing algorithm has been developed to calculate travel times as part of the tomographic inversion kernel. Numerical results show that a tomographic inversion on simple simulated data provides accurate results. The focusing effect due to the shape of the bend yields a phase rotation of the wavelet, which complicates accurate timing picking. This effect was excluded in the simulated ray tracing data. Based on these observations it is concluded that a more accurate, wave equation based forward modeling algorithm is required to obtain accurate inversion results on realistic data.

Eddy Current Tomography Based on a Finite Difference Forward Model with Additive Regularization

---**Adrien Trillon**, Alexandre Girard, Stéphanie Dubost, and Nicolas Paul, Electricite de France, Research and Development Division, Chatou, France; Adrien Trillon and Jérôme Idier, IRCCyN, Nantes, France; Adrien Trillon, Yves Goussard, and Frédéric Sirois, École Polytechnique de Montréal, Montréal, Québec, Canada

---Eddy current tomography is a nondestructive evaluation technique used for characterization of metal components. It is an inverse problem acknowledged as difficult to solve since it is both ill-posed and nonlinear. Our goal is to derive an inversion technique with improved trade-off between quality of the results, computational requirements and ease of implementation. This is achieved by fully accounting for the nonlinear nature of the forward problem by means of bilinear system of equations obtained through a finite difference modeling of the problem. The bilinear structure of the system of equations with respect to the electric field and the relative conductivity is taken advantage of through a simple contrast source inversion-like scheme. The ill-posedness is dealt with through the addition of regularization terms to the criterion, the form of which is determined according to computational constraints and the piecewise constant nature of the flaws. Therefore an edge preserving functional was selected. The performance of the resulting method is illustrated using 2D synthetic data examples.

Imaging Cracks by Laser Excited Thermography

---**J. Schlichting**, G.N. Kervalishvili, Ch. Maierhofer, and M. Kreutzbruck, BAM Federal Institute for Materials Research and Testing, Division VIII.4, Acoustical and Electrical Methods, 12205 Berlin, Germany

---During the last years active thermography is increasingly used in a number of NDT problems in production and maintenance. In this work we focus on the detection of vertical cracks starting at the surface, which is an important indication of structural failure. By using local thermal excitation it is possible to image anisotropies in the lateral diffusivity by recording the temporal temperature data with an infrared camera. The regional transient behavior of temperature distribution then can provide quantitative information of the crack parameter. In doing so, we present an advanced technique for the determination of the crack depth. The experimental set-up is based on a NdYAG laser. The beam is focused on the test sample by using an optical scanner to create the required lateral heat flow. The time resolved temperature distribution is recorded with an infrared camera (InSb FPA, 3 to 5 µm) providing a frame rate of up to 500 Hz. In addition we report on numerical simulation to investigate the concept of local heat excitation for a quantitative estimation of crack parameters. The modelling also includes the influence of thermal conduction, radiation and convection. We obtained a good consistency between experimental and theoretical data.

Two Novel ACM (Active Contour Model) Methods for Ultrasound Intravascular (IVUS) Image Segmentation

---**Chi Hau Chen**, Labhesh Potdat, and Rakesh Chittineni, University of Massachusetts Dartmouth, Electrical and Computer Engineering, 285 Old Westport Road, N. Dartmouth, MA 02747-2300

---One of the attractive image segmentation methods is an Active Contour which has been widely used in medical imaging as it always produce sub-regions with continuous boundaries. Intravascular ultrasound (IVUS) is a catheter based medical imaging technique which is used for quantitative assessment of atherosclerotic disease. The first active contour model involves gradient descent flow based on a energy functional which is capable of producing robust and accurate segmentation of IVUS images. The method consists of basically hybridization of local geodesic active contours and global region-based active contours. The advantage of combining these two methods is to allow curves deforming under the energy to find only significant local minima and delineate object borders despite noise, poor edge information and heterogeneous intensity profiles. Results for this algorithm are compared to standard techniques to demonstrate the method's robustness and accuracy. In the second method, the energy function is appropriately modified and minimized using a Hopfield neural network. Proper modifications in the definition of the bias of the neurons have been introduced to incorporate image characteristics. A simulated annealing scheme is included to ensure convergence at a global minimum. The method overcomes distortions in the expected image pattern, due to the presence of calcium, employing a specialized structure of the neural network and boundary correction schemas which are based on a priori knowledge about the vessel geometry. The presented method is very fast and has been evaluated using sequences of IVUS frames.

Parameter Estimation of Guided-Wave Reflection Signal for Quantitative Characterization of Defect in Pipeline

---**Xiaojuan Wang** and Peter W. Tse, Smart Engineering Asset Management Laboratory (SEAM), Department of Manufacturing Engineering & Engineering Management, City University of Hong Kong, Hong Kong

---The reflection signal from a defect in guided-wave based pipeline inspection usually includes sufficient information relevant to the parameters that can be used to detect and define the given defect. In our previous research, it has been identified that the reflection of guided waves from a defect is the cooperative result of interference between the reflection components from the frontend and the backend of the defect, and the complexity of the reflection signal is essentially a result of the different features represented by the two reflection components. The identification of each reflection component is therefore essential in accurately determining the concerned defect. In this research, we propose the method based on parameter estimation for the purpose of reflection decomposition so as to enable quantitative characterization of defect. The guided-wave reflection signal was modeled in terms of excitation waves distorted by the effect of dispersion and other noises in propagation. The parameters considered in each reflection component mainly included center frequency, amplitude, and phase, which were estimated using the expectation maximization (EM) algorithm. The axial extent of defect could be easily and accurately determined once the reflection components were identified. Both real experimental data and simulated signals were used to verify the effectiveness of the proposed methods.

Finite Element Based Hybrid Models for Ultrasonic NDE, Using Commercial Packages

---**Prabhu Rajagopal** and Michael J. S. Lowe, Imperial College, UK Research Centre in NDE, Mechanical Engineering, London, UK; Elizabeth Skelton and Richard Craster, Imperial College, Mathematics, London, UK

---This paper arises from the authors' interest in developing improved modeling tools to assist practical ultrasonic NDE of complex defects and structures. The capabilities and versatility of the Finite Element (FE) analysis for understanding the interaction of ultrasonic waves with defects have long been recognized. Recently approaches are also being developed to optimize the use of robust commercial FE packages which are now widely available. However challenges still impede the universal application of these techniques to realistic inspection situations. It is often necessary to refine the FE mesh to capture irregular features accurately, but then a fine mesh over a large volume of material results in an enormous model, particularly when working in three dimensions. FE representation of transduction methods commonly used in practical inspection is also time-consuming. One way of overcoming these challenges is to use a hybrid model consisting of an FE analysis in the vicinity of the defect but a less memory intensive method elsewhere. Hybrid models have been proposed by several researchers in the past but such work has usually been specific and often requiring creation of specialist codes, not easily accessible. Here we discuss the development of general procedures for an FE-based hybrid model which can be directly implemented using commercial modeling packages. We first consider concepts underlying the definition of hybrid models and features that would be required in modeling packages, for facilitating them. We then discuss the optimization of the defect domain modeled in a commercial FE package addressing the issues of domain geometry and size, and excitation parameters. Finally we discuss the interfacing of parameters from the defect domain with the global domain, and present results from an example hybrid model.

Session 11

SESSION 11
STUDENT POSTER COMPETITION
Memorial Union Ballroom

NOTE: Student posters are to be mounted Monday, July 27th 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 28th from 1:30-3:10 p.m. For more details on the student poster competition, please see the "Conference Guide" document (page 11) on the QNDE web site at: http://www.cnde.iastate.edu/QNDE/QNDE.html

1:30 PM

- Analytical and Finite Element Methods for Studying the Influence of the Air-Coupled Transducers Characteristics on the Purity of Guided Waves Generated in Solid
- Ultrasonic Guided Wave Focus Inspection of Bare and Coated Pipes
- Model Based Study of Time Reversal Imaging in Microwave NDE
- Laser Based Measurement of Plate Thickness Using a Fundamental Antisymmetric Mode of Lamb Wave
- Elastic Wave Propagation in a Layered Medium with Quadratic Nonlinearity
- Measuring Residual Stress Using Nonlinear Ultrasound
- On the Excitability of Second Harmonic Lamb Waves In Isotropic Plates
- An Intelligent Stand-Alone Ultrasonic Device for Monitoring Local Damage Growth in Civil Structures
- Development of Disposable Ultrasonic Probe for Hot Metal Inclusion Measurement
- Ultrasonic Modeling for Estimating Thickness Variations in Inaccessible Plate Like Structures
- Air Void Characterization Through Ultrasonic Attenuation Using an Immersion Procedure
- An Effective Medium Theory for Wave Propagation in Multi-Phase Materials
- SH Wave Magnetostrictive Transducer Using a Segmented Patch Array for Detecting Axial and Circular Location of a Crack in a Pipe
- On the Convergence of FE Scattering Models
- Efficient Perturbation Analysis of Lamb Wave Dispersion Curves
- On the Optimization of Temperature Compensation for Guided Wave Structural Health Monitoring
- Identifying Surface Defects Using Ultrasound and Machine Learning
- Improvement of Subharmonic Phased Array for Crack Evaluation (SPACE) for Field Inspections
- Inspection of Single Crystal Aerospace Components with Ultrasonic Arrays
- Model Based Study of Time Reversal Imaging in Microwave NDE
- Development of Disposable Ultrasonic Probe for Hot Metal Inclusion Measurement
- Hybrid Non-Contact Guided Wave Tomography for Imaging of Defects in Plate-Like Structure Using A Probabilistic Algorithm

3:10 PM ***Break***

SESSION 11 – POSTERS
ULTRASONIC METHODS, TRANSDUCERS AND PROBES, CIVIL STRUCTURES, AND PROCESS CONTROL
Memorial Union Ballroom

1:30 PM

Ultrasonic Methods

Time Reversal Beam Focusing of Ultrasonic Array Sensors on a Defect in Layered Media
---**H. Jeong** and J.-S. Lee, Wonkwang University, Division of Mechanical and Automotive Engineering, Iksan Jeonbuk, South Korea; C.-H. Lee, Wonkwang University, Division of Semiconductor and Display Technology, Iksan Jeonbuk, South Korea

Angular Spectrum of Plane Waves Method of Elastic Wave Field Calculation
---**Y. Adachi**, Kyoto University, Department of Physics, Kyoto, Japan; B. R. Tittmann, and C. Miyasaka, The Pennsylvania University, Department of Engineering Science and Mechanics, University Park, PA 16802

Laser Optoacoustic Nondestructive Method of Thickness Measurement of Subsurface Damaged Layer in Machined Silicon Waters
---**A. A. Karabutov** and N. B. Podymova, International Center, M. V. Lomonosov Moscow State University, Leninskie Gory, Moscow 119991, Russia

Application of Axicon Lenses in Ultrasonic Techniques
---**P. Katchadjian**, A. Garcia, and C. Desimone, Comision Nacional de Energía Atómica, UAENDE - INEND, Buenos Aires, Argentina

Plate Wave Transmission/Reflection at Geometric Obstructions: Model Study
---**R. A. Roberts**, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

Plate Wave Transmission/Reflection at Geometric Obstructions: Experiment
---**R. Reusser**, D. E. Chimenti, S. Holland, and R. Roberts, Iowa State University, Center for NDE, Ames, IA 50011

Model for Thickness and Anisotropy Measurements in Metal Plates Using Laser Ultrasonics
---**M. Engman** and M. Falkenström, Swerea KIMAB, Box 55970, 102 16 Stockholm, Sweden

Plate Wave Resonance with Air-Coupled Ultrasonics
---H. N. Bar[1], V. Dayal[2], D. Barnard[2], and **D. K. Hsu[2]**, [1]National Metallurgical Laboratory, Material Science & Technology Division, Jamshedpur, 831007, India; [2]Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

Advanced Crack Shape Analysis Using SAFT
---R. Boehm, D. Brackrock, G. Brekow, **M. Kreutzbruck**, and J. Kitze, Federal Institute for Materials Research and Testing, BAM, Berlin, Germany

A Parametric Study on Guided Wave Tomography via Modeling and Experiment
---**B. Shin[1]**, Y. Piao[1], Y. Cho[2], and B. Ahn[3], [1]Graduate School of Mechanical Engineering, Pusan National University, Busan 609-735, Republic of Korea; [2]School of Mechanical Engineering, Pusan National University, Busan 609-735, Republic of Korea; [3]Korea Research Institute of Standards and Science, Dejeon 305-340, Republic of Korea

Transducers and Probes

Development of Electromagnetic-Acoustic Sensors for Evaluation of Flaws in Gas Pipelines
---**H.-R. Yoo**[1], H.-J. Kim[2], S.-J. Song[2], D. K. Kim[1], S.-H. Cho[1], and Y.-W. Rho[1]; [1]School of Mechanical Engineering, Sungkyunkwan University, Suwon, 440-746, Korea; [2]Intelligent PIG R&D Group, R&D Division, Korea Gas Corporation, Incheon, 406-130, Korea

Simplified System Efficiency Functions for Linear Phased-Array Transducers
---**F. J. Margetan**[1], T. Gray[1], and R. Huang[2], Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011; [2]268 Congressional Lane, Apt. 203, Rockville, MD 20852

Acoustic Field Calculation of Ultrasonic Linear Phased Array Transducer with Curve Surface
---**C. Xu**, Beijing Institute of Technlogy, Mechanical and Vehicular Department, Beijing, China; S. H. Li, Beijing Institute of Technlogy, Mechanical and Vehicular Department, Beijing, China; X. Zhao, Beijing Institute of Technology, Mechanical and Vehicular Department, Beijing, China

Measurement of Uncertainty in Eddy Current Bolt Hole Crack Measurements for Use in POD
---**R. Underhill** and T. Krause, Royal Military College of Canada, Kingston, Ontario, Canada

A Real-Time Microwave Camera at K-Band (24 GHz)
---**M. T. Ghasr**, M. Abou-Khousa, M. A. Baumgartner, and R. Zoughi, Applied Microwave NDT Lab., Electrical and Computer Engineering Department, Missouri University of Science & Technology, 301 W. 16th, Rolla, MO 65409

Image and Signal Processing Algorithms for THz Imaging of Composite Materials
---P. Lopato and **T. Chady**, West Pomeranian University of Technology, Department of Electrical and Computer Engineering, Szczecin, Poland; K. Goracy, West Pomeranian University of Technology, Polymer Institute, Szczecin, Poland

An SH Guided Wave Transducer Module Using a Magnetostrictive Thin Element
---**B. Ahn**, S. H. Cho, J. H. Park, H.-S. Kwon, and S. S. Lee, Korea Research Institute of Standards and Science, Center for Safety Measurement, Taejon, Korea

Civil Structures

Joint Rigidity Assessment with Piezoelectric Wafers and Acoustic Waves
---**A. C. Montoya** and A. K. Maji, University of New Mexico, Department of Civil Engineering, Albuquerque, NM 87131-0001

NDE of Lumber Wood and Natural Fiber Products Using Air-Coupled Ultrasound
---**D. K. Hsu** and D. Utrata, Iowa State University, Center for NDE, Ames, IA 50011; M. Kuo, Iowa State University, Department of Natural Resource Ecology and Management, Ames, IA 50011

Nondestructive Evaluation of the State of Damage in Concrete under Uniaxial
---**P. Shokouhi**, A. Zoëga, and H. Wiggenhauser, BAM – Federal Institute for Material Research and Testing, Berlin, Germany

Characterization of Fatigue Damage in A36 Steel with Nonlinear Rayleigh Waves
---**S. E. Duncan**, J.-Y. Kim, J. Qu, and L. J. Jacobs, Georgia Institute of Technology, College of Engineering, 225 North Avenue, Atlanta, GA 30332-0355

Process Control

Observation of CVD Diamond Coating with Various Deposit Conditions by Using Nondestructive Method
---D. Y. Kim [1,2], T. Takagi[2], H. Miki[2], T. Uchimoto[2], **S.-J. Song**[1], and H.-J. Kim[1], [1]School of Mechanical Engineering, Sungkyunkwan University, Suwon, Gyeonggi-do, Korea; [2]Institute of Fluid Science, Tohoku University, Sendai, Japan

Validation of an X-ray Computer Tomography Based Image Processing Technique by Statistical Performance Analysis
---M. Amos, **E.-M. Rasselkorde**, and D. Pain, TWI NDT Validation Centre (Wales), Heol Cefn Gwrgan, Margam, Port Talbot Sa13 2EZ, United Kingdom

3:10 PM ***Break***

Analytical and Finite Element Methods for Studying the Influence of the Air-Coupled Transducers Characteristics on the Purity of Guided Waves Generated in Solid

---The measured characteristics (efficiency) of air-coupled transducers allow for the prediction of the absolute values of the pressure of the bulk waves generated in air. To simulate the generation of the guided waves in solid from air-coupled transducers, one can simulate the propagation in air and solid with Finite Elements model (J.Acoust.Soc.Am., Vol.123, No.4, 2008). In this paper, the propagation in air is replaced by an analytical model that predicts the repartition of the acoustic field in space. Knowing the efficiency of the transducer, it is straightforward to compute, in 3 dimensions and absolute values, the pressure field that is incident on a structure. Then these values are applied as boundaries conditions in the Finite Element model, that is as yet in 2 dimensions. This combination leads to a very fast computation of the fields generated in a plate for which we can obtain anywhere in the plate, the displacement and stress fields in absolute values. To check the complete simulation with the two models, a test bed uses an air-coupled transducer oriented with an adapted angle for generating the A_0 or S_0 mode in the plate. A laser probe reads the particular velocity at the surface of the plate for absolute values comparisons. An important feature in guided mode generation is the ability to produce pure mode, that means for instance for generating the A_0 mode with a very little percentage of S_0. Among the various transducer characteristics, its position is studied as a way to optimize the purity of the generation. It is shown from the computation and experiment results, that the purity of the mode depends on the plate position in the near or far incident field.

Ultrasonic Guided Wave Focus Inspection of Bare and Coated Pipes

---Ultrasonic guided waves in elastic bare pipes are studied from a theoretical point of view. Dispersion curves of both axisymmetric and non-axisymmetric waves are presented. A novel guided wave interference pattern of partial loading is visualized showing the natural focusing phenomenon. The parameters of 4-channel focusing are calculated by a phased array focusing algorithm and verified by FEM simulation. Experimentally four defects are all detected in a cased pipe inspection. The defect probability of detection is highly improved by applying the phased array focusing technique. Due to the difficulty of root searching in the complex domain of the theoretical global matrix method, guided waves in coated pipes are investigated by using a 1-D Semi-Analytical Finite Element (SAFE) technique. This theoretically driven hybrid SAFE method has perfectly tackled the guided wave problem in coated pipes, including dispersion curves (phase velocity dispersion curves and attenuation dispersion curves), wave structures, and cross-section deformations. The time delays and amplitudes of the 8-channel focusing in an 8in sch40 coated pipe are calculated by the SAFE algorithm and input to the FEM simulation in ABAQUS. Focusing performance is improved up to 67% by applying the coated pipe parameters compared with the bare pipe parameters.

Model Based Study of Time Reversal Imaging in Microwave NDE

---Time reversal experiments in acoustics have shown significant potential for the detection and imaging of flaws in materials. This paper presents the feasibility of detecting and localizing defects in non-conducting materials using principles of time reversal with microwaves. A time reversal based microwave imaging scheme is proposed as a nondestructive method to detect and localize defects in composite materials. The basic principle of the method is demonstrated using a two-dimensional finite difference time domain (FDTD) computational model for simulating the propagation of forward and time reversed wave fields. The simulation geometry considered is a time reversal cavity and the excitation source is a modulated Gaussian pulse of 2 GHz center frequency. The electric field is recorded on an array of receivers, time reversed and propagated backwards using the model to highlight the scatterer. Simulations results from the time reversal cavity as well as for the case of a dielectric scatterer will be presented. Initial results demonstrate the ability of the technique to localize and image defects. The computational burden associated with imaging is relatively low, thereby making the method attractive.

Laser Based Measurement of Plate Thickness Using a Fundamental Antisymmetric Mode of Lamb Wave

---Guided wave techniques are well known for a rapid inspection of a large structure at a minimum cost. Pitch-catch method using piezoelectric type transducers, EMATs, and magnetostrictive sensors are generally adopted for guided wave inspections in plates and pipes. Though defects can easily be located in the guided wave inspection, remaining thickness of plates and pipes, which is usually the most important factor in maintenances of oil storage tanks and pipe networks are not evaluated. This study takes a different approach by using a scanning laser source to excite the guided wave on plates with rounded shallow defects. Different intensity of Lamb waves were produced at intact and defect region of the plate and propagating from the scanning points. A fundamental antisymmetric mode, A0 of the Lamb waves was measured using an angle-beam transducer that was placed at the end of the plates. The A0 mode excited from the scanning laser source that was scanned over the plates demonstrates the thickness distributions in the plates with greater amplitudes at defect regions and smaller amplitudes at intact regions.

Elastic Wave Propagation in a Layered Medium with Quadratic Nonlinearity

---This paper considers propagation of a plane time-harmonic wave in a layered elastic medium. The layered medium consists of alternating plies of linear and nonlinear materials. The nonlinearity of nonlinear layers is assumed to be quadratic. The waves reflected from and transmitted through the layered medium are obtained for both deterministic and random cases. In the deterministic case, the structure of the layered medium is assumed known, i.e., the thickness of each ply is given deterministically. In the random case, the thickness of each ply is given as a random variable with known values of the assemble average and deviation. It is found that the reflected and transmitted waves can be used to infer the magnitude of the acoustic nonlinearity Beta of the layered medium. More importantly, it is found that the acoustic nonlinearity Beta of the layered medium depends sensitively on the types of statistical distribution of the nonlinear plies within the layered medium.

Measuring Residual Stress Using Nonlinear Ultrasound

---Near surface compressive residual stresses, which are generated by shot peening, are known to retard crack initiation and thus prolong the fatigue life of a metal component. The ability to effectively measure these near surface residual stresses would greatly aid in predicting the fatigue life of shot-peened components. This research uses the nonlinear surface acoustic wave technique to measure the residual stresses in a shot-peened component. Experiments are conducted on three different aluminum alloy (AA 7075) samples: as-received with no peeing, and shot-peened at the Almen intensities of 8A and 16A. Surface roughness measurements are carried out for these three samples. The nonlinear ultrasonic results show that the measured acoustic nonlinearity parameters increase by 81% and 115% for the 8A and 16A samples. These large increases in measured acoustic nonlinearity clearly indicate the potential of the nonlinear ultrasonic technique as an NDE tool to measure residual stresses. The effects of surface roughness on the ultrasonic measurement are also briefly examined. Finally, a preliminary model prediction is used to interpret the experimental results.

On the Excitability of Second Harmonic Lamb Waves In Isotropic Plates

---Recent developments have shown that early characterization of fatigue damage is closely related to a change of the material's nonlinear properties, rather than of its linear behavior. In the framework of linear waves, this change of material nonlinearity cannot be detected. Recent experimental results with nonlinear guided Lamb waves in plates, however, have succeeded in quantifying this nonlinear parameter by measuring the amplitudes of the second harmonic wave generated by the plate's material nonlinearity. In this experimental procedure a nonlinear phenomenon called the internal resonance is of crucial advantage for the measurements. Yet, due to the dispersive behavior of plates, this internal resonance is only possible for certain pairs of modes and frequencies. This paper investigates the excitability of second harmonic Lamb waves in isotropic plates using an analytical approach. Using a perturbation method up to quadratic terms of displacement, the nonlinear boundary value problem (BVP) is reduced to two linear BVPs, one with and one without a forcing term. The first BVP, which is related to the second harmonic wave, is solved using a modal expansion technique. It is found that a one-way cross-modal excitation from an anti-symmetric primary mode to a symmetric second harmonic mode can possibly occur. The physics supporting this phenomenon is analytically shown, and its utility in the practical nonlinear Lamb wave measurements is also discussed.

An Intelligent Stand-Alone Ultrasonic Device for Monitoring Local Damage Growth in Civil Structures

---For an aged, in-service civil structure, continuous structural health monitoring may be vital for preventing a catastrophic failure. While traditional ultrasonic devices are well-developed for scheduled local inspections, they are often not suitable for continuous in-situ monitoring due to various reasons, which include the requirement for long electrical cables associated with traditional ultrasonic testing. The objective of this research is to develop a stand-alone, self-reliant, and compact ultrasonic device for the continuous monitoring of large civil structures. The battery powered device integrates ultrasonic transducers with a compact high speed data acquisition and processing unit and a wireless communication module. Rayleigh surface waves, generated by the device, are used to detect and monitor surface cracks. Measured signals are analyzed on-board to minimize the amount of data necessary for wireless transmission. In this preliminary work, performance of the device is evaluated in a simulated environment, where artificial surface cracks with different depths are detected by the device. Collected signals are then processed and analysis results are sent to a central server. This device may be combined with global approaches such as the vibration-based techniques, to increase the sensitivity of damage detection at locations critical to the structure's safety.

Development of Disposable Ultrasonic Probe for Hot Metal Inclusion Measurement

---The application of ultrasonic scattering methodologies to a 'on the process line' inclusion measurement system could fulfill metal industries need to develop and incorporate techniques for understanding non-metallic particulate inclusion content or cleanliness at different process areas. The MV20/20 ultrasonic system developed in the Aluminum industry has achieved some success; however, the operational temperatures evident in steel production suggest an ultrasonic measurement system is impractical due to the inability to introduce/propagate an ultrasonic pulse directly into liquid steel. This paper continues to present the development of a novel disposable ultrasonic probe that overcomes pulse introduction difficulties as well as some of the associated issues evident in liquid steel application. A trial at the Corus pilot plant facility in the U.K shows that probe design allows approximately 70% of the energy of the incident ultrasonic pulse to pass from a transmission rod into the liquid steel.

Ultrasonic Modeling for Estimating Thickness Variations in Inaccessible Plate Like Structures

---The ability to model and simulate guided wave propagation provides an insight into the development of robust guided wave systems. This paper presents the finite-element method, a powerful computational technique used in the context of ultrasonic guided wave nondestructive evaluation of inaccessible plate like structures. Corrosion type surface defects with through wall depths of 10% to 50% are fabricated on a 3/8 inch thick steel plate. A series of computer runs are made for various wave modes and the results of the parametric study are then analyzed using signal processing methods. Based on the analysis, a quantitative method to estimate average thickness of the plate is suggested.

Air Void Characterization Through Ultrasonic Attenuation Using an Immersion Procedure

---The most prevalent method for the prevention of freeze-thaw and salt scaling damage in cement based materials is through the entrainment of air voids using air entraining chemical admixtures (AEA's). However, the common field methods for measuring air content in fresh concrete cannot distinguish between entrained and entrapped air voids, and the actual air content in the hardened concrete can vary from that determined by these tests due to a variety of factors such as workability, placing operations, consolidation effort, and environmental conditions. Previous research has shown the ability of ultrasonic attenuation to distinguish between entrained and entrapped air voids in hardened cement paste, providing a foundation for an inversion procedure to calculate the size and volume content of the two scatterer sizes. While additional challenges are present with measurement in fresh paste, the use of an immersion setup can overcome the limitations of cement paste containment vessels and provide a means to measure air content from batching to placement. An immersion procedure to measure ultrasonic attenuation in fresh cement paste will be described. This method will extend the aforementioned inversion procedure to predict both entrained and entrapped air fractions in fresh cement paste mixes.

An Effective Medium Theory for Wave Propagation in Multi-Phase Materials

---Existing wave propagation models for inhomogeneous materials deal with two-phase mixtures, mostly the matrix-inclusion system such as the fiber-reinforced composite. There are, however, numerous examples of multi-phase materials in which more than one phase are suspended in a matrix-phase. One of the common examples will be the concrete in which the cement paste and aggregates with different sizes and mechanical properties are mixed together. Most of the models for two-phase composites cannot be extended to a multi-phase composite. Among others, the effective medium theory is considered for two reasons: first, the formalism in this theory can easily be extended to multi-phase cases; second, the theory does not strictly define a specific microstructure between phases, which allows a simulation of the microstructure in which different inclusions are in contact. The mathematical formulation is presented that yields the formulae for the effective density and the effective bulk and shear moduli. Finally, the calculated wave speeds and attenuations for different materials are compared with experimental results.

SH Wave Magnetostrictive Transducer Using a Segmented Patch Array for Detecting Axial and Circular Location of a Crack in a Pipe

---The objective of this research is to develop a Shear-Horizontal (SH) wave magnetostrictive transducer for identifying both the axial and circumferential location of a crack in a pipe. Existing magnetostrictive patch-type transducers used for pipes can determine only the axial location of a crack, not its circumferential location. To detect the circumferential location of a crack as well by using a non-dispersive SH wave, a new magnetostrictive transducer configuration is devised. Instead of using a single patch completely wound around a pipe, an array of segmented magnetostrictive patches is employed and bonded on a test pipe. A set of a meander coil and bias magnets are placed individually to each of the patches. SH waves can be easily generated with a magnetostrictive patch if the applied dynamic magnetic field by a meander coil is perpendicular to the static bias field by magnets. For experiments, 6 segmented patches were placed around the circumference of a pipe and the working frequency was around 500 kHz. The underlying wave radiation pattern of the suggested transducer was investigated and its application to detect the circumferential location of a surface crack in a pipe was reported.

On the Convergence of FE Scattering Models

---The field of inverse scattering is growing rapidly and its application to imaging for NDE is being investigated. Inverse algorithms determine information about the scatterer such as its shape or material properties from scattering measurements. The inversion is based on a forward problem which predicts the outcome of scattering measurements for a virtual object. The physical properties of this object are iteratively updated so as to converge to the true object when the residual between the measured and predicted scattered field is minimized. The solution to the forward problem is obtained with approximate numerical methods such as finite elements. Error analysis in such methods is typically performed under the narrow criteria of plane wave propagation in free space; the question explored here is what effect the more complex scattering model would have on the error. This poster will explore a number of different scattering models, investigating how the mesh refinement must be increased to reach the same convergence criteria as a simple plane wave simulation. Scattering from a cylinder is investigated since comparisons are possible with a semi-analytical solution, whereas for more complex scatterers the errors are determined via the optical theorem of energy conservation.

Efficient Perturbation Analysis of Lamb Wave Dispersion Curves

---Lamb waves are used extensively in nondestructive evaluation and structural health monitoring applications. While many numerical methods to obtain dispersion curves for Lamb waves have been developed and implemented, in general they are time consuming and do not lend themselves to analyses involving the perturbation of parameters such as the small thickness and wave speed changes caused by temperature variations. Presented here are two methods of approximating the solutions of the Rayleigh-Lamb equations under a small perturbation assumption. The first method is a gradient-based linear approximation to the Raleigh-Lamb equations, and the second is a linear approximation method based on a number of pre-computed solutions to the Rayleigh-Lamb equations. Also presented is a simple algorithm to efficiently compute Lamb wave dispersion curves. This algorithm is used to study the approximation methods.

On the Optimization of Temperature Compensation for Guided Wave Structural Health Monitoring

---Recorded signals from a guided wave structural health monitoring system are sensitive to damage but also to even small temperature changes. This temperature sensitivity is a problem for methods that rely upon detecting changes in signals by comparison to a baseline. Previous studies have shown that stretching the baseline signal can provide reasonable compensation for a temperature change. However, this stretch is not perfect and its efficacy depends upon many factors, of which the most important is the magnitude of the temperature change. Often a small shift mismatch remains between the signal and the baseline after the stretching has taken place, which can cause problems comparing signals even if the shapes are well-matched. The work presented here considers and compares algorithms for determining and executing the signal stretch and shift. These algorithms are applied to both simulated data and experimental data. Simulations are performed first with a series of non-overlapping and controlled-time-arrival echoes, and then with a more realistic series of echoes with random amplitudes and arrivals. Experimental data is from an aluminum plate with and without simulated damage. The criterion for evaluation is a comparison of the residual signals after baseline subtraction before and after damage is introduced.

Identifying Surface Defects Using Ultrasound and Machine Learning

---Ultrasonic surface waves have a variety of uses in NDT. The use of a pair of electromagnetic acoustic transducers (EMATs) generating and detecting Rayleigh waves in pitch-catch mode has recently been investigated, with a view to characterizing surface defects. When either the detection or generation EMAT is very close to a surface crack, a distinctive enhancement of the signal is observed due to constructive interference of waves passing directly to the EMAT with those reflected and mode converted at the crack. For a defect which is angled away from the surface normal, extra enhancement effects are seen. This can lead to a distinctive pattern in the B-Scan which may be used to identify, for example, rolling contact fatigue (RCF) on rails, distinguishing RCF which are angled at about 25º to the rail surface from rail-joins. B-Scans have been produced by scanning EMATs over a variety of aluminum bar samples containing normal slots and angled slots of various sizes. An automated computer system is being developed to characterize defects, combining measuring changes in the amplitude and frequency content of the transmitted signal with a computer-based classification system using supervised learning methods, such as decision tree algorithms, for pattern identification.

Improvement of Subharmonic Phased Array for Crack Evaluation (SPACE) for Field Inspections

---Measurement of closed crack depths with high accuracy is very difficult since the closed cracks are almost transparent to ultrasound. To solve this problem, we have developed a novel method to image opened and closed cracks at the same time, SPACE (subharmonic phased array for
crack evaluation), and its performance was demonstrated in closed fatigue cracks and stress corrosion cracks. In this study, we improved SPACE to make it appropriate for field inspections. First, we optimized the computation procedures for real-time crack imaging. We also fabricated a shoe to move the transmitter and receiver together for easier and smoother scanning. Moreover, we obtained new findings by evaluating cracks using an 8-channel LiNbO3 transmitter array, in order to realize a wider range of the incident angles, and to increase sensitivity for cracks. We also applied a new imaging method which utilizes a long burst incident waves to improve the discrimination between linear and non-linear responses (Long-burst SPACE). Based on these improvements, we discuss advantages and additional possibility of SPACE.

Inspection of Single Crystal Aerospace Components with Ultrasonic Arrays

---Single crystal metal alloys are used extensively in the manufacture of jet engine components for their excellent mechanical properties at elevated temperatures. The increasing use of these materials and demand for longer operational life and improved reliability motivates the requirement to have capable NDE methods available. Ultrasonic arrays are well established at detecting sub-surface defects, however these methods are not currently suitable to the inspection of single crystal components due to their high elastic anisotropy causing directional variation in ultrasonic waves. In this paper a model of wave propagation in anisotropic material is used to correct an ultrasonic imaging algorithm and is applied to single crystal test specimens. The orientation of the crystal in a specimen must be known for this corrected-algorithm; therefore a crystal orientation method is also presented that utilizes surface skimming longitudinal waves under a 2D array. The work detailed in this paper allows an ultrasonic 2D array to measure the orientation of a single crystal material and then perform accurate volumetric imaging to detect and size defects.

Model Based Study of Time Reversal Imaging in Microwave NDE

---Time reversal experiments in acoustics have shown significant potential for the detection and imaging of flaws in materials. This paper presents the feasibility of detecting and localizing defects in non-conducting materials using principles of time reversal with microwaves. A time reversal based microwave imaging scheme is proposed as a nondestructive method to detect and localize defects in composite materials. The basic principle of the method is demonstrated using a two-dimensional finite difference time domain (FDTD) computational model for simulating the propagation of forward and time reversed wave fields. The simulation geometry considered is a time reversal cavity and the excitation source is a modulated Gaussian pulse of 2 GHz center frequency. The electric field is recorded on an array of receivers, time reversed and propagated backwards using the model to highlight the scatterer. Simulations results from the time reversal cavity as well as for the case of a dielectric scatterer will be presented. Initial results demonstrate the ability of the technique to localize and image defects. The computational burden associated with imaging is relatively low, thereby making the method attractive.

Development of Disposable Ultrasonic Probe for Hot Metal Inclusion Measurement

---The application of ultrasonic scattering methodologies to a 'on the process line' inclusion measurement system could fulfill metal industries need to develop and incorporate techniques for understanding non-metallic particulate inclusion content or cleanliness at different process areas. The MV20/20 ultrasonic system developed in the Aluminum industry has achieved some success; however, the operational temperatures evident in steel production suggest an ultrasonic measurement system is impractical due to the inability to introduce/propagate an ultrasonic pulse directly into liquid steel. This paper continues to present the development of a novel disposable ultrasonic probe that overcomes pulse introduction difficulties as well as some of the associated issues evident in liquid steel application. A trial at the Corus pilot plant facility in the U.K shows that probe design allows approximately 70% of the energy of the incident ultrasonic pulse to pass from a transmission rod into the liquid steel.

Hybrid Non-Contact Guided Wave Tomography for Imaging of Defects in Plate-Like Structure Using A Probabilistic Algorithm

---A hybrid non-contact ultrasonic using laser generation and single air coupled transducer to generate and detect guided waves is very attractive technique to develop. It can be used for online inspection and structural health monitoring (SHM) where contact method using embedded sparse sensors cannot be applied as in the case of high temperature application. In this study, a tomography based on probabilistic algorithm was applied for this hybrid non-contact method. This algorithm can be used for detecting, locating and imaging defect on aluminum plates both for single defect and multiple ones respectively. The probabilistic algorithm is principally based on the signal difference coefficient of guided waves detected for good and faulty conditions. The simplicity of this algorithm makes it suitable to be applied for non contact online and automation inspection of plate-like structures.

Ultrasonic Methods

Time Reversal Beam Focusing of Ultrasonic Array Sensors on a Defect in Layered Media

---**Hyunjo Jeong** and Jeong-Sik Lee, Wonkwang University, Division of Mechanical and Automotive Engineering, Iksan Jeonbuk, South Korea; Chung-Hoon Lee, Wonkwang University, Division of Semiconductor and Display Technology, Iksan Jeonbuk, South Korea

---The ability of time reversal techniques to focus ultrasonic beams on the source location is important in many aspects of ultrasonic nondestructive evaluation. In this paper, we investigate the time reversal beam focusing of ultrasonic array sensors on a defect in layered media. Numerical modeling is performed using the commercially available software which employs a time domain finite difference method. Two different time reversal approaches are considered – the through transmission and the pulse-echo. Linear array sensors composed of N elements of line sources are used for signal reception/excitation, time reversal, and reemission in time reversal processes associated with the scattering source of a side-drilled hole located in the second layer of two solid layer structure. The simulation results demonstrate the time reversal focusing even with multiple reflections from the interface of layered structure. We also examine the lateral resolution of focused beam that is related to the propagation distance, the size of array sensor and the wavelength.

Ultrasonic Methods

Angular Spectrum of Plane Waves Method of Elastic Wave Field Calculation

---**Yasuhiko Adachi**, Kyoto University, Department of Physics, Kyoto, Japan; Bernhard R. Tittmann and Chiaki Miyasaka, The Pennsylvania University, Department of Engineering Science and Mechanics, University Park, PA 16802

---When emitting ultrasonic waves from an acoustic lens into an isotropic or anisotropic solid via a coupling medium (e. g., water), the propagation directions of the waves within the solid depend on the incident angles of the waves and are determined by the lens geometry, the position of the lens, and the frequency of the waves. The displacement amplitudes of the waves can be experimentally mapped by a laser interferometer. However, it is very difficult to identify what wave modes are visualized. In this case, an angular-spectrum approach to the waves is useful to predict the amplitude of the waves. With this method, the amplitudes on any planes in the specimen interior can also be calculated if the wave amplitude distribution is known on any plane. The main complication to this approach is to solve Christoffel's equation for the z-component of the wave-vector and all in-plane wave-vector components. We found that the equation can be analytically solved for eight out often cases of the elastic constant stiffness coefficient matrices. Our approach allows rapid calculation of the wave amplitudes in any direction for any lens geometry and any orientation. The technique will accelerate the speed of the computer simulation relating ultrasonic wave propagation within an arbitrary solid.

Ultrasonic Methods

Laser Optoacoustic Nondestructive Method of Thickness Measurement of Subsurface Damaged Layer in Machined Silicon Waters

---**Alexander A. Karabutov** and Natalia B. Podymova, International Center, M. V. Lomonosov Moscow State University, Leninskie Gory, Moscow 119991, Russia

---Nondestructive measurements of the thickness of subsurface damaged layer in silicon wafers induced by machine cutting is critically important for its cost-effective manufacturing for microelectronic devices. In the present work we propose the laser optoacoustic (OA) method for quantitative nondestructive evaluation of the thickness of damaged layers in machine cut silicon wafers. It is based on different mechanisms of laser excitation of ultrasound in monocrystalline silicon – the concentration-deformation mechanism and in a damaged layer – the thermoelastic one by absorption of Q-switched Nd:YAG laser pulse at the fundamental harmonic. Due to the uniform heating of a damaged layer during the laser pulse action the amplitude of the positive phase (A+) of the excited OA signal is proportional to the damaged layer thickness L. The negative phase of OA signal (A-) arises by absorption of the rest of laser energy in monocrystalline silicon beneath the damaged layer. Comparison of the value R=A+/A- with the scanning electron microscopy measurements of L has shown the linear dependence of R vs L within the nonuniformity limits of L and the corresponding spread of OA signals amplitudes. This provides the possibility of nondestructive laser optoacoustic measurement of the thickness of the damaged layer in silicon wafers. The evaluated minimum detectable value of damaged layer thickness is 0,15-0,2 micron.

Ultrasonic Methods

Application of Axicon Lenses in Ultrasonic Techniques

---**Pablo Katchadjian**, Alejandro Garcia, and Carlos Desimone, Comision Nacional de Energía Atómica, UAENDE - INEND, Buenos Aires, Argentina

---In this work we study the acoustic characteristics of ultrasonic transducers with the addition of axicon lenses. We make a comparison between this combination, a standard transducer and another type of lenses, showing some of their advantages such as the near field elimination, the beam focalization in a line and the focus diameter reduction. For this purpose we built lenses with different angles and materials, and we used different liquids in the transducer-lens interface. We drew the curves of signal amplitude against reflector depth, vertical beam profile, acoustic pressure distribution and front end noise for each case. We analyzed which configurations between all the proposed ones showed the best results. Finally, we give some guidelines for the lenses design and we show some practical applications of them in different components.

Ultrasonic Methods

Plate Wave Transmission/Reflection at Geometric Obstructions: Model Study

---**R. A. Roberts**, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50014

---This paper reports on work to model the transmission characteristics of arbitrarily shaped geometric obstructions in problems of plate wave propagation, such as joints, stiffeners, thickness transitions, and bends. The motivation for this work is noise source location in structures, the specific application being the location of air leaks in spacecraft skins, funded by NASA. The approach applies the boundary element method (BEM) to the geometric obstruction, using impedance boundary conditions over the regions where the plate(s) join to the obstructing feature. A simple BEM analysis over a semi-infinite plate is used to determine the traction/displacement impedance relation over the joining regions, in which the Green function for an infinite plate is used to confine the analysis to the joining edge of the plate. Transmission and reflection coefficients are extracted from the far-field analysis of displacements in the plate using the computed displacements/tractions on the plate edge. The analysis is used to examine the transmission and reflection characteristics of various geometric features of interest. Results are compared to experimental measurements for selected cases.

Ultrasonic Methods

Plate Wave Transmission/Reflection at Geometric Obstructions: Experiment

---**R. Reusser**, D. E. Chimenti, S. Holland, and R. Roberts, Center for NDE, Iowa State University, Ames, IA 50011

---This paper reports on the experimental examination of the transmission and reflection characteristics of arbitrarily shaped geometric obstructions in problems of plate wave propagation, such as joints, stiffeners, thickness transitions, and bends. The motivation for this work is noise source location in structures, the specific application being the location of air leaks in spacecraft skins, funded by NASA. In this work, it has been demonstrated that leaks can be located at a distance using array-based sensors which determine the direction of signal propagation at the sensor location. The limiting factor in practice is the influence of geometric obstructions between the leak and the sensor. This work reports a quantitative examination of the transmission properties of various obstructions such as stiffening ribs. Surface motions arising from a distant source are recorded over a local array of spatial positions using a scanned laser vibrometer. Spatial Fourier analysis is then applied to determine the individual contributions of the constituent mode types to the measured signals. Transmission properties of intervening geometric obstructions are determined by comparison to unobstructed signals. Comparisons to theoretical predictions of transmission characteristics will be presented for selected cases.

Ultrasonic Methods

Model for Thickness and Anisotropy Measurements in Metal Plates Using Laser Ultrasonics

---**Martin Engman** and Magnus Falkenström, Swerea KIMAB, Box 55970, 102 16 Stockholm

---A technique for thickness measurements of plates, using laser ultrasonic's, which is independent of the wave velocity of the material will be described. The principle of the technique is to look at the relations between the consecutive echoes when inducing the ultrasonic wave at a distance from the detecting laser. In case of an isotropic material the relations between the echoes are exclusively dependent of the distance between the two lasers and the thickness of the sample. If the material investigated is anisotropic, the technique described above can be used as a tool for quantifying the direction dependent velocity in the plate. The ratio between the calculated thickness and the true thickness is a direct value of the "anisotropy".

Ultrasonic Methods

Plate Wave Resonance with Air-Coupled Ultrasonics

---H. N. Bar[1], V. Dayal[2], D. Barnard[2], and **D. K. Hsu[2]**, [1]National Metallurgical Laboratory, Material Science & Technology Division, Jamshedpur, 831007, India; [2]Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---Air-coupled ultrasonic can excite the plate waves in metals and composites. The coincidence effect, i.e., the wave vector of plate wave coincides with projection of exciting airborne sound vector, leads to a resonance which strongly amplifies the sound transmission through the plate. The resonance depends on the angle of incidence and the frequency. In the present study, the incidence angle for maximum transmission (θmax) is measured in plates of steel, aluminum, carbon fiber reinforced composites and honeycomb sandwich panels. The variations of (θmax) with plate thickness are compared with theoretical values in steel, aluminum and quasi-isotropic carbon fiber composites. The enhanced transmission of air-coupled ultrasound at oblique incidence can substantially improve the probability of flaw detection in plates and especially in honeycomb structures. Experimental air-coupled ultrasonic scan of subtle flaws in CFRP laminates showed definite improvement of signal-to-noise ratio with oblique incidence at θmax.

Ultrasonic Methods

Advanced Crack Shape Analysis Using SAFT
---R. Boehm, D. Brackrock, G. Brekow, **M. Kreutzbruck**, and J. Kitze, Federal Institute for Materials Research and Testing, BAM, Berlin, Germany

---The spatial resolution in Ultrasonic Testing as a wave phenomenon in nature is limited to a certain fraction of the wavelength, usually defined to be close to the Rayleigh The spatial resolution in Ultrasonic Testing as a wave phenomenon in nature is limited to a certain fraction of the wavelength, usually defined to be close to the Rayleigh criterion. In case of complicated reflector surfaces – such as stress corrosion cracking - this limitation prevents an exact visualization of the defect shape. There exist a few approaches to improve the spatial resolution, whose reconstruction quality all in common also depend on the achieved signal-to-noise ratio of the raw data. In this work we present a specific SAFT analysis, in which a high number of different angles of incidence produce a sufficiently high number of different reflections at the crack edges resulting in an improved SNR. In doing so, we reconstruct a coherent crack structure. First investigations were made at artificially simulated crack configurations with different contours and curvatures in flat and cylindrical test blocks. The measurements results – visualized by representative scans – show details of crack design and crack orientation. We also will present a comparison of the SAFT analysis between modelling and phased array measurements criterion. In case of complicated reflector surfaces – such as stress corrosion cracking - this limitation prevents an exact visualization of the defect shape. There exist a few approaches to improve the spatial resolution, whose reconstruction quality all in common also depend on the achieved signal-to-noise ratio of the raw data. In this work we present a specific SAFT analysis, in which a high number of different angles of incidence produce a sufficiently high number of different reflections at the crack edges resulting in an improved SNR. In doing so, we reconstruct a coherent crack structure. First investigations were made at artificially simulated crack configurations with different contours and curvatures in flat and cylindrical test blocks. The measurements results – visualized by representative scans – show details of crack design and crack orientation. We also will present a comparison of the SAFT analysis between modelling and phased array measurements.

Ultrasonic Methods

A Parametric Study on Guided Wave Tomography via Modeling and Experiment
---**Bongjae Shin**[1], Yunri Piao[1], Younho Cho[2], and Bongyoung Ahn[3], [1]Graduate School of Mechanical Engineering, Pusan National University, Busan 609-735, Rupublic of Korea; [2]School of Mechanical Engineering, Pusan National University, Busan 609-735, Republic of Korea; [3]Korea Research Institute of Standards and Science, Dejeon 305-340, Republic of Korea

---The structural health monitoring with guided wave is one of promising methods to meet the demand for an efficient way to inspect large structures with a reasonable sensitivity for defect detection. In order to develop a more reliable imaging technology, further parametric studies have been needed. In this study, we performed both modeling and experiment of guided wave scattering from a defect for comparison. Modeling of guided wave scattering was achieved via hybrid boundary element technique. The time domain signals resulted from modeling then were used as input features for tomographic imaging using RAPID (Reconstruction Algorithm of the Probabilistic Inspection of Damage). While experiment was performed using PZT sparse sensors, the data was compared with the modeling results. Through the comparison, a feature based data analysis is explored to pursue a more quantitative scheme.

Transducers and Probes

Development of Electromagnetic-Acoustic Sensors for Evaluation of Flaws in Gas Pipelines

---**Hui-Ryng Yoo**[1], Hak-Joon Kim[2], Sung-Jin Song[2], Dae Kwang Kim[1], Sung-Ho Cho[1],and Yong-Woo Rho[1]; [1]School of Mechanical Engineering, Sungkyunkwan University, Suwon, 440-746, Korea; [2]Intelligent PIG R&D Group, R&D Division, Korea Gas Corporation, Incheon, 406-130, Korea

---For in-line inspection (ILI) of gas pipelines, pig system with magnetic flux leakage (MFL) method is widely adopted. MFL pig systems show relatively good performance in detection of flaws in the pipelines. But, it is not easy to detect and evaluate disbondment of pipeline coating, stress-corrosion cracking (SCC) and etc using MFL pig system. So, to improve detectability of various types of flaws in the pipelines, recently, EMAT (Electromagnetic Acoustic Transducer) based pig systems have been developed. Generally, magnetostrictive EMATs use to generate and receive SH- or SV- guided waves propagating through circumferential direction of the pipes for detecting for detecting SCC, coating disbanding and etc since the gas pipeline is ferromagnetic material. However, for applying EMAT to ILI-pigging system of gas pipelines, optimally designed EMAT for generating guided waves in the pipe with desired mode and signal analysis techniques for reducing noise and sizing detected flaws are needed. So, in this study, we fabricate EMAT transmitter and receiver for generating and receiving SH guided waves in large diameter of gas pipes. Also, denoising techniques (Wavelet transform, curve fitting and etc) for improving S/N and signal interpretation techniques for evaluating flaws is developed. Using the fabricated EMAT and developed signal analysis techniques, detecting and evaluating flaws (cracks and coating disbanding) in the pipe specimens will be performed in order to verity performance of the fabricated sensors and developed signal analysis methods. In this presentation, we will show fabricate EMAT sensors and describe basic principal of developed denosing methods and signal interpretation methods. And, performance of the EMAT sensor and signal analysis method will be presented.

Transducers and Probes

Simplified System Efficiency Functions for Linear Phased-Array Transducers

---**Frank J. Margetan**[1], Tim Gray[1], and Ruiju Huang[2], Center for NDE, Iowa State University, 1915 Scholl Road, Ames, IA 50011; [2]268 Congressional Lane, Apt. 203, Rockville, MD 20852

---Computer models are often used to simulate ultrasonic inspections of industrial components. One ingredient of such simulations is a frequency dependent function which describes the efficiency of the inspection system for converting electrical energy to sound and vice versa. For a phased-array transducer there are many such efficiency functions, namely one for each pair of piezoelectric elements. In this paper we describe a simplified, approximate approach for specifying these functions. Element-to-element differences are accounted for by two “residual” parameters: (1) a strength factor which describes the relative "hotness" of an element compared to its peers; and (2) a time delay which describes the extent to which an element fires later or earlier than its peers when all elements are instructed to fire in unison. These residuals are used to relate the system efficiency function for any pair of elements to that of an average efficiency which can be readily measured. The use of this approach is demonstrated using front-wall and back-wall responses from a steel block, as acquired using a 32-element, linear, phased-array transducer.---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.

Transducers and Probes

Acoustic Field Calculation of Ultrasonic Linear Phased Array Transducer with Curve Surface

---**Chunguang Xu**, Beijing Institute of Technlogy, Mechanical and Vehicular Department, Beijing, China; Shuang Li, Beijing Institute of Technlogy, Mechanical and Vehicular Department, Beijing, China; Xinyu Zhao, Beijing Institute of Technology, Mechanical and Vehicular Department, Beijing, China

---Nowadays, contact surface of ultrasonic phased array is generally rigid plane or line. If the surface of component is not plane or line, it can reduce the testing sensitivity due to unmatched contact. Thus it is necessary to develop ultrasonic phased array with curve surface to fit actual surface of the piece. Circle arc linear phased array is the simplest curve surface phased array, which is the base of analyzing irregular surface linear phased array transducer. Focused law and acoustic field computation method were discussed about circle arc linear phased array. According to Huygen's principle, acoustic field of transducer cand be achieved by the use of coordinate transform and an approximation with rectangle element instead of circle arc element, and was validated using Rayleigh-Sommerfeld Integral and non approximate axis multiple Gaussian beam model respectively. The results of two methods match well, thus the method proposed is feasible. Then geometric parameters of transducer, such as element number, element elevation, element space and element width were studied for their influence on acoustic field. On the condition of constant element width, element number is increased to eliminate grating lobe and produce better beam performance; on the premise of good beam, high pressure is obtained by increasing element width.

Transducers and Probes

Measurement of Uncertainty in Eddy Current Bolt Hole Crack Measurements for Use in POD

---**Ross Underhill** and Thomas Krause, Royal Military College of Canada, Kingston, Ontario, Canada

---In order to obtain valid POD estimates of a90/95 for cracks in bolt holes using eddy current techniques, it is essential that an accurate model for the measurement uncertainty be used in the fit of the a-hat vs a data. In the absence of explicit error handling schemes, the use of a log axis for the dependent variable implies that the uncertainty is proportional to the variable and a linear axis implies a constant uncertainty. We have analyzed the data from a recent large round robin study of EDM notches and fatigue cracks and demonstrated that, once the calibration errors have been removed, the remaining uncertainty is constant at very low crack sizes and, above a certain threshold (approximately 0.75 mm), increases linearly with the crack size. The proportionality constant appears to be bigger for fatigue cracks than EDM notches.

Transducers and Probes

A Real-Time Microwave Camera at K-Band (24 GHz)

---**M. T. Ghasr**, M. Abou-Khousa, M. A. Baumgartner, and R. Zoughi, Applied Microwave NDT Lab., Electrical and Computer Engineering Department, Missouri University of Science & Technology, 301 W. 16th, Rolla, MO 65409

---Nondestructive testing (NDT) community has been moving towards effective and robust inspection systems that can provide real-time information about materials, geometrical, structural, and mechanical characteristics of composite materials/structures. Moreover, in many applications it is desired to have an image of the structure, after which the information contained in the image is correlated to the above characteristics. Microwave signals penetrate inside of dielectric composite structures and their interaction with the interior of the structure renders critical information for NDT purposes. Subsequently, this information (i.e., magnitude and phase or reflected signal) may be used to produce an image of the interior of the structure revealing potential flaws or anomalies. Image processing and reconstruction techniques may also be incorporated to produce high-resolution images (i.e., synthetic-aperture, back-propagation, etc.). There are several different approaches for designing a real-time microwave camera system. One approach is based on modulated scatterer technique (MST), which is used to tag scattered electric field in a discrete two-dimensional (2D) spatial domain (e.g. a retina) resulting in the 2D magnitude and phase distribution of the scattered electric field which is required for producing an image of a material or structure under inspection. The ability to rapidly modulate resonant slot antennas in such a retina along with using receivers with fast responses provide for real-time image production capability. Design issue and criteria become more challenging at higher frequencies and for a relatively large retina size. This paper presents the basic design and challenges for a microwave camera with a retina size of 6" by 6" operating at a frequency of 24 GHz. In addition, this microwave camera will be demonstrated as part of the interactive Poster Session.

Transducers and Probes

Image and Signal Processing Algorithms for THz Imaging of Composite Materials

---Przemyslaw Lopato and **Tomasz Chady**, West Pomeranian University of Technology, Department of Electrical and Computer Engineering, Szczecin, Poland; Krzysztof Goracy, West Pomeranian University of Technology, Polymer Institute, Szczecin, Poland

---Due to high: stiffness, corrosion resistance and strength to weight ratio, glass fiber reinforced composite materials continue to be used in numerous applications. There exist many, various methods of glass fiber laminates evaluation, e.g. ultrasonics, x-rays or thermography. The inner structure of those materials is complicated and highly heterogeneous (multi-layer nature and fiber waviness), thus the examination process especially identification of defects and their types is very difficult. An application of terahertz frequencies electromagnetic waves (often called T-rays) and time domain pulsed measurements creates opportunity to achieve signals allowing to identify various defects types very precisely. In this paper algorithms for image and signal processing of THz C-scans will be shown. Enhanced THz images enable better defects identification and classification results. Proposed algorithms were verified using C-scans achieved for various types of defects (e.g. inclusions, delaminations or fiber waviness) and composite materials. For this reason a catalogue of possible defects will be prepared.

Transducers and Probes

An SH Guided Wave Transducer Module Using a Magnetostrictive Thin Element
---**Bongyoung Ahn**, Seung Hyun Cho, Jae Ha Park, Hyun-Sang Kwon, and Seung Seok Lee, Korea Research Institute of Standards and Science, Center for Safety Measurement, Taejon, Korea

---In guided wave based NDE, the appropriate selection of the operating wave is very critical since the test performance is highly dependent on the wave mode. As far as plate-like structures are concerned, so far, SH guided waves have not been frequently applied compared to Lamb waves due to the lack of proper and convenient transducers to generate and detect the SH waves. In this investigation, a novel small-sized SH guided wave transducer based on magnetostriction is proposed. The present transducer was designed to be modular and can be used with shear wave couplant to avoid the inconvenience of the existing magnetostrictive patch transducers, which comprises the ferromagnetic patch tightly bonded to a structure. The transducer is composed of a magnetostrictive element, a periodic solenoid, and permanent magnets. The wave transduction mechanism and the detailed configuration of the present transducer are presented. Experimental verification was also conducted on test specimens and the results confirm the good performance of the present transducer module. Interestingly, SH waves can be efficiently measured at a ferromagnetic specimen as well as a nonferromagnetic one with the present transducer.

Civil Structures

Joint Rigidity Assessement with Piezoelectric Wafers and Acoustic Waves
---**Angela C. Montoya** and Arup K. Maji, University of New Mexico, Department of Civil Engineering, Albuquerque, NM 87131-0001

---There has been an interest in the development of rapid deployment satellites. In a modular satellite design, different panels of specific functions can be pre-manufactured. The satellite can then be assembled and tested just prior to deployment. Traditional vibration testing is time-consuming and expensive. An alternative test method to evaluate the connection between two plates will be proposed. The method investigated and described employs piezoelectric wafers to induce and sense lamb waves in a thin aluminum plate. Lamb wave behavior and piezoelectric material properties will be discussed; the experimental setup and results will be presented. A set of 4 piezoelectric ceramic wafers, with PiezoSystems' Designation PSI-5A4E, were used alternately as source and sensor. The wafers were bonded to two aluminum plates, which were joined by steel brackets to form an ‘L-Style’ joint. The driving frequency on the transducer was varied at 0.01 second intervals, and recorded against the output amplitude. The energy transmitted was shown to correlate with a mechanical assessment of the joint, demonstrating that this method of testing is a feasible and reliable way to inspect the rigidity of joints.

Civil Structures

NDE of Lumber Wood and Natural Fiber Products Using Air-Coupled Ultrasound

---**David K. Hsu** and David Utrata, Iowa State University, Center for NDE, Ames, IA 50011; Monlin Kuo, Iowa State University, Department of Natural Resource Ecology and Management, Ames, IA 50011

---Due to the porous nature of wood and natural fiber based products, conventional fluid or gel coupled ultrasonic inspection is unsuitable. Air-coupled ultrasonic transmission scanning, being non-contact, is ideally suited for inspecting lumber, wood and natural fiber based products. We report here several successful applications of air-coupled ultrasound for the inspection of wood. Air-coupled ultrasonic scan at 120 kHz can easily detect “sinker-stock” lumber in which bacterial damage of ray tissue cells had occurred during anaerobic pond storage. Channels in ash lumber board caused by insect bore were imaged in transmission scan. Delamination and material inhomogeneities were mapped out in manufactured wood and natural fiber products including medium density fiberboards, compression molded shredded waste wood with formaldehyde resin, and acoustic panels molded with kenaf fibers. The study has demonstrated some of the capabilities of air-coupled ultrasound in the NDE of forest products.

Civil Structures

Nondestructive Evaluation of the State of Damage in Concrete under Uniaxial

---**Parisa Shokouhi**, Andreas Zoëga, and Herbert Wiggenhauser, BAM – Federal Institute for Material Research and Testing, Berlin, Germany

---The changes in the mechanical properties of concrete under stress were investigated in this study. The macroscopic effects of stress-induced damage were evaluated nondestructively by measuring the changes in characteristics of mechanical wave propagation through concrete under uniaxial compression. Surface wave velocities at the sonic frequency range were measured on concrete specimens undergoing various cycles of loading and unloading. Acoustic Emission test (AE) was conducted simultaneously to monitor the microcracking activities at different levels of loading. The surface deformation was also measured using a high-resolution optical 3D deformation analysis system. The sonic surface wave velocity was found to be highly stress-dependent. Several experiments on different concrete specimens of different types proved that the changes in surface wave speed are repeatable and follow a particular trend. The observed trend could be explained by microcracking theory. The arguments were supported by the results of AE test as well as the deformation measurements. Based on the changes in wave velocity measurements from various tests, a model to predict the level of damage in concrete under uniaxial pressure is proposed.

Civil Structures

Characterization of Fatigue Damage in A36 Steel with Nonlinear Rayleigh Waves

---**Suzanne E. Duncan**, Jin-Yeon Kim, Jianmin Qu, and Laurence J. Jacobs, Georgia Institute of Technology, College of Engineering, 225 North Avenue, Atlanta, GA 30332-0355

---The objective of this research is to use nonlinear Rayleigh surface waves to quantitatively characterize the amount of fatigue damage in A36 steel components. A36, or mild steel, is a standard structural steel alloy used for bridges and buildings in the United States. This study develops an experimental procedure to evaluate material damage in A36 steel due to plastic deformation by measuring the second order harmonic of Rayleigh surface waves. These nonlinear Rayleigh waves are generated and detected with a wedge transducer system. The amplitude ratio of the first and second order harmonic is related to the nonlinearity parameter β which has been used to describe changes in microstructure and fatigue damage. This research characterizes changes in the nonliterary parameter of A36 steel as measured with Rayleigh waves for damage caused by both monotonic loading above yield and cyclic fatigue. The results show an increase in the second order harmonic amplitude with increasing plastic strain, and demonstrate the potential of developing a quantitative monitoring system for life prediction of bridge and building components.

Process Control

Observation of CVD Diamond Coating with Various Deposit Conditions by using Nondestructive Method

---Dong-Yeol Kim [1,2], T. Takagi[2], H. Miki[2], T. Uchimoto[2], **Sung-Jin Song**[1], and Hak-Joon Kim[1], [1]School of Mechanical Engineering, Sungkyunkwan University, Suwon, Gyeonggi-do, Korea; [2]Institute of Fluid Science, Tohoku University, Sendai, Japan

---CVD diamond coating was utilized for wide industrial application because of outstanding mechanical properties such as high hardness, low thermal expansion coefficient, high electrical resistivity. CVD diamond coating was affected by various deposit conditions such as surface roughness of substrate, kinds of substrate, deposit time, flow rate of H2 or CH4 etc. Therefore, it is necessary to observe and evaluate CVD diamond coating layer for improvement of quality of CVD diamond coating. For that purpose, in this study, we will prepare CVD diamond coating specimens with various deposit conditions. And then, we will observe CVD diamond coating layer by using various nondestructive methods such as Raman spectroscopy, XRD diffraction, scanning electron microscopy (SEM), and acoustic microscopy. Especially, acoustic microscopy is a common detection method which produces high resolution images with focalized ultrasonic waves. Therefore, we will obtain acoustic image of coating layers and evaluate them by using acoustic microscopy. In this presentation, we will suggest the most appropriate nondestructive evaluation method of CVD diamond coating layers and the best condition of diamond deposit process.

Process Control

Validation of an X-ray Computer Tomography Based Image Processing Technique by Statistical Performance Analysis

---Mathew Amos, **El-Mahjoub Rasselkorde**, and Damien Pain, TWI NDT Validation Centre (Wales), Heol Cefn Gwrgan, Margam, Port Talbot Sa13 2EZ, United Kingdom

---X-ray Computer Tomography (CT) in terms of Non Destructive Testing (NDT) is becoming increasingly used in many industrial sectors due to its impressive results. It has been shown that the use of the correct energy setting for the material being imaged optimizes the detail detectability of the CT inspection. If a multi density component is being imaged then a single energy CT system cannot be fully optimized for that component resulting in a reduced quality of the inspection. Dual Energy CT could potentially overcome this constraint but is mainly used for material composition analysis and has not yet been utilized for enhanced defect detection. This paper describes the development and validation of a Dual Energy image processing program to be implemented in the CT reconstruction process of single energy scanning systems, with the specific aim of improving defect detection in multi density components.

Session 12

SESSION 12
GUIDED WAVES II
D. Chimenti, Chairperson
Chafee 277

3:30 PM **The Reflection of the Fundamental Torsional Mode from Defects in Pipes with Varying Depth Profile**
---**R. Carandente**, J. Ma, and P. Cawley, Imperial College, UK Research Centre in NDE, Mechanical Engineering, London, United Kingdom

3:50 PM **Implementation of Focused Guided Waves to Locate Axial Defects in Pipes**
---**S. Fletcher** and M. J. S. Lowe, Imperial College, UK Research Centre in NDE, Mechanical Engineering, London SW7 2AZ, United Kingdom; C. Brett, E.ON Engineering Ltd., Technology Centre, Ratcliffe on Soar, Nottingham, United Kingdom; M. Ratassepp, Department of Mechanics, Tallinn University of Technology, Tallinn, Estonia

4:10 PM **Beamforming of Wavefield Data From Embedded Sources for Rapid Follow-Up Inspection of Inaccessible Areas**
---**J. E. Michaels**, N. Gandhi, J. S. Hall, S.-J. Lee, and T. E. Michaels, Georgia Institute of Technology, School of Electrical and Computer Engineering, Atlanta, GA 30332-0250; M. Ruzzene, Georgia Institute of Technology, School of Aerospace Engineering, Atlanta, GA 30332-0150

4:30 PM **Use of Microwaves for the Detection of Corrosion Under Insulation**
---**R. Jones**, F. Simonetti, and M. J. S. Lowe, Imperial College, UK Research Centre in NDE, Mechanical Engineering, London, United Kingdom; I. Bradley, BP, Sunbury on Thames, United Kingdom

4:50 PM **Aircraft Bond Repair Patch Inspection Using Ultrasonic Guided Waves**
---**P. Puthillath**, Pennsylvania State University, Engineering Science and Mechanics, Department, University Park, PA 16802; J. L. Rose, FBS Inc., State College, PA 16804

5:10 PM **Pulse-Echo Reflection of the SH0 Guided Wave Mode from a Part-Thickness Elliptical Defect**
---**J. Ma** and P. Cawley, Imperial College, UK Research Centre in NDE, Mechanical Engineering, London, United Kingdom

The Reflection of the Fundamental Torsional Mode from Defects in Pipes with Varying Depth Profile

---**Rosalba Carandente**, Jian Ma, and Peter Cawley, Imperial College, UK Research Centre in NDE, Mechanical Engineering, London, United Kingdom

---Guided ultrasonic waves have been successfully applied to detect defects and corrosion in plate and pipes; however, defect sizing is more challenging. Past research has considered scattering from defects with simple geometries and uniform depth profiles. However, realistic defects have much more complex depth profiles, which may affect the strength and frequency dependence of the guided wave reflections. A study of the reflection of the fundamental torsional mode T(0,1) from an axi-symmetric notch with varying depth profile has been carried out via finite element (FE) modelling and experimental validation. Defects with gradually varying depth can be represented by a series of tapered steps. It is shown that, for both up- and down-steps, the T(0,1) wave packet is reflected only at the start and end of the steps and the wave propagates at an unchanged velocity along the step. The magnitude and phase of the reflections from the start and end of the step have been predicted and the frequency dependence of the overall reflection from the step has been studied. The reflections from successive down- and up-steps have been combined to predict analytically the reflection from a V-shaped defect and the results have been compared with those obtained from a direct model and from experimental measurements. The reflection coefficient spectrum varies periodically with frequency due to the constructive/destructive interference between waves reflected from the two sides of the defect. The reflection coefficient is controlled by two parameters, the slope of the tapered sections of the defect and the average axial length of the defect expressed in wavelengths. With tapered defects, the amplitude of successive reflection coefficient peaks decreases as the frequency increases, so tapered defects are more difficult to detect at higher inspection frequencies.

Implementation of Focused Guided Waves to Locate Axial Defects in Pipes

---**Samuel Fletcher** and Michael J. S. Lowe, Imperial College, UK Research Centre in NDE, Mechanical Engineering, London SW7 2AZ, UK; Colin Brett, E.ON Engineering Ltd., Technology Centre, Ratcliffe on Soar, Nottingham, UK; Madis Ratassepp, Department of Mechanics, Tallinn University of Technology, Tallinn, Estonia

---The interaction of fundamental torsional mode guided waves with axially aligned defects in pipes has been investigated. This follows previously presented work involving similarly aligned defects in plates. Results from both finite element computer models and real pipes are presented and the data shows good agreement. Experiments were performed on 5 inch pipework over the frequency range 20kHz – 65kHz. The dependence of reflection coefficient on crack length was measured for both through thickness and part depth (80% through thickness) axially aligned notches. In particular the use of guided wave focusing has been examined. Focusing is necessary to improve the reflection coefficient from axially aligned defects, as it has been shown that the signals are very weak. The Common Source Method (CSM) of focusing has been applied which makes it possible to apply focusing to previously collected data. The results show that, although the reflections are still small, there is an improvement when focusing is employed.

Beamforming of Wavefield Data From Embedded Sources for Rapid Follow-Up Inspection of Inaccessible Areas
---**Jennifer E. Michaels**, Navneet Gandhi, James S. Hall, Sang-Jun Lee, and Thomas E. Michaels, Georgia Institute of Technology, School of Electrical and Computer Engineering, Atlanta, GA 30332-0250; Massimo Ruzzene, Georgia Institute of Technology, School of Aerospace Engineering, Atlanta, GA

---Structural health monitoring systems employing embedded guided wave sensors are being considered for aerospace applications. If these systems detect changes that may be caused by damage, rapid follow-up inspection is desirable; however, the region of suspected damage may be inaccessible. Proposed here is a method whereby one or more of the embedded sensors are used as sources, and limited wavefield data are recorded outside of the inaccessible region via a non-contact method such as a laser vibrometer or scanned air-coupled transducer. These wavefield data are then used to form images of sources and scatterers inside the inaccessible region via a beamforming algorithm. The feasibility of this method is demonstrated for several different cases using numerical wavefield data generated by an efficient ray tracing algorithm. Experimental results are also shown.

Use of Microwaves for the Detection of Corrosion Under Insulation
---**Robin Jones**, Francesco Simonetti, and Michael J. S. Lowe, Imperial College, UK Research Centre in NDE, Mechanical Engineering, London, United Kingdom; Ian Bradley, BP, Sunbury on Thames, United Kingdom

---Corrosion Under Insulation (CUI) is a major cause of pipeline failure in the oil industry. When water breaches the external cladding used to protect the insulation, it starts to corrode the external surface of the pipe. Inspection of the pipe by removal of the insulation is expensive and time consuming. This paper explores the possibility of detecting CUI with an indirect approach aimed at monitoring the presence of water in the insulation; a necessary precursor to CUI. In particular, it is observed that the pipe and the cladding form a coaxial waveguide which can be used to propagate microwaves within the insulation along the length of the pipe. An accumulation of water in the insulation will act as an impedance discontinuity within the waveguide, causing a reflection of the microwave signal. These reflections can be used to detect and locate water accumulations, and hence locate the regions of the pipe at risk of CUI. Here, we discuss the characteristics of the dispersion curves of the modes that can propagate in clad pipelines for typical pipeline geometries and propose an antenna array design for pure mode excitation. We then present initial experimental results using time domain reflectometry on a mock 12” coaxial waveguide that demonstrates the possibility of detecting small water patches.

Aircraft Bond Repair Patch Inspection Using Ultrasonic Guided Waves

---**Padmakumar Puthillath**, Pennsylvania State University, Engineering Science and Mechanics, Department, University Park, PA 16802; Joseph L. Rose, FBS Inc., State College, PA

---Aircraft and other structures are subject to fatigue loads and environmental conditions that leads to a reduction in their service life. The useful life of such structures can be extended by machining the surface of the damaged part and adhesively bonding metal or composite repair patches to the surface. Similar to the adhesively bonded joints in the primary aircraft structures, the inspection of the repair patches is essential in order to assess their reliability. Ultrasonic guided waves provide a non-destructive technique for inspection of the adhesively bonded repair patches. The guided wave phase velocity dispersion curves are used in conjunction with wave structures to determine optimal conditions like larger shear stress or larger in-plane displacements at the adhesive interface, for inspection of these repair patches. Aluminum plates with epoxy bonded titanium repair patches were prepared with interfacial weakness conditions simulated by using teflon inserts and other surface variation techniques. The optimal guided wave mode was generated in the bonded sample using an ultrasonic transducer mounted on an acrylic wedge. The transmitted signal was processed using physically based features and pattern recognition as well as appropriate signal processing techniques. The difference in transmission in terms of the signal content was successfully analyzed and used to discriminate between the defective and non-defective regions in the structure.

Pulse-Echo Reflection of the SH0 Guided Wave Mode from a Part-Thickness Elliptical Defect

---**Jian Ma** and Peter Cawley, Imperial College, UK Research Centre in NDE, Mechanical Engineering, London, United Kingdom

---Guided ultrasonic wave inspection has been proven to be an effective technique for pipe and plate structures; however defect characterization remains challenging and requires a full understanding of the interaction of guided waves with a realistic representation of the defect. In this paper, a study of the pulse-echo reflection of the SH0 mode from a part-thickness elliptical defect in plates in the frequency-thickness range 200-1000 kHz-mm is presented. An elliptical defect can be characterized by a number of parameters including size, aspect ratio, maximum depth and depth profile. The effect of these parameters on the reflection coefficient spectrum of the SH0 mode has been examined. The pulse-echo reflections for different incidence angles have been studied via 3D finite element simulations and experimental validations. The study shows that the reflection coefficient spectrum of the SH0 mode from an elliptical defect exhibits periodic peaks and troughs due to interference between reflections from the leading and trailing edges of the defect. For normal incidence, the pattern of the reflection coefficient spectrum is determined by the length of the ellipse, while the magnitude is affected by the maximum depth and aspect ratio of the defect. Both the shape and magnitude of the reflection coefficient spectrum are found to be highly sensitive to the incidence angle, and the form of the variation with incidence angle is only a function of the aspect ratio of the elliptical defect. In addition, a study of defects with tapered depth profiles indicates that reflections diminish as the taper becomes more gradual. The implications of the findings for defect characterization are discussed.

Session 13

SESSION 13

EDDY CURRENT FUNDAMENTALS AND PROBES II

J. Bowler, Chairperson
CBLS 010

3:30 PM **Evaluation of Eddy Current Signals from Cracks in Cylindrical Structures**
---**J. R. Bowler**[1] and T. Theodoulidis[2], [1]Center for NDE and Department of Electrical and Computer Engineering, Iowa State University, Ames, IA 50011; [2]Department of Mechanical Engineering of the University of Western Macedonia, Kozani, Greece

3:50 PM **Performance Evaluation of Several Types of Pulsed Eddy Current Probes for Detecting Wall Thickness Reduction**
---**Y.-K. Shin** and D.-M. Choi, Kunsan National University, Dept. of Electrical Engineering, Kunsan, Chonbuk, Korea; H.-S. Jung, Sae-An Engineering Corporation, R&D Institute, Seoul, Korea; T.-G. Um, Sae-An Engineering Corporation, ECT Inspection Department, Seoul, Korea

4:10 PM **Analytical and Numerical Modeling of Pulsed Eddy Current Response to Thin Conducting Plates**
---**A. A. Tetervak** and T. W. Krause, Royal Military College of Canada, Department of Physics, Kingston, ON, K7K 7B4, Canada

4:30 PM **Pulsed Eddy Current Thickness Measurement of Selective Phase Corrosion on Nickel Aluminum Bronze Valves**
---T. W. Krause, D. D. Harlley, **V. K. Babbar**, and K. D. Wannamaker, Royal Military College of Canada, Department of Physics, Kingston, Ontario, Canada

4:50 PM **Determination of Four-Point Alternating Current Potential Drop on Rods and Shafts**
---**J. R. Bowler** and Y. Lu, Iowa State University, Center for NDE and Department of Electrical and Computer Engineering, Ames, IA 50011

Evaluation of Eddy Current Signals from Cracks in Cylindrical Structures

---**John R. Bowler**[1] and T. Theodoulidis[2], [1]Center for NDE and Department of Electrical and Computer Engineering, Iowa State University, Ames, IA 50010; [2]Department of Mechanical Engineering of the University of Western Macedonia, Kozani, Greece

--- We have computed the electromagnetic field at cracks in cylindrical structures, including bore holes and tubes, due to eddy current coils. The flaw field is used to determine the variation of coil impedance with position and frequency. A numerical solution of a matrix equation, based on a boundary element scheme, is used to find an approximation of the field at the surface of a crack. By using a Green's kernel that ensures continuity of the tangential electric and magnetic field at the cylindrical surfaces, it is only necessary to render the flaw region in a discrete form. By limiting the number of unknowns needed for an accurate calculation, the computational efficiency is enhanced. The effect of a crack is represented by a current dipole layer orientated normal to the crack surface. The probe impedance variation is computed for both closed ideal cracks and open cracks/slots. This requires two related but different treatments of the singular element. Predictions are given of the variation of the coil impedance with position relative to the crack.---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.

Performance Evaluation of Several Types of Pulsed Eddy Current Probes for Detecting Wall Thickness Reduction

---**Young-Kil Shin** and Dong-Myung Choi, Kunsan National University, Dept. of Electrical Engineering, Kunsan, Chonbuk, Korea; Hee-Sung Jung, Sae-An Engineering Corporation, R&D Institute, Seoul, Korea; Tae-Gun Um, Sae-An Engineering Corporation, ECT Inspection Department, Seoul, Korea

---In the nuclear power plant, there are many pressure tubes, which are thermally insulated. To detect wall thinning of these tubes, the pulsed eddy current (PEC) inspection is considered in this paper since it is a non-contact method. Also, it is expected to be rich of information and to have deeper penetration than the conventional eddy current testing method because of its broadband nature. In usual reflection type PEC testing, the sensor coil detects not only the magnetic fields produced by induced eddy currents, but also source fields. To avoid sensing source fields, two solutions may be possible. One is to shield coils to prohibit excitation fields from reaching the sensor coil. The other is to utilize a differential arrangement of two sensor coils so that influences from the excitation fields, which are common to both sensor coils, counteract and cancel each other. In this paper, a numerical modeling method, such that the backward difference in time and the finite element method for space, is used for the numerical simulation. Four types of PEC probes, namely, absolute, reflection, shielded reflection, and differential sensing probes, are designed and their performances of detecting wall thickness reduction is compared. Numerical simulation is performed for Copper, Tungsten and Inconel 600 with various thicknesses. Simulation results show that each PEC signal has very similar signal characteristics. Three signal features are utilized to evaluate the probe's sensitivity to the wall thickness variation. They are the peak value, the time to peak value and the zero crossing time. To compare signals from different types of PEC probes, these signal features are normalized by the respective value at the normal wall thickness without any wall thinning. In this paper, 5 mm is assumed normal. The normalized signal features indicate that the shielded reflection probe provides the best sensitivity to the wall thickness reduction for all three features.

Analytical and Numerical Modeling of Pulsed Eddy Current Response to Thin Conducting Plates

---**Alexander A. Tetervak** and Thomas W. Krause, Royal Military College of Canada, Department of Physics, Kingston, ON, K7K 7B4, Canada

---The modeling of transient eddy current response in planar structures is important for the development of inspection technologies with applications to multilayer conducting structures. Unlike conventional eddy current where known frequencies are used to interrogate the test piece, transient eddy current is affected by the combined transient response of all the elements within the system comprised of exciting and pick-up coils and the conducting structure being investigated. The combined response includes the feedback processes that in turn modify the time constants within the system. Modeling therefore requires incorporation of all elements of the system. In this work analytical and finite element methods are utilized to solve for those feedback mechanisms within the circuit-conductor system generating the final pick-up coil response. Further, applying numerical analysis to results of the modeling, we parameterize probe-sample interaction via lumped-circuit analogies based on field-energy arguments. Results are compared with experimental measurements where these parameters have been characterized.

Pulsed Eddy Current Thickness Measurement of Selective Phase Corrosion on Nickel Aluminum Bronze Valves

---Thomas W. Krause, David D. Harlley, **Vijay K. Babbar**, and Kevin D. Wannamaker, Royal Military College of Canada, Department of Physics, Kingston, Ontario, Canada

---As a result of its corrosion resistance and high strength, Nickel Aluminum Bronze (NAB) is an alloy that has marine environment applications. However, when exposed to seawater, selective phase corrosion (SPC) may occur, leaving behind a weaker matrix that has a higher relative percentage of copper. The high conductivity of the SPC phase does not allow measurement of corrosion thickness, much beyond 1 mm, by conventional eddy current techniques. Due to its potential for increased depth of penetration pulsed eddy current (PEC) was evaluated for determination of SPC thickness on a 20 mm thick walled NAB valve section with access from the surface corroded side. Signal characteristics were correlated with SPC thickness variations observed along the cut sample's edge over the sensing diameter of the probe. A primarily linear response of PEC amplitude up to the maximum available SPC thickness of 4 mm was observed. Variability in observed PEC signal response was attributed to 1) SPC thickness variations on surface length scale of less than 5 mm, 2) effects on signal amplitude due to the proximity of the sample edge, and 3) the anticipated limits to depth-of-penetration of the sensing field.

Determination of Four-point Alternating Current Potential Drop on Rods and Shafts

---**John R. Bowler** and Y. Lu, Center for NDE and Department of Electrical and Computer Engineering, Iowa State University, Ames, IA 50010

---Four point ACPD is used to measure conductivity, cracks and surface treatments such as case hardening. With the aim of using theoretical models to analyze the measurement data, analytical expressions have been derived for the electromagnetic field produced by alternating current injected into a cylindrical conductive rod via two point-contact electrodes. The potential drop between two voltage electrodes due to the injected current has also been determined in order to predict measurements made with a four-point probe. The theory has been developed for current injection into an infinite cylindrical conductive rod, a tube and a layered rod. Predictions of the alternating potential drop signals are made and compared with experimental measurements showing good agreement.---This material is based upon work supported by the NSF/IU Program at Iowa State University's Center for NDE.

Session 14

SESSION 14
THERMOGRAPHY AND THERMOSONICS I
X. Han, Chairperson
CBLS 100

3:30 PM **Thermal Conductivity Measurement for Thermal Barrier Coatings Based on One- and Two-Sided Thermal Imaging Methods**
---**J. Sun**, Argonne National Laboratory, Argonne, IL 60439

3:50 PM **Reliable Crack Detection in Turbine Blades Using Thermosonics: An Empirical Study**
---**G. Bolu**, A. Gachagan, and G. Pierce, University of Strathclyde, Centre for Ultrasonic Engineering, Glasgow, United Kingdom; G. Harvey, Rolls Royce, East Kilbride, United Kingdom

4:10 PM **Analysis of Impact Damage Using Line Scanning Thermography**
---**O. Ley** and V. Godinez, Physical Acoustics Corporation, Princeton Junction, NJ 08550; S. Chung, J. Schutte, and A. Caiazzo, Materials Sciences Corporation, Horsham, PA, 19044

4:30 PM **Calibration Standards for Thermosonic Nondestructive Evaluation**
---**D. Xiang** and Y. Qin, Intelligent Automation, Inc., Rockville, MD 20858; R. Tenaglia, LSP Technologies, Inc., Dublin, OH 43016; Z. Ouyang, Pratt & Whitney, East Hartford, CT 06108; R. Fields, RJ Fields Consulting, Grayson, GA 30017

4:50 PM **Efficacy of Sonic IR for Detecting Impact Damage in CFRP Composites**
---**J. C. Chen**, D. Fung, and W. Kyi, California Polytechnic State University, Department of Mechanical Engineering, San Luis Obispo, CA 93407

Thermal Conductivity Measurement for Thermal Barrier Coatings Based on One- and Two-Sided Thermal Imaging Methods
---**Jiangang Sun**, Argonne National Laboratory, Argonne, IL 60439

---The thermal conductivity of thermal barrier coatings (TBCs) is normally measured using laser flash method, which is a two-sided thermal imaging method. In these measurements, TBC samples are usually prepared in a single coating layer, or in their natural two-layer form with the coating bonded on a substrate. While laser flash method for single-layer samples is well established, it is not standard for two-layer samples. Because laser flash cannot be used for TBCs applied on real components, one-sided thermal imaging method is being developed for potential nondestructive inspection and monitoring of TBC conditions during service. One such method is a multilayer thermal modeling method developed at Argonne National Laboratory. In this study, the accuracy of conductivity measurement by these methods for two-layer TBC samples is analyzed based on analytical and numerical simulation data. In particular, it is identified that the columnar structure of the EB-PVD (electron beam physical vapor deposition) TBCs may cause systematic prediction deviation. This paper will describe these thermal-imaging methods and present the analysis results.

Reliable Crack Detection in Turbine Blades using Thermosonics: An Empirical Study
---**Gabriel Bolu**, Anthony Gachagan, and Gareth Pierce, University of Strathclyde, Centre for Ultrasonic Engineering, Glasgow, United Kingdom; Gerald Harvey, Rolls Royce, East Kilbride, United Kingdom

---Thermosonics or Sonic-IR has been shown to be capable of detecting cracks in aero-engine components such as turbine blades. An ultrasonic horn excites the component and heat generated by a crack is detected using an IR camera. Excitation generated by these horns can be non-reproducible, raising concerns that cracks in some locations can be missed. Reliability of an NDT method depends on the repeatability of inspections, which is measured as how consistently the inspection result agrees in repeated tests by a single operator. This study investigates whether variations in excitation or in the testing process affects repeatability of crack detection in turbine blades when conducted in an industrial setting. Operating parameters including vibration amplitude, horn static force, vibration time and coupling material were optimised to maximize the temperature rise from a crack. Using the optimized testing technique, 60 blades with known cracks were tested three times each. The cracks in 57 blades were detected in at least one test, while 52 blades showed 100% repeatability in the three tests. These results show that thermosonics can be employed in an industrial environment as a reliable screening NDT process.

Analysis of Impact Damage Using Line Scanning Thermography

---**Obdulia Ley** and Valery Godinez, Physical Acoustics Corporation, Princeton Junction, NJ 08550; Simon Chung, Jaco Schutte, and Anthony Caiazzo, Materials Sciences Corporation, Horsham, PA, 19044

---Impact damage in a composite shaft was studied using Line Scanning Thermography (LST), a novel dynamic thermography technique capable of inspecting large areas in short times. The LST technique scans the surface of interests using a line heat source that moves in tandem with a thermal camera. It is expected that projectile impact in a laminate composite will generate a discontinuity that affects heat propagation; as heat is deposited over the region with the delamination, a hot spot will be observed. The temperature rise associated to a delamination is the result of the material properties, the severity of the delamination, the amount of heat applied, and the time after heat application at which the temperature is recorded. It is expected that observation at very early time after heat application will show small areas with severe damage; for further times after heat application, the heat deposited will dissipate, the temperature of the hot spot will drop and the size of the region affected will be larger. This indicates that assessing impact damage using thermography is a dynamic process, which should be accounted for when using dynamic thermography to quantify impact damage severity. In the study presented here, several impact points were performed in a composite shaft, the impact points were evaluated using UT and LST. To quantify the damage produced by a controlled impact, the size of the region showing a given temperature increase and how the size of such area evolved after heat application was analyzed. The thermal images generated using LST provided information about the region affected by impact damage, which was consistent with the damage region determined using UT.

Calibration Standards for Thermosonic Nondestructive Evaluation

---**Dan Xiang** and Yexian Qin, Intelligent Automation, Inc., Rockville, MD 20858; Richard Tenaglia, LSP Technologies, Inc., Dublin, OH 43016; Zhong Ouyang, Pratt & Whitney, East Hartford, CT 06108; Richard Fields, RJFields Consulting, Grayson, GA 30017

---Laser shock peening (LSP) is a means of surface treatment for metals by inducing surface compressive stresses, which inhibits fatigue crack formation. While LSP is a mature and reliable manufacturing process, slight anomalies during the process or variations in material ductility can cause small subsurface cracks the material that cannot be detected by most existing production NDE techniques. The emerging Thermosonic imaging technique has proven to be capable of detecting very small surface and subsurface cracks formed during the LSP process. In this paper, we present the development of calibration standards for Thermosonic NDE. Calibration standards consist of a set of specially-designed coupon specimens. Each standard specimen contains fabricated artifacts, which resemble the real subsurface cracks in LSP processed components. The size of cracks in standard coupons is quantified by acoustic microscopy, validated by Thermosonic imaging, and verified with metallographic analysis. Even though the main focus of this paper is on acoustic microscopy for quantitative measurements of micro cracks, a series of issues in the calibration standard development process, including the standard coupon design, subsurface crack fabrication, micro crack quantification, validation, and verification, etc., will also be discussed.

Efficacy of Sonic IR for Detecting Impact Damage in CFRP Composites

---**John C. Chen**, Derrick Fung, and Wei Kyi, California Polytechnic State University, Department of Mechanical Engineering, San Luis Obispo, CA 93407

---We will present results from a preliminary study of the efficacy of sonic IR for detecting impact damage in carbon fiber reinforced polymer (CFRP) composite samples. Such composites are widely deployed in engineering applications and cost-effective and reliable nondestructive inspection techniques need to be developed. In this study we first examine fundamental issues such as sample preparation - including manufacturing and simulated impacts - and test reproducibility. Next, we examine the sonic IR's sensitivity for detecting low-energy impact damage in relation to the different mechanisms and locations of damage.

Session 15

Tuesday, July 28, 2009

SESSION 15
BENCHMARK PROBLEMS
L. Schmerr, Chairperson
Chafee 273

3:30 PM **Radiographic Benchmark Problem 2009 — Scatter Calculations in Modeling**
---**G.-R. Jaenisch** and C. Bellon, BAM (Federal Institute of Materials Research and Testing), Division VIII.3 Radiology, Berlin, Germany; A. Schumm, Electricité de France R&D (EDF), Clamart, France; J. Tabary, CEA LETI, Grenoble, France; P. Duvauchelle, INSA-Lyon, Laboratoire de Contrôle Non Destructif par Rayonnements Ionisants Bat Saint Exupéry, Villeurbanne, France

3:50 PM **Recent Survey and Applications of the simSUNDT Software**
---**G. Persson** and H. Wirdelius, Chalmers University of Technology, Department of Materials and Manufacturing Technology, Gothenburg, Sweden

4:10 PM **An Overview of Ultrasonic Beam Propagation and Flaw Scattering Models Integrated in the CIVA Software**
---S. Mahaut, S. Chatillon, M. Darmon, N. Leymarie, **R. Raillon**, and P. Calmon, CEA, LIST, F-91191 Gif-sur-Yvette, France

4:30 PM **UTSim — Overview and Application**
---M. Garton[1], T. Gray[1], and **I. Gray**[2], [1]Center for NDE, Iowa State University, 1915 Scholl Road, Ames, IA 50011; [2]NDE Technologies, Inc., Charlottesville, VA 22911

4:50 PM **Ultrasonic Benchmarking with UTDefect**
---**P.-A. Jansson** and A. Bostrom, Chalmers University of Technology, Department of Applied Mechanics, Goteborg, Sweden

5:10 PM **Ultrasonic Modeler Overview of Capabilities and Results of 2009 Benchmark Problems**
---**V. Lupien**, Acoustic Ideas, Inc., 27 Eaton Street, Wakefield, MA 01880

5:30 PM **Results of the 2009 UT Modeling Benchmark Obtained with CIVA: Responses of Notches, Side-Drilled Holes and Flat-Bottom Holes of Various Sizes**
---**R. Raillon**, S. Bey, A. Dubois, S. Mahaut, and M. Darmon, CEA, LIST, SYSSC, F-91191 Gif-sur-Yvette, France

5:50 PM **Model Prediction Results for 2009 Ultrasonic Benchmark Problems**
---**H.-J. Kim**, S.-J. Song, and YeJing, School of Mechanical Engineering, Sungkyunkwan University, Suwon, 440-746, Korea

Radiographic Benchmark Problem 2009 – Scatter Calculations in Modeling

---**Gerd-Ruediger Jaenisch** and Carsten Bellon, BAM (Federal Institute of Materials Research and Testing), Division VIII.3 Radiology, Berlin, Germany; Andreas Schumm, Electricité de France R&D (EDF), Clamart, France; Joachim Tabary, CEA LETI, Grenoble, France; Philippe Duvauchelle, INSA-Lyon, Laboratoire de Contrôle Non Destructif par Rayonnements Ionisants Bat Saint Exupéry, Villeurbanne, France

---Code Validation is a permanent concern in computer modeling, and has been addressed repeatedly in eddy current and ultrasonic modeling. Over the last years a series of benchmark sessions has been installed at QNDE to address this subject to the NDE community. A good benchmark problem is sufficiently simple to be taken into account by various codes without strong requirements on geometry representation capabilities, focuses on few or even a single aspect of the problem at hand to facilitate interpretation and to avoid that compound errors compensate themselves, yields a quantitative result and is experimentally accessible. In this paper we attempt to address code validation for one aspect of radiographic modeling, the scattered radiation prediction. An update of the results of the 2008 benchmark is presented. Additionally we discuss the extension of this benchmark on the lower energy part for 60 and 80 keV as well as for higher energies up to 10 MeV to study the contribution of pair production. Of special interest will be the primary radiation (attenuation law as reference), the total scattered radiation, the relative contribution of scattered radiation separated by order of scatter events (1st, 2nd, …, 20th), the spectrum of scattered radiation, and the variance of total scattered radiation. The second part of the benchmark problem investigates the influence of discontinuities on the distribution of the scattered radiation. For this purpose a notch simulating planar-like flaws is introduced into a plate of 10 mm thickness. Here we study the contribution of scatter radiation to the imaging contrast and unsharpness. We present the results of three Monte Carlo codes (MC-Ray, Sindbad and Moderato) as well as an analytical first order scattering code (VXI) and compare to MCNP as reference.

Recent Survey and Applications of the simSUNDT software

---**Gert Persson** and Håkan Wirdelius, Chalmers University of Technology, Department of Materials and Manufacturing Technology, Gothenburg, Sweden

---The simSUNDT software is based on a previous developed program (SUNDT). The latest version has been customized in order to generate realistic synthetic data (including a grain noise model), compatible with a number of off-line analysis software. The software consists of a Windows®-based pre- and postprocessor together with the mathematical kernel UTDefect. The model employs various integral transforms and integral equation and enables simulations of the entire ultrasonic testing situation. The model is completely three-dimensional though the simulated component is two-dimensional. It is of great importance that validated inspection methods are used and the capability of detection of cracks and defects are quantified. In order to achieve this, statistical methods such as Probability of Detection (POD) often are applied, with the ambition to estimate the detectability as a function of defect size. The presentation will describe the developed model that will enable simulation of a phased array NDT inspection and the ambition to use this simulation software to generate POD information. The paper also includes a specification of the ongoing experimental validations that are conducted together with Siemens and Volvo Aero.

An Overview of Ultrasonic Beam Propagation and Flaw Scattering Models Integrated in the CIVA Software

---S. Mahaut, S. Chatillon, M. Darmon, N. Leymarie, **R. Raillon**, and P.Calmon, CEA, LIST, F-91191 Gif-sur-Yvette, France

---This paper aims at presenting an overview of the current capabilities of the ultrasonic models of the CIVA software platform (for ultrasonics, eddy current and radiography techniques), developed by CEA-LIST and partners. Those models are based on semi-analytical approaches and numerical integration (integral methods upon the surface of probe or the flaw) in order to address fairly complex configurations while keeping reduced computation times. Such skills are obviously reached within the range of validity of the semi-analytical models, which have to be carefully studied. In this context, benchmarks organized by the World Federation of NDE centers (WFNDEC) from 2004 have largely contributed, thanks to experimental data and comparison with other codes of the community, to the validation of simulation codes. Those benchmarks were mostly dealing with canonical problems (in terms of probes, component geometry and flaw shapes). This paper aims at providing an extended insight of models skills and validity range for other complex configurations not considered (yet) in the benchmark problems.

UTSim – Overview and Application

---Mike Garton[1], Tim Gray[1], and **Irving Gray**[2], [1]Center for NDE, Iowa State University, 1915 Scholl Road, Ames, IA 50011; [2]NDE Technologies, Inc., Charlottesville, VA 22911

---UTSim is a software package developed to help plan and refine ultrasonic inspections for complex shaped components. The software reads 3D solid-model CAD representations of the components. Virtually any shape or complexity of object can be loaded and examined using the ultrasonic ray tracing tools in UTSim. For many applications, the software can also be used to model ultrasonic beam propagation as well as the response from flaws within a component. This presentation will give an overview of UTSim and its features and will demonstrate examples of its ultrasonic simulation capabilities.

Ultrasonic Benchmarking with UTDefect
---**Per-Ake Jansson** and Anders Bostrom, Chalmers University of Technology, Department of Applied Mechanics, Goteborg, Sweden

---The program UTDefect has been developed for more than 15 years at Chalmers University of Technology with emphasis on applications in the nuclear power industry. In UTDefect ultrasonic testing of a homogeneous component is modeled, including the ultrasonic transmitter, the receiver, and scattering from various types of defects of simple shape. Isotropic as well as anisotropic components are modeled. The basic idea behind UTDefect is to use solutions to the elastodynamic wave equation that are essentially exact. To solve the wave propagation and scattering problems Fourier representations, separation of variables, the null field method, and integral equation methods are employed. In the near future we plan to incorporate scattering from a rectangular crack in an anisotropic cladding in UTDefect. In another ongoing project interaction between a rectangular crack and a non-planar backsurface is studied using a combination of a singular integral equation method and BEM. UTDefect has been validated throughout the years ever since its first version was released. In particular, some of the benchmark problems of the WFNDEC have been used, in most cases with a favorable outcome. Some results will be presented here, including comparisons with the most recent experimental data obtained by CEA in France.

Ultrasonic Modeler Overview of Capabilities and Results of 2009 Benchmark Problems
---**Vincent Lupien**, Acoustic Ideas, Inc., 27 Eaton Street, Wakefield, MA 01880

---Acoustic Ideas' Ultrasonic Modeler software package calculates phased array focal laws, ultrasonic fields and ultrasonic responses from discontinuities, and helps develop and validate both conventional and phased array inspections. Ultrasonic Modeler's unique status as an official MATLAB third party toolbox provides users with the full scientific computing flexibility of MATLAB. Each Ultrasonic Modeler function can be called individually allowing customized usage according to the researcher's needs, an especially valuable feature for innovative NDE projects. Ultrasonic Modeler supports any transducer shape or element subdivision pattern and mode conversions in multiple fluid or solid materials of arbitrary shape. Ultrasonic propagation is modeled using an approximate Green's function method. Interactions with discontinuities are modeled using a combination of Kirchhoff specular and Biot-Tolstoy diffracted contributions. Example inspection scenarios are presented, most particularly those for the 2009 Ultrasonic Benchmarking problems.

Results of the 2009 UT Modeling Benchmark Obtained with CIVA: Responses of Notches, Side-Drilled Holes and Flat-Bottom Holes of Various Sizes

---**R. Raillon**, S. Bey, A. Dubois, S. Mahaut, and M. Darmon, CEA, LIST, SYSSC, F-91191 Gif-sur-Yvette, France

---This communication presents the results obtained on the configurations proposed in the 2009 UT modeling benchmark with the ultrasonic models implemented in the CIVA software platform. The aim, this year, is to compare the amplitude of corner echoes for “2D” and non “2D” flaw shapes. Experiment have been performed with contact probes (single element or phased array) radiating shear or pressure waves at 45° incidence angle on planar mock-ups containing flat-bottom hole, side-drilled holes and backwall breaking notches of different heights and widths. The echoes are simulated by applying an integral formulation for the field radiated by the probe (the pencil-model) and different scattering models for the different kind of defects. Comparison between simulated and experimental results are presented and discussed.

Model Prediction Results for 2009 Ultrasonic Benchmark Problems

---**Hak-Joon Kim**, Sung-Jin Song, and YeJing, School of Mechanical Engineering, Sungkyunkwan University, Suwon, 440-746, Korea

---The World Federation of NDE Centers (WFNDEC) has addressed the 2009 ultrasonic benchmark problems including orthogonal scanning side drilled holes (SDH) of different diameters, flat bottomed holes and rectangular defects of two different lengths at various heights in a steel block. The experimental signals including scanning results obtained from the flaws using three different types of transducers are provided by CEA. Transducers adopted for acquiring ultrasonic signals are as fallow: two standard contact probes generating reflected 45 degree shear wave with rectangular aperture (Probe WB45) and circular aperture (Probe MSWQC) and a linear phased array probe with 45 elements, 5 MHz center frequency. To solve this year ultrasonic benchmark problems, we will apply multi-Gaussian beam models and linear phasing multi-Gaussian beam model for calculating insonifying fields radiated from standard contact probes and a linear phased array probe, respectively. And, for calculating far-field scattering amplitude of the flaws, Kirchhoff approximation, separation of variable method, geometrical theory of diffraction (GTD) method will be applied. By integrating the ultrasonic beam models and far-field scattering models with system functions, A-scan signals for the flaws will be predicted. Using the model predicted signals, relative amplitudes in dB of the flaws with Probe WB45, Probe MSWQC and the linear phased array transducer will be provided in order to compare the model predictions with experimental data. In this presentation, basic principal of the ultrasonic models used in this study and comparison results to the experiments will be presented.

WEDNESDAY

WEDNESDAY, JULY 29, 2009

	Session 16 Thermography and Thermosonics II *CBLS 100*	Session 17 New Applications and Techniques I *Chafee 277*	Session 18 Structural Health Monitoring *CBLS 010*	Session 19 NDE of Armor and Armor Systems *Chafee 273*
8:30 AM				
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10:10	COFFEE BREAK			
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12:10 PM	LUNCH			
	Session 20 **Laser UT** ***CBLS 100***	**Session 21** **Civil Structures** ***Chafee 277***	**Session 22** **NDE for Corrosion, Plastic Deformation, and Fracture** ***CBLS 010***	**Session 23** **NDE in Design, Manufacturing, and Process Control** ***Chafee 273***
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Session 24 – SPECIAL EVENING SESION – 8:00 PM – CBLS 100

Session 16

SESSION 16
THERMOGRAPHY AND THERMOSONICS II
X. Han, Chairperson
CBLS 100

8:30 AM **Infrared Imaging of Carbon and Ceramic Composites: Data Reproducibility**
---B. Knight, D. R. Howard, and **H. I. Ringermacher**, General Electric Global Research, Schenectady NY 12309; L. D. Hudson, NASA Dryden Flight Research Center, Edwards AFB, CA 93523

8:50 AM **Simulations of the Thermographic Response of Near Surface Flaws in Reinforced Carbon-Carbon Panels**
---**W. P. Winfree** and P. A. Howell, NASA Langley Research Center, MS 231, Hampton, VA 23681-2199; E. R. Burke, United Space Alliance, MS USK-823, NASA Kennedy Space Center, FL 32899

9:10 AM **Automated Induction Thermography of Generator Components**
---**M. Goldammer**, H. Mooshofer, and M. Rothenfusser, Siemens AG, CT PS 9, Munich, Germany; J. Vrana, Siemens Energy Inc., Orlando, FL 32826; J. Bass, Siemens Energy Inc., Charlotte, NC 28221

9:30 AM **The Effect of Crack-Opening on Thermosonics (Sonic IR) and Laser-Spot Thermography**
---**B. Weekes** and P. Cawley, Imperial College, UK Research Centre in NDE, Mechanical Engineering, London, United Kingdom; D. Almond, University of Bath, Materials Research Centre, Mechanical Engineering, Bath, United Kingdom

9:50 AM **Progress on Developing Sonic Infrared Imaging for Defect Detection in Composite Structures**
---**X. Han**, Q. He, Y. Song, and D. Zhang, Department of Electrical and Computer Engineering, Wayne State University, Detroit, MI 48202; G. Godfrey and R. L. Thomas, Department of Physics and Astronomy, Wayne State University, Detroit, MI 48202; G. Newaz and L. D. Favro, Institute for Manufacturing Research, Wayne State University, Detroit, MI 48202

10:10 AM ***Break***

10:30 AM **Synthetic Defects for Vibrothermography**
---**J. B. Renshaw**, S. D. Holland, R. B. Thompson, and D. J. Eisenmann, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

10:50 AM **The Frequency Dependency of Vibrothermography**
---**W. Zhang**, S. D. Holland, and J. Renshaw, Iowa State University, Center for NDE, Ames, IA 50011

11:10 AM **Measurement Limits in Active Thermography**
---**S. M. Shepard**, Thermal Wave Imaging, Inc., 845 Livernois, Ferndale, MI 48220

11:30 AM **Combined Ultrasound and Thermography for a Defect Detection System**
---**S. E. Burrows** and S. Dixon, University of Warwick, Department of Physics, Coventry, United Kingdom; T. Li and D. P. Almond, University of Bath, Materials Research Centre, Bath, United Kingdom

11:50 AM **Aerospace Applications of Lockin-Thermography with Optical, Ultrasonic, and Inductive Excitation**
---**P. Menner**, C. Spiessberger, A. Gleiter, and G. Busse, University of Stuttgart, Institute of Polymer-Technology, Department, Non-Destructive Testing, Stuttgart, Germany

12:10 PM ***Lunch***

Infrared Imaging of Carbon and Ceramic Composites: Data Reproducibility

---Bryon Knight, Donald R. Howard, and **Harry I. Ringermacher**, General Electric Global Research, Schenectady NY 12309; Larry D. Hudson, NASA Dryden Flight Research Center, Edwards AFB, CA

---Infrared NDE techniques have proven to be superior for imaging of flaws in ceramic matric composites (CMC) and carbon composites (C/SiC). Not only can one obtain accurate depth gaging of flaws such as delaminations and layered porosity in complex-shaped components such as airfoils and other aeronautical components, but also stunning reproducibility of image data is obtainable using the STTOF (Synthetic Thermal Time-of-Flight) methodology. The imaging of large complex shapes is fast and reliable. This methodology as applied to large C/SiC flight components at the NASA Dryden Flight Research Center will be described.

Simulations of the Thermographic Response of Near Surface Flaws in Reinforced Carbon-Carbon Panels

---**William P. Winfree** and Patricia A. Howell, NASA Langley Research Center, MS 231, Hampton, VA 23681-2199; Eric R. Burke, United Space Alliance, MS USK-823, NASA Kennedy Space Center, FL 32899

---Thermographic inspection is a viable technique for detecting in-service damage in reinforced carbon-carbon (RCC) composites that are used for thermal protection in the leading edge of the Space Shuttle. A significant advantage of thermography is the ability to provide a rapid, noncontacting, full field imaging, single-sided inspection that can be performed between flights without removing the RCC panels from the vehicle. This paper presents an assessment of a thermographic technique for detection of near surface flaws in RCC composite structures. Results are compared to finite element models of the heat diffusion in structures with expected flaw configurations. There is a good agreement between the simulation results and experimental measurement. Applying the simulations to develop a better understanding of the measurements and optimizing the technique is discussed.

Automated Induction Thermography of Generator Components

---**Matthias Goldammer**, Hubert Mooshofer, and Max Rothenfusser, Siemens AG, CT PS 9, Munich, Germany; Johannes Vrana, Siemens Energy Inc., Orlando, FL; Jason Bass, Siemens Energy Inc., Charlotte, NC

---Using Active Thermography defects such as cracks can be detected fast and reliably. Choosing from a wide range of excitation techniques the method can be adapted to a number of tasks in non-destructive evaluation. Induction thermography is ideally suited for testing metallic components for cracks at or close to the surface. In power generation a number of components are subjected to high loads and stresses – therefore it is important to avoid defects in these parts. Apart from combustion turbines this also applies to generators: At regular inspection intervals even small cracks have to be detected to avoid crack growth and consequently failure of the component. As an imaging technique thermography allows for a fast 100% testing of the complete surface of all relevant parts. An automated setup increases the cost effectiveness of induction thermography significantly. Time needed to test a single part is reduced, the number of tested parts per shift is increased, and cost for testing is reduced significantly. In addition, automation guarantees a reliable testing procedure which defects all critical defects. We present how non-destructive testing can be automized using as an example an industrial application at the Siemens sector Energy, and a new induction thermography setup for generator components.

The Effect of Crack-Opening on Thermosonics (Sonic IR) and Laser-Spot Thermography

---**Benjamin Weekes** and Peter Cawley, Imperial College, UK Research Centre in NDE, Mechanical Engineering, London, United Kingdom; Darryl Almond, University of Bath, Materials Research Centre, Mechanical Engineering, Bath, United Kingdom

---Laser-spot thermography is a novel method for detecting surface-breaking cracks in metals. Another active thermographic research method is thermosonic (Sonic IR) inspection, which may potentially compete with or complement laser-spot thermography in the detection of surface-breaking cracks. Thermosonic inspection generates heat predominantly by friction of crack-faces under high-power ultrasonic excitation, the resulting surface temperature rise being imaged with an infrared camera. Thermosonic inspection is therefore best suited to defects that are closed over part of their length. In contrast, laser-spot thermography detects defects by the perturbation of the radial heat-flow from a spot heated with a short-pulse laser, the increased thermal impedance presented by air between the faces of the crack blocking the conduction of heat. This paper presents an experimental comparison of the performance of thermosonics and laser-spot thermography on a series of samples with different crack sizes, the opening of each crack being varied by 3-point bend loading.

Progress on Developing Sonic Infrared Imaging for Defect Detection in Composite Structures

---**Xiaoyan Han**, Qi He, Yuyang Song, and Ding Zhang, Department of Electrical and Computer Engineering, Wayne State University, Detroit, MI 48202; Garrett Godfrey and Robert L. Thomas, Department of Physics and Astronomy, Wayne State University, Detroit, MI 48202; Golam Newaz and Lawrence D. Favro, Institute for Manufacturing Research, Wayne State University, Detroit, MI 48202

---At last year's QNDE conference, we presented our development of Sonic IR imaging technology in metal structures, with results from both experimental studies and theoretical computing. In the latest aircraft designs, such as the B787 from Boeing, composites have become the major materials in structures such as the fuselage and wings. This is in contrast to composites' use only in auxiliary components such as flaps and spoilers in the past. With today's advanced technology of fabrication, it is expected the new materials can be put in use in even more aircraft structures due to its light weight and high strength (high strength-to-weight ratio), high specific stiffness, tailorability of properties, design flexibility etc. Especially, with increases in fuel cost, reducing the aircraft's body weight becomes more and more appealing. In this presentation, we will describe the progress on our development of Sonic IR imaging for aircraft composite structures. Both experimental work and simulation results will be shown.

Synthetic Defects for Vibrothermography

---**Jeremy B. Renshaw**, Stephen D. Holland, R. Bruce Thompson, and David J. Eisenmann, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---We have developed a new type of synthetic defect designed specifically for use with vibrothermography (Sonic IR). These defects consist of holes filled with a viscous material that converts sound or vibration into heat. These defects are useful for evaluating test coverage in complicated geometries. We present preliminary results showing that heat generation from these synthetic defects correlates with heat generation from cracks. These defects can be applied to both laboratory specimens as well as real-world parts.---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 Frequency Dependency of Vibrothermography

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

---It has long been postulated that vibrothermographic heating – the heating of cracks due to sound or vibration-induced rubbing – may be frequency dependent. It has been difficult to factor out the innate frequency dependence of the heat-generation process from the geometry-dependent mode structure. We present experiments showing the heating of cracks in slender Inconel/Titanium samples at different transverse resonances. The results show a clear increase of heating with vibration frequency.

Measurement Limits in Active Thermography

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

---Although active thermography has traditionally been regarded as a qualitative NDT method, its potential for quantitative measurement of thermophysical properties including wall thickness, flaw size and depth, thermal diffusivity or effusivity has been the subject of numerous investigations. Enabled by improvements in IR camera technology and fast, abundant and inexpensive computing power for advanced signal processing, measurement results have been reported using a variety of excitation and signal processing schemes. Results are often presented as a correlation between thermography data and nominal properties or independent measurements by another “validated” method. However, the quantization and sampling operations that are implicit in using an IR camera as a temperature sensor define certain limits as to the sensitivity and resolution of thermographic measurement. While many benefits can be achieved with improved instrumentation, efficient energy insertion or optimized signal processing, ultimately, these limits, as well as those imposed by diffusion and instrumentation, take precedence, and cannot be circumvented. In this paper, the effects of camera frame rate, noise and heating energy on basic measurement capabilities are examined, using a 1-dimensional diffusion model.

Combined Ultrasound and Thermography for a Defect Detection System

---**Susan E. Burrows** and Steve Dixon, University of Warwick, Dept of Physics, Coventry, United Kingdom; Teng Li and Darryl P. Almond, University of Bath, Materials Research Centre, Bath, United Kingdom

---A combined ultrasound and thermography system has been developed for identifying surface breaking defects using a raster scanned, Q-switched, pulsed Nd:YAG laser as both a thermal and an ultrasonic source. Heat is generated on a sample surface by absorption of laser light and the resulting thermal radiation from the sample is imaged using a thermal camera. When a defect is present, the flow of heat in the sample will be disturbed and a change in shape of the thermal spot can be detected, provided the gape and dimensions of the defect are large enough. Simultaneously the laser generates an ultrasonic wave that can be detected by an electromagnetic acoustic transducer; here the presence of a defect will change both the amplitude, phase and frequency content of the received wave. Two dimensional and three dimensional Finite Element Modelling of the interaction between Lamb waves and defects have been performed and compared with experimental data, in order to better understand the experimental data and ascertain what type of analysis should be performed on the ultrasonic data to identify a defect. The fusion of these two non-contact methods within a single scan will make the detection of defects more reliable.

Aerospace Applications of Lockin-Thermography with Optical, Ultrasonic, and Inductive Excitation

---**Philipp Menner**, Christian Spiessberger, Andreas Gleiter, and Gerd Busse, University of Stuttgart, Institute of Polymer-Technology, Department, Non-Destructive Testing, Stuttgart, Germany

---Lockin thermography is a reliable and fast NDT-technique that is applicable to quite a broad range of testing problems in aerospace applications. It is robust and sensitive enough to be used in industrial environments. Several different excitation methods based on specific physical mechanisms allow to distinguish between defective and intact material. Optically excited thermography, for instance, can detect boundaries, like delaminations. Ultrasound excited thermography, however, responds to the heat that is generated inside the inspected sample by flaws, cracks, or any other defects that convert high frequency mechanical oscillation into local heat. Therefore the method is defect-selective. Similarly, eddy-current lockin thermography responds selectively to local changes e.g. of conductivity in metals or carbon fiber composites. The paper describes the principle of optically, ultrasound, and eddy-current excited thermography and presents several applications of these modern NDE techniques for the inspection of typical aerospace structures.

Session 17

SESSION 17
NEW APPLICATIONS AND TECHNIQUES I
B. W. Maxfield, Chairperson
Chafee 277

8:30 AM **Structural Damage Monitoring on Overhead Transmission Lines Using Guided Waves and Signal Processing**
---C. D. Hernandez–Salazar and A. Baltazar, Centro de Investigación y Estudios Avanzados del IPN, Unidad, Saltillo,Saltillo, Coahuila, Mexico; **R. Mijarez**, Instituto de Investigaciones Electricas, Gerencia de Control e Instrumentacion, Cuernavaca, Morelos, Mexico

8:50 AM **Development of Inspection Modality for Shell Weld of Core Support Structure Using CIVA**
---C. B. Rao, G. K. Sharma, **T. Jayakumar**, and B. Raj, Indira Gandhi Center for Atomic Research, Non Destructive Evaluation Division, Kalpakkam, Tamil Nadu, India; R. Raillon and P. Benoist, French Atomic Energy Commission (CEA), Saclay, France

9:10 AM **3D RF-ECT Simulations of ISI of U-Bend SG Tubes in FBR**
---**O. Mihalache**, T. Yamaguchi, M. Ueda, and K. Tsukimori, Japan Atomic Energy Agency, Fast Breeder Reactor Plant Engineering Research Center, Tsuruga, Fukui, Japan

9:30 AM **Shear Wave Incident Time of Flight Diffraction (SWI-TOFD) Technique**
---**T. Balasubramanian** and K. S. Reddy, National Institute of Technology Tiruchirapalli, Department of Physics, Trichy, Tamilnadu, India; K. Balasubramaniam, and C. V. Krishnamurthy, Indian Institute of Technology Madras, Centre for Non Destructive Evaluation, Department of Mechanical Engineering, Chennai, Tamilnadu, India

9:50 AM **Guided Wave Detection of Gas Voids in Piping Systems**
---**M. J. Quarry** and N. R. Camilli, Electric Power Research Institute, NDE Center, 1300 WT Harris Boulevard, Charlotte, NC 28262

10:10 AM ***Break***

10:30 AM **Feasibility Study of Corrosion Detection on Flexible Riser Utilizing Low Frequency Electromagnetic Method**
---**S. Quek**, V. Torres, and P. Gaydecki, The University of Manchester, School of Electrical and Electronic Engineering, Manchester, United Kingdom

10:50 AM **Modeling and Results for Creating Oblique Fields in a Magnetic Flux Leakage Survey Tool**
---**J. C. Simek**, T. D. Williamson Inc., Engineering and Technology Development, Salt Lake City, UT 84107

11:10 AM **GPGPU Techniques to Accelerate Modelling in NDE**
---D. Romero, O. Martínez, **C. J. Martín**, and L. G. Ullate, Instituto de Automática Industrial (C.S.I.C.), Madrid, Spain; G. Godoy, Universidad de Jaen

11:30 AM **Wide Dynamic Range Acquisition for Ultrasonic Signals**
---**W. Weber**, UTEX Scientific Instruments Inc., 2319 Dunwin Drive, Unit 8, Mississauga, Ontario, Canada, L5L 1A3

11:50 AM **Polarized Shear Waves for Crack Detection and Characterization**
---S. J. Turner and **B. W. Maxfield**, Analogic Engineering, Inc. Buford WY 82052

12:10 PM **Development of Disposable Ultrasonic Probe for Hot Metal Inclusion Measurement**
---**A. Currie** and S. Johnstone, School of Engineering, Durham University, Durham DH1 3LE United Kingdom; S. Millman, Corus UK Ltd., Grangetown, Middlesbrough, TS6 6US United Kingdom

12:30 PM ***Lunch***

Structural Damage Monitoring on Overhead Transmission Lines Using Guided Waves and Signal Processing

---C. D. Hernandez–Salazar and A. Baltazar, Centro de Investigación y Estudios Avanzados del IPN, Unidad, Saltillo,Saltillo, Coahuila, Mexico; **R. Mijarez**, Instituto de Investigaciones Electricas, Gerencia de Control e Instrumentacion, Cuernavaca, Morelos, Mexico

---Many overhead transmission lines constructed in the second half of the 20th century are over 50 years. Environmental degradation such as random overloads and corrosion has leaded to failure. Therefore, it is a necessity to develop a continuous monitoring system for detecting damage at an early stage, which could allow replacing old conductors before failures occur. This work addresses an experimental investigation of damage detection using guided waves in a multi-wire ACSR cable of 0.9m length. A simplified model of an aluminum conductor with steel in its core is used to calculate the dispersion curves. Piezoelectric transducers were employed in through transmission and pitch and catch configurations for the generation and detection of guided waves. The response of longitudinal modes is studied at different levels of artificial cross-section damage using the Short Time Fourier Transform and the Wavelet Transform. The ultrasonic energy detected was correlated to the size of the defect with a minimum sensitivity of 1mm. For practical application of the developed system for continuous damage monitoring, a sensor that can be attached to the periphery of the cables is proposed.

Development of Inspection Modality for Shell Weld of Core Support Structure Using CIVA

---Chelamchala Babu Rao, Govind Kumar Sharma, **Tammana Jayakumar**, and Baldev Raj, Indira Gandhi Center for Atomic Research, Non Destructive Evaluation Division, Kalpakkam, Tamil Nadu, India; Raphale Raillon and Philippe Benoist, French Atomic Energy Commission (CEA), Saclay, France

---A 500 MWe Prototype Fast Breeder Reactor (PFBR) is being constructed at Kalpakkam, India. The entire primary sodium circuit is contained in main vessel (13 m diameter). This is welded at the top to the roof slab. The core subassemblies are supported on the grid plate, which in turn is supported on the core support structure (CSS). The CSS is welded to the 40 mm thick base plate of the main vessel along the complete circumference. This ‘shell weld’ (K weld) is situated at a distance of about 435 mm away from the weld overlay of the core support structure and is immersed in sodium. The shell weld is in-accessible to contact mode ultrasonic testing during in-service inspection. An ultrasonic methodology was developed for this purpose. The proposed methodology is of unconventional type. Therefore, this inspection modality is validated using the ultrasonic module of CIVA simulation software. The developed methodology involves inspection from the outside surface of the main vessel. The ultrasonic wave is skewed in the weld overlay and enters the support shell structure at an angle and gets reflected every time it encounters the plate surface. The echo from any defect retraces the path backwards. In the above mode of inspection, the beam encounters multiple reflections within the support structure up to the weld. The CIVA software can not handle multiple reflections. Hence, the concept of unfolding is introduced in the modeling to simulate multiple reflections. Correspondingly each real defect is transformed, in the unfolded model, into an ensemble of virtual defects following reflection laws. B-scan image of this ensemble of defects along the scanning axis is a signature of the defect in this inspection modality. The simulated results are in reasonable agreement the experimental measurements.

3D RF-ECT Simulations of ISI of U-Bend SG Tubes in FBR

---**Ovidiu Mihalache**, Toshihiko Yamaguchi, Masashi Ueda, and Kazuyuki Tsukimori, Japan Atomic Energy Agency, Fast Breeder Reactor Plant Engineering Research Center, Tsuruga, Fukui, Japan

---In the Fast Breeder Reactor (FBR) Monju, In-Service Inspection (ISI) of steam generator (SG) tubes is performed using remote field eddy current technique (RF-ECT). The 90 meter SG tubes, made of 2.25Cr-1Mo alloy, have an intricate geometry containing helical, bend and straight tube parts. Liquid sodium, used to transfer the heat from the reactor core to the electrical turbine, adheres to the outer SG tube surface, in a small layer. ISI is performed after sodium is drained and the SG unit is cool down from 5000C to the room temperature. During draining, sodium drops and sodium layers with variable layer thickness, as indicated by experimental measurements in a mock up test with limited number of tubes, form preferentially under the U-bend SG tube part. The paper focus on 3-dimensional (3D) finite element (FE) of the SG inspection using RF-ECT in order to asses the ISI in the above conditions, by using a FE code developed in house. It is evaluated the influences of the SG tubes U-bend curvature on the eddy current sensor signal by taking into account the 3D model in which multiple tubes are located close to each other, as in the real situation. The 64-bit 3D-RFECT code was enhanced to run on parallel architectures using both PC machines (multiple cores) or Unix clusters. Femap 8.3 was employed for both pre and post processor analysis. 3D computational burden details and parallel performance are presented using up to 128 CPUs on 2 UNIX cluster machines and a 64bit PC. The simulations asses the noise in the ECT signal due to the presence of sodium drops, U-bend tube curvature and the signal/noise ratio for defects in SG U-bend tube part.

Shear Wave Incident Time of Flight Diffraction (SWI-TOFD) Technique

---**T. Balasubramanian** and K.Sanjeeva Reddy, National Institute of Technology Tiruchirapalli, Department of Physics, Trichy, Tamilnadu, India; Krishnan Balasubramaniam and C. V. Krishna Murthy, Indian Institute of Technology Madras, Centre for Non Destructive Evaluation, Department of Mechanical Engineering, Chennai, Tamilnadu, India

---This paper reports the use of Shear wave incident Time of Flight Diffraction Technique (SWI-TOFD) for the inspection of near surface defects in thin materials. We calculated defect depth and size for the following cases (1). Shear wave incidence and extracting longitudinal wave diffracted signals (S-L TOFD). (2) Shear wave incidence and extracting the shear wave diffracted signals(S-S TOFD).We obtain the Diffraction amplitudes for line sources in 2D using expressions for displacements derived by Miller & Pursey and employing the “Fresnel Diffraction Model”. We obtain the optimum angles for getting maximum diffracted signal amplitudes from the crack which is placed symmetrically with respect to the transmitter and receiver. The simulated 2D results for diffracted signal amplitudes from a surface breaking crack of different lengths in aluminum as well as steel sample is compared with the Finite Difference Time Domain(FDTD) simulated data. A comparative discussion between the simulated 2D results and experiments will be presented.

Guided Wave Detection of Gas Voids in Piping Systems

---**Michael J. Quarry**, and Nicholas R. Camilli, Electric Power Research Institute, NDE Center, 1300 WT Harris Blvd., Charlotte, NC 28262

---Detecting gas voids in piping systems is a concern of the nuclear power industry. Gas voids can potentially cause pumps to bind and reduce reliability of safety cooling systems. Conventional methods use bulk wave ultrasonic sensors to detect water levels in the pipe. However, many systems have inaccessible areas and multiple bends and elbows. Sensitivity requirements are generally about 2% to 5% air void as a percentage of total system volume. Guided wave techniques were investigated to detect gas voids in a water filled piping system. Piezoelectric and magnetostrictive excitation and detection systems were used to obtain modes with optimal performance, which includes sufficient propagation length while maintaining required sensitivity.

Feasibility Study of Corrosion Detection on Flexible Riser Utilizing Low Frequency Electromagnetic Method

---**Sung Quek**, Vladimir Torres, and Patrick Gaydecki, The University of Manchester, School of Electrical and Electronic Engineering, Manchester, United Kingdom

---This work reports initial study conducted on corrosion detection of flexible riser. The objective is to establish the feasibility of detecting both surface corrosion and pitting corrosion based on low frequency electromagnetic method. The prime requirement is to be able to detect these 2 forms of corrosion at a maximum depth of 40mm. The studies encompass essential issues including the modes of excitation, sensor design, the excitation frequency, sensing method and the appropriate parameters to be measured. A sensing coil with a resonant frequency of 200 kHz has been constructed. Studies have been conducted to assess the mode of excitation utilizing a LC tuned oscillator and a fixed frequency. Results indicate that the LC approach is more appropriate for this application as is sensitive to both the change in the permeability and conductivity of the target. In general, the amplitude of the measure signal provides give indication with respect to the conductivity of the target while its frequency correlates with permeability. Further studies also indicate that a LC oscillator can be selective tuned to be sensitive to change in the conductivity or permeability.

Modeling and Results for Creating Oblique Fields in a Magnetic Flux Leakage Survey Tool

---**James C. Simek**, T. D. Williamson Inc., Engineering and Technology Development, Salt Lake City, UT 84107

---Integrity management programs designed to maintain safe pipeline systems quite often will use survey results from Inline inspection tools in addition to data from other sources. Commonly referred to as “smart pigs”, one of the most widely used types are those based upon the magnetic flux leakage technique, typically used to detect and quantify metal loss zones. The majority of pipelines surveyed to date have used tools with the magnetic field direction axially aligned with the length of the pipeline. In order to enable detection and quantification of extremely narrow metal loss features or certain types of weld zone anomalies, tools employing magnetic circuits directing the magnetic fields around the pipe circumference have been designed and are used in segments where these feature categories are a primary concern. Modeling and laboratory test data of metal loss features will be used to demonstrate the response of extremely narrow metal loss zones as the features are rotated relative to the induced field direction. Based upon these results, the basis for developing a magnetizer capable of creating fields oblique to either pipeline axis will be presented along with the magnetic field profile models of several configurations.

GPGPU Techniques to Accelerate Modelling in NDE

---David Romero, Oscar Martínez, **Carlos J. Martín**, and Luis G. Ullate, Instituto de Automática Industrial (C.S.I.C.), Madrid. Spain; Gregorio Godoy, Universidad de Jaen

---Field modeling is a common practice in NDE. However, it is a very time consuming task, making difficult its use in systems demanding real time response. All NDE simulation problems present a common characteristic: the computing algorithm is applied to a large amount of points, in such a way that it is relatively easy to increase the parallelism in order to reduce the computing time Parallel architectures for computing currently imply very complex and expensive systems. However, the great evolution of graphics processors has driven the development of “Graphics Processing Units” (GPUs) which are fully programmable devices with a high level of parallelism adequate for computationally intensive applications, with a good relation between price and performance. This work is focused on exploring the GPU parallelism for NDE modeling algorithms. Several examples are presented, which are based in the Piwakowski solution for acoustic field computation. We show that using a simple graphics card equipped with NVIDIA CUDA technology, the field computing time is drastically reduced in approximately two orders of magnitude with respect to CPU implementations. We conclude that shifting the computation of acoustic fields from CPU to programmable GPU can be a very good solution for field computing in NDE.

Wide Dynamic Range Acquisition for Ultrasonic Signals

---**Walter Weber**, UTEX Scientific Instruments Inc., 2319 Dunwin Drive, Unit 8, Mississauga, Ontario, Canada, L5L 1A3

---This paper describes our progress in the development of a novel technique of dynamic range expansion called DRE. The resulting algorithms provide 16 effective bits and a spurious-free dynamic range of 96dB for most RF digitizers, even those collecting at 5GS/sec or higher. The recorded signals are linear and require no log amplifiers. Log amplifiers may provide acceptable dynamic range yet they introduce undesirable distortion and a significant loss of amplitude resolution. Wide dynamic range collection has always been desirable but elusive. Without DRE, large signals such as interface echoes become saturated when gain is increased in order to view smaller echoes. The result is a loss in near surface resolution and severe distortion of the interface echoes. Gains constantly need to be adjusted based on what you want to measure. We will report on our experimental results using DRE for the inspection of Titanium billet and composite airframe structures. All of the experiments utilize virtually no ultrasonic instrument gain, yet were able to simultaneously record undistorted interface echoes and all responses down to a #1 FBH. Wide dynamic range digitization allows up to 50dB of time variable gain to be applied to the recorded signals using post processing.

Polarized Shear Waves for Crack Detection and Characterization

---Steven J. Turner and **Bruce W. Maxfield**, Analogic Engineering, Inc. Buford WY 82052

---This paper describes a new approach to the detection and sizing of cracks in metals. It uses a new technique based on shear waves having varying polarization direction. This is done using a specially designed EMAT where the polarization direction is established by a combination of coil design and electrical parameters of the electronic system that controls the current through two orthogonal coils. These electrical parameters can be changed on the millisecond time scale so a rapid pulse sequence of gradually changing polarization can be achieved. The reflected/scattered shear wave resulting from each incident shear wave is received and detected with respect to the parameters of the original excitation pulse (phase sensitive, cross-correlation is used). The received signal contains information about the defect orientation, depth and, when scanning is included, the defect lateral extent. Cracks or stringer-like defects and more 3D defects like surface pits or inclusions give dramatically different responses. Of particular interest may be the ability to detect and at least partially characterize cracks contained within surface pits. Measurements on simulated surface defects (saw-cuts, milled spherical caps) have been made. These shear waves are reflected from a surface (we used 316 stainless steel approximately 1.75 inches (44.5 mm) thick). These two classes of defects affect horizontally polarized shear waves very differently. When the polarization is perpendicular to the face of the saw cut, there is a large reduction in the reflected signal. The signal reduction is related to the crack depth and length. Although much further work is needed on this topic, it appears that an inspection method based upon an externally-mounted shear-wave birefringence EMAT may be a means of both detecting and quantifying internal cracks even in the presence of substantial surface roughness and pitting. A model to explain most features of these observations has yet to be developed.

Development of Disposable Ultrasonic Probe for Hot Metal Inclusion Measurement

---**Alex Currie** and Sherri Johnstone, School of Engineering, Durham University, Durham, DH1 3LE United Kingdom; Stuart Millman, Corus UK Ltd, Grangetown, Middlesbrough, TS6 6US United Kingdom

---The application of ultrasonic scattering methodologies to a ‘on the process line’ inclusion measurement system could fulfill metal industries need to develop and incorporate techniques for understanding non-metallic particulate inclusion content or cleanliness at different process areas. The MV20/20 ultrasonic system developed in the Aluminum industry has achieved some success; however, the operational temperatures evident in steel production suggest an ultrasonic measurement system is impractical due to the inability to introduce/propagate an ultrasonic pulse directly into liquid steel. This paper continues to present the development of a novel disposable ultrasonic probe that overcomes pulse introduction difficulties as well as some of the associated issues evident in liquid steel application. A trial at the Corus pilot plant facility in the U.K shows that probe design allows approximately 70% of the energy of the incident ultrasonic pulse to pass from a transmission rod into the liquid steel.

Session 18

SESSION 18
STRUCTURAL HEALTH MONITORING
S. Krishnaswamy, Chairperson
CBLS 010

8:30 AM **Global Material Characterization and SHM of Composite Plate-Like Structures Using STMR Technique**
---**K. Balasubramaniam**, V. Rajesh, J. Vishuvardhan, and C. V. Krishnamurthy, Center for Nondestructive Evaluation and Department of Mechanical Engineering, Indian Institute of Technology Madras, Chennai – 600036, India

8:50 AM **Fatigue Crack Monitoring of a Bolted Aluminum Joint Structure**
---**C. J. Lissenden**, C. S. Kim, and H. Cho, The Pennsylvania State University, Engineering Science and Mechanics, University Park, PA 16802

9:10 AM **Fatigue Crack Growth Monitoring Using Rayleigh-Like Waves**
---B. Masserey and **P. Fromme**, University College London, Department of Mechanical Engineering, London, WC1E 7JE, United Kingdom

9:30 AM **Development of Structural Health Monitoring for Wind Turbine Rotor Blades**
---B. Frankenstein, L. Schubert, B. Weihnacht, E. Schulze, **B. Koehler**, and N. Meyendorf, Fraunhofer IZFP, Dresden Branch, Dresden, Germany; C. Ebert and H. Friedmann, Wolfel Beratende Ingenieure GmbH & Co. KG, Hochberg, Germany

9:50 AM **A Continuous Health Monitoring Guide Wave FMD System for Retrofit to Existing Offshore Oilrigs**
---**R. Mijarez**, L. Solis, and F. Martinez, Instituto de Investigaciones Eléctricas, Gerencia de Control e Instrumentación, Calle Reforma #113, Col. Palmira, 62490 Cuernavaca, Morelos, Mexico

10:10 AM ***Break***

10:30 AM **Optimization of Experimental Parameters for Sparse Array Imaging**
---**A. J. Hunter** and A. J. Croxford, Dept Mechanical Engineering, University of Bristol, Bristol, United Kingdom

10:50 AM **Detection of Disbonding in GLARE Composites Using Lamb Wave Approach**
---**Q. Huang**, B. Regez, O. Balogun, N. Yang, and S. Krishnaswamy, Center for Quality Engineering and Failure Prevention, Northwestern University, Evanston, IL 60208

11:10 AM **Characterization of Water-Saturated Porous Cement by Acoustic Slow Wave**
---**N. Yang**[1], O. Balogun[1], S. Krishnaswamy[1], and J. J. Thomas[2], [1]Center for Quality Engineering and Failure Prevention, Northwestern University, Evanston, IL 60208; [2]Department of Civil and Environmental Engineering, Northwestern University, Evanston, IL 60208

11:30 AM **Local Detection of Acoustic Emission Sources Using Multiplexed Optical Fiber Bragg Grating Sensors**
---**Y.-J. Zhu**, O. Balogun, and S. Krishnaswamy, Center for Quality Engineering and Failure Prevention, Northwestern University, Evanston, IL 60208

11:50 AM **Improved Sensor Designs for Structural Health Monitoring**
---**J. P. Koduru** and J. L. Rose, Pennsylvania State University, Engineering Science and Mechanics Department, University Park, PA 16802

12:10 PM ***Lunch***

Global Material Characterization and SHM of Composite Plate-Like Structures Using STMR Technique

---**Krishnan Balasubramaniam**, V. Rajesh, J. Vishuvardhan, and C. V. Krishnamurthy, Center for Nondestructive Evaluation and Department of Mechanical Engineering, Indian Institute of Technology Madras, Chennai – 600036, India

---The Single Transmitter Multiple Receiver (STMR) Arrays have been shown before to have the ability to locally characterize the stiffness properties of a composite material with anisotropy. The STMR arrays have also been demonstrated for SHM applications using phase reconstruction techniques. The guided ultrasonic Lamb waves are used where the central PZT transducer emits the guided waves, particularly A0 mode, and the other sensors receive the Lamb wave signals. In the current work, this technique has been extended to the determination of global elastic moduli using the signals that are reflected from features in the structure such as edge of the plate, bolt holes, etc. that are known apriori. This is accomplished using an Genetic Algorithm(GA) based inversion algorithm that optimizes a objective function for a particular configuration of the STMR and the elastic moduli of the component. The solution to this inversion is the global elastic moduli of the composite which is then used to determine the unknown defects in the test component. The study also reports on the effect of defects on the reconstruction of the global elastic moduli and defect imaging.

Fatigue Crack Monitoring of a Bolted Aluminum Joint Structure

---**Cliff J. Lissenden**, ChungSeok Kim, and Hwanjeong Cho, The Pennsylvania State University, Engineering Science and Mechanics, University Park, PA 16802

---The monitoring of fatigue crack growth within a bolted joint of an aluminum plate structure is investigated. The objective of the experimental work is to detect, locate, and size a fatigue crack with online-capable structural health monitoring technology. A joint containing multiple bolts is subjected to fatigue loading in the laboratory. An array of surface mounted piezoelectric wafer active sensors is used to excite and receive Lamb waves transmitted through and reflected from the joint. The received signals are analyzed and tomograms are created through comparison to a baseline. The ability to describe the probability density function of the crack size enables probabilistic fatigue life prediction and reliability estimates. Key SHM requirements for input to the crack growth model are briefly discussed. There are a number of steps taken to meet the objective stated above: determine minimum detectable crack size, find the minimum detectable crack size growing from a bolt hole, correlate training data from an open slot to a fatigue crack, describe the effect of joint overlap on crack characterization, and quantify the probability of detecting a crack of a specific size.

Fatigue Crack Growth Monitoring Using Rayleigh-like Waves

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

---A common problem in aircraft maintenance is the development of fatigue cracks at fasteners due to stress concentration. The use of Rayleigh-like waves for the monitoring of fatigue crack growth at a fastener hole in tensile, aluminium specimens is investigated. Rayleigh-like waves can propagate along the structure and have good sensitivity for the detection of small defects. They are excited in the specimens during fatigue experiments using standard wedge transducers and measured using both standard pulse-echo equipment and laser interferometry. Fatigue crack growth during cyclic loading is monitored optically and the changes in the ultrasonic signal caused by crack growth are quantified. The laser measurements show a good sensitivity for the early detection of fatigue damage. The sensitivity and repeatability of the pulse-echo measurements is ascertained, having the potential for the monitoring of fatigue crack growth at difficult to access locations from a stand-off distance. Good agreement is observed between the experimental results and predictions from full three-dimensional simulation of the scattering of the Rayleigh wave at the fastener hole and crack using Finite Difference (FD) method. The robustness of the methodology for practical in-situ ultrasonic monitoring of fatigue crack growth is discussed.

Development of Structural Health Monitoring for Wind Turbine Rotor Blades

---Bernd Frankenstein, Lars Schubert, Bianca Weihnacht, Eberhard Schulze, **Bernd Koehler**, and Norbert Meyendorf, Fraunhofer IZFP, Dresden Branch, Dresden, Germany; Carsten Ebert and Herbert Friedmann, Wolfel Beratende Ingenieure GmbH & Co. KG, Hochberg, Germany

---Currently, the federal German government plans to raise the energy share from wind power up to 25% until 2025. In order to reach this ambitious goal, it will be necessary to built and operate off-shore wind power plants in the Northern and Baltic Sea. To operate those plants safely and efficiently, Structural Health Monitoring (SHM) systems for the main components are of increasing importance. This report presents the development of an SHM system which should monitor the condition of rotor blades and detect and locate structural changes before total failure in time. It is based on a combination of measuring techniques with guided waves in the ultrasonic frequency range and low frequency modal analysis. The combination of both techniques has been used during rotor blade investigation successfully so far. The modal analysis offers the possibility to monitor the global behavior of the rotor blade structure. Parts with high risks of failure due to high loads are separately monitored by guided waves in the ultrasonic frequency range. Typical damage scenarios of rotor blades are presented. The influence on the structural behavior is discussed on the basis of computer simulations and the resulting demands on a condition monitoring system are shown. Based on this concept a full scale fatigue test on a real rotor blade (40m) was realized. Interesting preliminary results of the still ongoing test will be discussed.

A Continuous Health Monitoring Guide Wave FMD System for Retrofit to Existing Offshore Oilrigs

---**Rito Mijarez**, L. Solis, and F. Martinez, Instituto de Investigaciones Eléctricas, Gerencia de Control e Instrumentación, Calle Reforma #113, Col. Palmira, 62490 Cuernavaca, Morelos, Mexico

---Many offshore oilrigs are aging and the amount of steel material demanding inspections is very large. FMD is a method of inspecting a complete structure in a very short time. The detection of water inside hollow cross-beam members is taken as the basis for this method, normally operated by divers or ROVs using ultrasound and x-ray. The integration of this field-proven technique, within the context of structural health monitoring, has been proposed by the authors for new oilrigs installations. This work however, presents a guided wave FMD system for retrofit to existing offshore oilrigs. The system employs a smart transmitter composed of a PZT-element, electronics and batteries, and a receiver instrumentation package comprised of a PZT ultrasound transducer and a DSP based module connected to a PC via USB for monitoring purposes. The transmitter and receiver are attached to the external wall of a steel tube. The transmitter sends continuously 40 kHz ultrasonic guided wave, predominantly longitudinal, pulses. Longitudinal pulses are highly sensitive to water loading that leads to attenuation of the received signals, which is taken as the basis for the detection. Experiments carried out in the laboratory using a tubular steel structure, 1m x 27 cm x 2mm, have successfully identified automatically the detection of flooding.

Optimization of Experimental Parameters for Sparse Array Imaging

---**Alan J. Hunter** and Anthony J. Croxford, Dept Mechanical Engineering, University of Bristol, Bristol, United Kingdom

---Significant research effort has been put into developing permanently attached sparse array networks for structural health monitoring. It is envisaged that such networks will be used to monitor the state of a complete structure over time. When these systems are installed on existing structures, it is possible that there will be errors in the assumed transducer locations due to the complexity of the structure and the large areas that will need to be populated. This has the potential to adversely affect the ability of a sensor network to detect the presence of a defect or to misclassify detected features. This paper addresses this problem, presenting an autofocus algorithm for correcting errors in the experimental parameters, including transducer locations, group velocity and equipment delay. The improvements on the resulting imagery and defect detection are shown, clearly indicating an enhancement in the point spread function. The ability of the technique to correct the parameters for complex geometries is illustrated using experimental data.

Detection of Disbonding in GLARE Composites Using Lamb Wave Approach

---**Qiaojian Huang**, Brad Regez, Oluwaseyi Balogun, Ningli Yang and Sridhar Krishnaswamy, Center for Quality Engineering and Failure Prevention, Northwestern University, Evanston, IL 60208

---Fiber Metal Laminiates (FML) are hybrid composites consisting of thin alternating bonded layers of metal sheets and fiber-reinforced epoxy prepreg. GLAss-REinforced (GLARE) laminate is a new class of FML for advanced aerospace structural application due to their superior mechanical properties and significant weight reduction. In this paper, methods to develop structural health monitoring systems for GLARE 2A-2/1-0.4 laminates will be described. This structure has 2 layers of aluminum alloy (0.4mm in thickness) and 1 layer of glass fiber/epoxy prepreg (0.25mm thick). In a first step, a pulsed laser was used to launch Lamb waves in the GLARE laminate in order to measure the dispersion. The Lamb wave signals were detected with a PZT transducer. The measured phase velocity dispersion curves were consistent with a theoretical calculation using the classical transfer matrix method for layered media. Based on the obtained dispersion curve, modally-selective PZT interdigital transducers were developed to generate and detect Lamb waves in the sample. Specimens with and without disbonds show distinct differences in the Lamb-wave signature which can be used to monitor disbond growth. Finally, thermal-imaging and acoustic full-field imaging were used to inspect the disbond region to correlate the signals measured by the PZT sensors with the actual disbond size.

Characterization of Water-Saturated Porous Cement by Acoustic Slow Wave

---**Ningli Yang**[1], Oluwaseyi Balogun[1], S. Krishnaswamy[1], and Jeffrey J. Thomas[2], [1]Center for Quality Engineering and Failure Prevention, Northwestern University, Evanston, IL 60208; [2]Department of Civil and Environmental Engineering, Northwestern University, Evanston, IL 60208

---Water-saturated porous cement is a particular engineered material. The most significant parameters defining a porous cement are porosity, tortuosity and permeability, which strongly influence many geotechnical and hydrogeological properties. Acoustical methods are very important tools for the characterization of porous materials. Slow compressional waves in fluid-saturated porous medium provide valuable information to study the material properties. This work concerns the transmission of acoustic wave through water-saturated cements with various porosity levels. Wide-band ultrasonic pulses are generated by laser acoustic effect. Two distinct compressional waves are clearly observed, which are consistent with the fast and slow waves predicted in the theory of Biot. An ultrasonic mode conversion technique is applied to confirm the existence of this second compressional wave. The two compressional waves are both used for characterization of porous cement. The tortuosity of the sample, which is the key parameter describing pore architecture, is obtained for the high frequency limit from the dispersion curve of the slow waves. The dependence of tortuosity, wave speed of both fast wave and slow wave on pore volume fraction of the cement samples is discussed.

Local Detection of Acoustic Emission Sources Using Multiplexed Optical Fiber Bragg Grating Sensors

---**Yan-jin Zhu**, Oluwaseyi Balogun, and Sridhar Krishnaswamy, Center for Quality Engineering and Failure Prevention, Northwestern University, Evanston, IL 60208

---An optical fiber Bragg grating (FBGs) based sensor system designed for the local detection of acoustic emissions in engineering structures is presented. The system uses an array of surface mounted FBG sensors, each with a spectral reflectivity in the C-band. Each sensor responds to the local dynamic strain caused by a propagating acoustic emission by a shift in its spectral reflectivity spectrum, which is monitored with a two-wave mixing photorefractive interferometer based spectral demodulator. The demodulator offers several unique characteristics; it is self adaptive to quasi-static spectral shifts, it allows for multiplexed demodulation of multiple sensor responses in a single photorefractive crystal, and it provides a high sensitivity to dynamic (> 300 kHz) spectral shifts in FBG sensors. In this work, we present experimental results detailing the simultaneous detection of high frequency acoustic emissions at multiple points on a metal panel. The measured data are processed using time-frequency analysis approaches to obtain the group velocity dispersion curves for the specimen, which are in-turn used to predict the source of the acoustic emission using simple triangulation approaches. This work may find potential application in the structural health monitoring of aerospace, civil, and mechanical structures.

Improved Sensor Designs for Structural Health Monitoring

---**Jaya Prakash Koduru** and Joseph L. Rose, Pennsylvania State University, Engineering Science and Mechanics Department, University Park, PA 16802

---Guided Lamb wave techniques provide an effective means for inspecting large areas of thin structures. Surface defects arising from corrosion, cracking, impacts etc. can be monitored continuously by permanently embedding sensors on the structure. However with the permanently embedded sensors, multiple wave modes are normally generated making the received signals complex to analyze. Interdigital transducers (IDT's) can be used to achieve mode control giving the capability to excite individual modes significantly enhancing the ability to extract meaningful information from the received signals. PVDF is can be used with appropriate electrodes spacing to excite the desired wave mode in the structure. However, due to its low electromechanical coupling coefficient, performance on structures like carbon fiber composites is very poor. Piezoplatelet transducers as an array of miniature piezoceramic plates in an epoxy matrix are proposed as an alternative to PVDF as the active element for the IDT's. The performance of the piezoplatelet transducer is evaluated experimentally for wavemode generation and application in guided wave line of sight, tomography and phased array imaging for excellent defect detection, sensitivity and location analysis. Aspects and demonstrations of theory and experiment applied to metals and composite structures will be discussed.

Session 19

SESSION 19
NDE OF ARMOR AND ARMOR SYSTEMS
R. Brennan and W. Roy, Co-Chairpersons
Chafee 273

8:30 AM **NDE Studies of Armor Materials and Designs**
---**L. Brasche** and R. B. Thompson, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

8:50 AM **Ultrasound and X-Ray Characterization of Damage in Alumina Structural Ceramics**
---**R. E. Brennan**, J. M. Sands, and W. H. Green, U.S. Army Research Laboratory, Aberdeen Proving Ground, MD 21005

9:10 AM **Nondestructive Inspection Techniques for Armor Applications**
---**R. Spencer**, P. White, and E. Todorov, Edison Welding Institute, 1250 Arthur E. Adams Drive, Columbus, OH 43221

9:30 AM **Application of Air-Coupled UT for Evaluating Composite Armor Panels and Panel Constituent Components**
---**D. J. Barnard**, D. K. Hsu, V. Dayal, A. D. Patz, and B. J. Herbers, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

9:50 AM **Structural Diagnostics of Ballistic-like Damage Variation Via Wave Propagation-Based Filtering Techniques**
---**J. T. Ayers** and M. Ruzzene, Georgia Institute of Technology, School of Aerospace Engineering, Atlanta, GA 30332-0150; D. Le, Army Research Laboratory, Mechanics Division, Aberdeen, MD 21001

10:10 AM ***Break***

10:30 AM **Baseline UT Measurements for Armor Inspection**
---**F. Margetan**, N. Richter, D. Barnard, D. Hsu, T. Gray, and R. B. Thompson, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

10:50 AM **Acoustoultrasonic Characterization of Composite Structures and Armor**
---**N. J. Gianaris**, General Dynamics (GDLS); T. J. Meitzler, RDECOM TARDEC, AMSD-TAR-R, MS 263, Warren, MI 47397-5000; V. F. Godinez-Azcuaga and O. Ley, Mistras Group

11:10 AM **Enabling Smart Protective Armor Systems Using SMART Technology**
---H. Chung, X. P. Qing, and **S. J. Beard**, Acellent Technologies, Inc., 835 Stewart Drive, Sunnyvale, CA 94085

11:30 AM **Optimizing a Portable Microwave Interference Scanning System for Nondestructive Testing of Multi-Layered Dielectric Materials**
---**K. F. Schmidt** and J. R. Little, Evisive, Inc., Baton Rouge, LA 70808; W. A. Ellingson, Argonne National Laboratory, Argonne, IL 60439-3848; W. Green, Army Research Laboratory, Aberdeen Proving Ground, MD 21005

11:50 AM **Ultrasonic Characterization of Defect Engineered Armor-Grade Alumina**
---**S. Bottiglieri**, A. R. Portune, and R. A. Haber, Rutgers University, Department of Material Science and Engineering, 607 Taylor Road, Piscataway, NJ 08854

12:10 PM ***Lunch***

NDE Studies of Armor Materials and Designs
---**Lisa Brasche** and R. Bruce Thompson, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---Modernization of manned ground vehicles is a high priority for the US Army to ensure the protection of our soldiers. To improve the mobility and readiness of ground troops, new armor concepts are being considered which use lighter weight materials without compromising the ballistic performance. This past year, a program was initiated at ISU to support the development of inspection methods for use in the production, i.e., quality assurance, of these new armor concepts. Both fundamental studies of the base materials and of representative armor concepts are underway. An overview of the program will be provided.

Ultrasound and X-Ray Characterization of Damage in Alumina Structural Ceramics
---**Raymond E. Brennan**, James M. Sands, and William H. Green, U.S. Army Research Laboratory, Aberdeen Proving Ground, MD 21005

---Destructive testing and nondestructive evaluation methods have been utilized to analyze impact damage in alumina structural ceramics. Incremental damage was produced in alumina tiles using both drop tower(DT) testing for low velocity impact with a high mass indenter and fragment simulating projectile(FSP) testing for high velocity impact with a low mass projectile. Under sufficient impact velocity and energy conditions, DT testing produced large cracks while FSP testing produced hairline cracks in the tiles. Each set of tests resulted in a threshold range below which there was no impact damage and above which fracture occurred. Comparison of visual inspection to ultrasound (UT) C-scan imaging, digital radiography (DR), and x-ray computed tomography (XCT) demonstrated the capabilities of nondestructive methods for detecting internal damage in the alumina tiles. Qualitative image analysis of surface and bulk cracks and quantitative percent damage assessment were used to compare the integrity of the various nondestructive techniques. While all three methods were able to successfully detect surface cracks, C-scan imaging was the most effective at detecting internal damage including radial cracks and material inhomogeneities. The XCT images were the most effective at characterizing radial and cone crack propagation through the fractured tiles, from which 3-D representations were reconstructed.

Nondestructive Inspection Techniques for Armor Applications

---**Roger Spencer**, Perry White, and Evgueni Todorov, Edison Welding Institute, 1250 Arthur E. Adams Drive, Columbus, OH 43221

---In support of the materials joining development projects undertaken at Edison Welding Institute (EWI), various nondestructive inspection techniques have been applied and solutions developed. These techniques include phased array ultrasonic inspection, eddy current inspection and digital radiography. This presentation will summarize work completed under projects sponsored by the Department of Defense (DoD), US Department of Transportation (DoT), and commercial interests. EWI has successfully applied a combination of phased array ultrasonic inspection and radiography to ground combat vehicle hull structure manufacturing. EWI has also developed techniques to ensure spot weld integrity in automotive structures. As new ground combat armor packages using exotic material combinations emerge, existing inspection techniques may need to be modified or new research adopted. This presentation will provide a menu of nondestructive inspection approaches and discuss their capabilities and limitations in the light of emerging armor materials.

Application of Air-Coupled UT for Evaluating Composite Armor Panels and Panel Constituent Components

---**Daniel J. Barnard**, David K. Hsu, Vinay Dayal, Andrew D. Patz, and Brice J. Herbers, Center for NDE, Iowa State University, 1915 Scholl Road, Ames, IA 50011

---Air-coupled ultrasonic testing (ACUT) has been applied to composite armor panel build-ups and panel constituent components as part of an overall project intended to develop inspection methods for current and future generation armor. Early TTU amplitude C-scan results demonstrated a lower sensitivity to engineered defects in the panels compared to immersion UT, but revealed what appeared to be resonance effects. Subsequent results have demonstrated that the ceramic tile components of the panels have strong resonances at the ACUT frequencies applied, and demonstrate particular mode shape patterns that are revealed in images, both in TTU and in single-sided pitch-catch C-scans. The imaging of mode shapes with ACUT C-scans might be exploited to overcome the lower sensitivity to defects in amplitude C-scans, where the idea is to identify the change in modal pattern with different coupling (bonding) conditions within the panel or damaged ceramic tiles as a result of battlefield exposure. Comparisons of finite-element model results and the ACUT c-scan images will be presented for nominal and flawed ceramic tile components as well as c-scan results of built-up armor panels.---Research was sponsored by the Army Research Laboratory and was accomplished under Cooperative Agreement Number W911NF-08-2-0036. The views and conclusions contained in this document are those of the authors and should not be interpreted as representing the official policies, either expressed or implied, of the Army Research Laboratory or the U.S. Government. The U.S. Government is authorized to reproduce and distribute reprints for Government purposes notwithstanding any copyright notation hereon.

Structural Diagnostics of Ballistic-like Damage Variation Via Wave Propagation-Based Filtering Techniques

---**James T. Ayers** and Massimo Ruzzene, Georgia Institute of Technology, School of Aerospace Engineering, Atlanta, GA 30332-0150; Dy Le, Army Research Laboratory, Mechanics Division, Aberdeen, MD

---Wave propagation-based interrogative methods have shown promise to accurately identify and quantify structural defects produced by ballistic-like impact. Specifically, this paper seeks to evaluate a wave propagation-based filtering technique which utilizes Lamb wave mode separation in the frequency-wavenumber domain. The mode separation is central to the filtering technique in quantifying the damage, whereas the phase gradient of the apparent converted and reflected modes are used to locate the defects. The techniques are subsequently applied to finite element plate models that explicitly model the damage, and experimentally extracted data from Scanning Laser Doppler Vibrometry tests. Numerical and experimental parametric studies are conducted, and the current strengths and weaknesses of the approaches are discussed. Moreover, the specific damage type is varied to represent common external ballistic impact, from a sharp rectangular notch to a semi-circular depression. This variation yields a unique signature scattering from the damage, which is evaluated using a combination of Fourier and Wavelet transforms of the reflected, converted and transmitted modes. The reliability of the techniques are consequently analyzed.

Baseline UT Measurements for Armor Inspection

---**Frank Margetan**, Nate Richter, Dan Barnard, David Hsu, Tim Gray, and R. Bruce Thompson, Center for NDE, Iowa State University, 1915 Scholl Road, Ames, IA 50010

---Some prototype armor panels are fabricated from several layers of material including ceramics, graphite and/or glass composites, and rubber. The ultrasonic properties of these layers influence inspections for armor defects. In this paper we describe measurements of ultrasonic velocity, attenuation, and sound beam distortion for the individual armor layers comprising one prototype. We also discuss how knowledge of these properties can be used when designing UT inspections of armor panels.---Research was sponsored by the Army Research Laboratory and was accomplished under Cooperative Agreement Number W911NF-08-2-0036. The views and conclusions contained in this document are those of the authors and should not be interpreted as representing the official policies, either expressed or implied, of the Army Research Laboratory or the U.S. Government. The U.S. Government is authorized to reproduce and distribute reprints for Government purposes notwithstanding any copyright notation hereon.

Acoustoultrasonic Characterization of Composite Structures and Armor

---**Nicholas J. Gianaris**, General Dynamics (GDLS); Thomas J. Meitzler, RDECOM TARDEC, AMSD-TAR-R, MS 263, Warren, MI 47397-5000; Valerie Francisco Godinez-Azcuaga and Obdulia Ley, Mistras Group

---Acoustoultrasonic (AU) characterization methods have been developed and systemized for the NDE of composite structures and armor. The initial prototype system was limited to a specific material, laminate, and armor design configuration. However, the AU technology was proven to be effective for characterization of anomalies in the composite. It was recognized that further refinement of the AU technology would allow for an improvement of the NDE data from the composite. Improvements to the probe design, software, and robustness of the system for evaluating multiple composite configurations with respect to the AU technology will be presented.

Enabling Smart Protective Armor Systems Using SMART Technology

---Howard Chung, Xinlin P. Qing, and **Shawn J. Beard**, Acellent Technologies, Inc., 835 Stewart Drive, Sunnyvale, CA 94085

---Armor is used to protect our military forces in ground combat situations. To create an effective shield against ballistic projectiles, both personal body armor and vehicle armor systems are generally comprised of multiple layers of energy absorption materials including fiber-reinforced composites and ceramic plates. However, the protective effectiveness greatly depends on the structural integrity of the armor system. Because of the brittle nature of ceramics and the inherent interface incompatibility among the various materials, non-ballistic events may induce hidden damage, leaving soldiers and assets vulnerable to enemy fire. Real-time detection of any existing damage in the protective armor is critical and essential to ensure the safety of our soldiers. Nondestructive inspection techniques, such as ultrasound and x-ray, typically rely on human interpretation and need to be performed in a well-controlled laboratory environment, thus making field use difficult. Structural Health Monitoring (SHM) using a built-in sensor network offers a promising solution to these inspection challenges. An SHM system utilizing SMART Technology for in-situ assessment of the health of ceramic/composite plates for both personal body armor and vehicle armor has been developed. The SMART Technology consists of a modular sensor network, data acquisition electronics, and data interpretation software. Sensors were integrated with personal body armor inserts and larger vehicle armor laminates. Impact testing of the armor was conducted with the Army, and a diagnostic imaging technique was used to detect and highlight the location of the resulting damage.

Optimizing a Portable Microwave Interference Scanning System for Nondestructive Testing of Multi-Layered Dielectric Materials

---**Karl F. Schmidt** and Jack R. Little, Evisive, Inc., Baton Rouge, LA 70808; William A. Ellingson, Argonne National Laboratory, Argonne, IL; William Green, Army Research Laboratory, Aberdeen Proving Ground, MD

---Projected microwave energy pattern, wave guide geometry, positioning methods and process variables have been optimized for use of the portable, non-contact, lap-top computer-controlled microwave interference scanning system on multi-layered dielectric materials. The system is used in situ with one-sided access. It has demonstrated capability of damage detection on composite ceramic armor. Specimens used for validation included specially fabricated surrogates, and ballistic impact-damaged specimens. Microwave data results were corroborated with high resolution direct-digital x-ray imaging. Microwave interference scanning detects cracks, laminar features and material properties variations. This paper will present details of the system, optimization steps and discuss results obtained.

Ultrasonic Characterization of Defect Engineered Armor-Grade Alumina

---**Stephen Bottiglieri**, Andrew R. Portune, Richard A. Haber, Rutgers University, Department of Material Science and Engineering, 607 Taylor Road, Piscataway, NJ 08854

---High frequency ultrasonic characterization was performed on a series of alumina samples of varying homogeneity and composition. These samples were specifically manufactured with known additives of porosity, SiO2 and CaO inclusions, and SiC fragments. Ultrasound attenuation coefficient C-scan mapping and acoustic spectroscopy were employed in order to establish a baseline fingerprint for each defect type. Characterization was performed using 20MHz and 75MHz planar transducers. In addition, alumina samples fired to a range of temperatures were tested for attenuative and elastic properties in order to ascertain microstructural variations during the sintering process. Ultrasonic characterization was successful in demonstrating insight into the effect of sample position during sintering. The spatial distribution of high attenuative regions throughout the sample was shown to depend upon the firing temperature. This study showed the veracity of high frequency ultrasound as a diagnostic tool in locating and characterizing specific defect types within armor-grade alumina materials.

Session 20

SESSION 20
LASER UT
S. Kruger, Chairperson
CBLS 100

1:30 PM **Extraction of Interface Stiffness in Superlattices and Assessment of Interface Coherency Using Picosecond Ultrasound Spectroscopy**
---**H. Ogi**, T. Shagawa, N. Nakamura, and M. Hirao, Graduate School of Engineering Science, Osaka University, Toyonaka, Osaka 560-8531, Japan

1:50 PM **Coding Methods for Low Power Laser Generation of Ultrasound**
---**A. Cleary**, I. Veres, G. Thursby, C. McKee, G. Pierce, and B. Culshaw, Centre for Microsystems and Photonics, Department of Electronic and Electrical Engineering, University of Strathclyde, Glasgow, G1 1XW, Scotland

2:10 PM **Investigation of Laser Generated Rayleigh Waves in Elastic Plates**
---**M. D. Rogge** and I. C. Ume, Georgia Institute of Technology, Woodruff School of Mechanical Engineering, Atlanta, GA 30332-0405

2:30 PM **Microstructure Imaging Using Frequency Spectrum Spatially Resolved Acoustic Spectroscopy**
---**S. D. Sharples**, W. Li, M. Clark, and M. G. Somekh, University of Nottingham, Electrical Systems & Optics Research Division, Nottingham, United Kingdom

2:50 PM **Optoacoustic Method for Determination of Submicron Metal Coating Properties**
---I. M. Pelivanov, D. S. Kopylova, N. B. Podymova, and **A. A. Karabutov**, Moscow State University, International Laser Center, Moscow, Russia

3:10 PM ***Break***

3:30 PM **Development of Laser Based Remote Sensing System for Inner-Concrete Defects**
---**Y. Shimada**, O. Kotiaev, S. Uchida[1], M. Shinoda[2], H. Omura[2], N. Misaki, K. Kondo, Shinji, and Y. Sakamoto[3], Institute for Laser Technology, [1]Tokyo Institute of Technology, [2]Railway Technical Research Institute, [3]West Japan Railway Company

3:50 PM **Study on Laser Generation of Narrowband Lamb Wave Using Superimposed Line Sources Technique**
T.-Y. Wu and I. C. Ume, Georgia Institute of Technology, G. W. Woodruff School of Mechanical Engineering, Atlanta, GA 30332-0405

4:10 PM **Relations Between Material Properties in Metals and Laser Ultrasonic Signals**
---**M. Falkenström** and M. Engman, Swerea KIMAB, Box 55970, 102 16 Stockholm, Sweden

4:30 PM **Laser Ultrasonics for Detection of Elastic Nonlinearity Using Collinear Mixing of Surface Acoustic Waves**
---**S. D. Sharples**, T. Stratoudaki, R. Ellwood, I. J. Collison, M. Clark, and M. G. Somekh, University of Nottingham, Electrical Systems & Optics Research Division, Nottingham, United Kingdom

4:50 PM **Laser Induced Shock Waves for Adhesive Bond Testing**
---Z. Gu, M. Perton, S. E. Kruger, A. Blouin, D. Levesque, and **J.-P. Monchalin**, Industrial Materials Institute, National Research Council of Canada, Boucherville, Quebec, Canada;
A. Johnston, Institute for Aerospace Research, National Research Council of Canada, Ottawa, Ontario, Canada; M. Boustie, ENSMA/LCD, Box 40109, 86961 Futuroscope, France; L. Berthe, LALP/CNRS/Arts et Métiers Paris Tech, 151 Bd de l'Hopital, 75013 Paris, France; M. Arrigoni, LBMS/ENSIETA, 2 rue Francois Verny, 29806 Brest, France

Extraction of Interface Stiffness in Superlattices and Assessment of Interface Coherency Using Picosecond Ultrasound Spectroscopy

---**Hirotsugu Ogi**, Tomohiro Shagawa, Nobutomo Nakamura, and Masahiko Hirao, Graduate School of Engineering Science, Osaka University, Toyonaka, Osaka 560-8531, Japan

---We consider a theoretical model to extract the interface elastic stiffness in superlattices from resonance measurements with picosecond ultrasound spectroscopy. Thickness phonon vibrational modes are excited and detected in a five-layered superlattice, consisting of three (thick) matrix layers and two ultrathin interlayers, by the excitation and detection with the ultrafast light pulses. The thickness of the interlayer is varied between 0.2 and 1 nm. We define the interface elasticity parameter from the ratio of the resonance frequencies of the fundamental and first higher phonon modes, which are insensitive and sensitive to the interface elastic constants, and inversely determine the elastic stiffness of the interlayer. Using Pt as the matrix and Co, Fe, or Pd as the interlayers, we systematically evaluate the interface stiffness as a function of the interlayer thickness. The interface stiffness is considerably lower than the bulk value when the interlayer thickness is smaller, indicating the presence of interfacial defects such as interface dislocations. Thus, the picosecond ultrasound spectroscopy can be a useful tool for evaluating the reliability of the interface through the elastic stiffness.

Coding Methods for Low Power Laser Generation of Ultrasound

---**Alison Cleary**, István Veres, Graham Thursby, Campbell McKee, Gareth Pierce, and Brian Culshaw, Centre for Microsystems and Photonics, Department of Electronic and Electrical Engineering, University of Strathclyde, Glasgow, G1 1XW, Scotland

---Characterization of the material properties of thin microstructured samples presents an interesting problem in that non-contact interrogation of these samples is difficult to achieve. Previous work has established how material properties in thick (>1 mm) samples can be obtained through ultrasonic dispersion curves, where the excitation of a wide range of frequencies was achieved with high peak power pulsed lasers that tended to produce surface ablation. The use of modulated low power laser diodes instead of high peak power pulsed sources for the thermoelastic generation of ultrasound in thin samples has the advantage of being entirely non-destructive. However, when using a lower power modulated source, the magnitude of the ultrasonic waves produced is much smaller due to the lower incident peak power which is approximately 1 W. The use of pseudo-random binary sequence (PRBS) coding mechanisms such as m-sequences for timing the excitation can improve the signal-to-noise ratio of the ultrasonic signal that is detected. Here we demonstrate the effectiveness of such coding methods in conjunction with detection by a laser vibrometer, and evaluate the applicability of these methods to the detection and evaluation of propagating ultrasonic waves in thin (micrometer-scale) plate-like samples.

Investigation of Laser Generated Rayleigh Waves in Elastic Plates

---**Matthew D. Rogge** and I. Charles Ume, Georgia Institute of Technology, Woodruff School of Mechanical Engineering, Atlanta, GA 30332-0405

---An investigation of the properties of laser generated Rayleigh waves in elastic plates is presented in this paper. Previous work has shown that when a laser pulse generates ultrasound on the top surface of a plate, low frequency Rayleigh waves can be present on the bottom surface. These Rayleigh waves have been effective towards nondestructive measurement of weld penetration depth. However, the means through which the Rayleigh wave is present on the bottom surface was not determined. It was speculated that the Rayleigh wave is the result of bulk waves that travel to the bottom surface and undergo mode conversion. In order to determine the source of the Rayleigh wave and to predict the frequency content of the waves, a numerical model based on Generalized Ray Theory is developed. Experiments are performed in which the Rayleigh waves are measured at many locations on the bottom surface of different plates with thicknesses ranging from 3.3 to 25.4mm. Experiment results show good agreement with the model predictions. Dominant frequency and amplitude of the Rayleigh wave is shown to decrease as plate thickness increases. In addition, the source of the Rayleigh wave is identified and a range of thickness for which these waves are present is discussed.

Microstructure Imaging Using Frequency Spectrum Spatially Resolved Acoustic Spectroscopy

---**Steve D. Sharples**, Wenqi Li, Matt Clark, and Mike G. Somekh, University of Nottingham, Electrical Systems & Optics Research Division, Nottingham, United Kingdom

---Material microstructure can have a profound effect on the mechanical properties of a component, such as strength and resistance to creep and fatigue. SRAS - spatially resolved acoustic spectroscopy - is a laser ultrasonic technique which can image microstructure using highly localized surface acoustic wave (SAW) velocity as a contrast mechanism, as this is sensitive to crystallographic orientation. The technique is noncontact, nondestructive, rapid, can be used on large components, and is highly tolerant of acoustic aberrations. Previously, the SRAS technique has been demonstrated using a fixed frequency excitation laser and a variable grating period (k-vector) to determine the most efficiently generated SAWs, and hence the velocity. Here, we demonstrate an implementation which uses a fixed grating period with a broadband laser excitation source. The velocity is determined by analyzing the measured frequency spectrum. Experimental results using this "frequency spectrum SRAS" (f-SRAS) method are presented. Images of microstructure on industrially relevant materials are compared to those obtained using the previous SRAS method ("k-SRAS"), excellent agreement is observed. Moreover, f-SRAS is much simpler and potentially much more rapid than k-SRAS as the velocity can be determined at each sample point in one single laser shot, rather than scanning the grating period.

Optoacoustic Method for Determination of Submicron Metal Coating Properties

---Ivan M. Pelivanov, Daria S. Kopylova, Natalia B. Podymova, **Alexander A. Karabutov**, Moscow State University, International Laser Center, Moscow, Russia

---Optoacoustic (OA) conversion in the system containing metal film deposited on a transparent dielectric substrate and covered by a transparent liquid is considered both theoretically and experimentally. This consideration implies a method for non-destructive evaluation of submicron metal coatings. The main principle of the method is the following. Irradiation of the metal film by a nanosecond laser pulse leads to transient heating and expansion of the film that in turn results in the generation of an acoustic signal. The waveform of the signal results from two contributions: the “primary” signal from the thermal expansion of the metal film, that repeats the temporal profile of the laser pulse envelope, and the “secondary” signal, that originates from the thermal expansion of the adjacent liquid layer. Due to low thermal conductivity of liquid compared to metal, the liquid accumulates heat that is released in metal and produces that “secondary” contribution into the OA conversion. This contribution is very sensitive to the properties of the film. The influence of the film thickness and its thermophysical parameters on the frequency-dependent efficiency of OA conversion and on the temporal profile of excited OA signals is discussed in detail. The method for nondestructive evaluation of submicron metal coatings properties is proposed.

Development of Laser Based Remote Sensing System for Inner-Concrete Defects

---**Yoshinori Shimada**, Oleg Kotiaev, Shigeaki Uchida[1], Masahiro Shinoda[2], Hirokazu Omura[2], Norimazu Misaki, Ken-ichi Kondo, Shinji, and Yasuhiko Sakamoto[3], Institute for Laser Technology, [1]Tokyo Institute of Technology, [2]Railway Technical Research Institute, [3]West Japan Railway Company

---A laser-based system for remote non-destructive inspection of concrete structures has been developed. The system is intended for the location of inner flaws in concrete structures, mainly in concrete transportation tunnels. The technique is based on the initiation and detection of standing Lamb waves and multi-reflecting ultrasound wave from inner defect in concrete layers. Vibration in concrete is initiated by laser impact provided by a pulsed Nd:YAG laser operating at wavelength of 1064 nm. A CW Nd:YAG laser radiation of 532 nm wavelength is used for detection of initiated vibration. The detection is performed with the use of a laser photorefractive interferometer. The interferometer uses principles of dynamic holography via two-wave mixing in photorefractive crystal and homodyne detection. A photorefractive crystal - Bismuth Silicon Oxide (BSO) - is used as a nonlinear medium for the recording of the dynamic hologram. Concrete samples examined in the laboratory experiments reproduce real concrete material used in transportation tunnels. Detection of various types of inner defects like voids, slits and honeycombs has been demonstrated. A mobile model of the system has been assembled and demonstrated in the field conditions. We have been done the field experiments at real tunnel concrete. It was possible to find the real inner defect in concrete. The result of the experiments was that the mobile system was useful for inspection of inner defect in concrete with rapidly and accuracy.

Study on Laser Generation of Narrowband Lamb Waves Using Superimposed Line Sources Technique

---**Tsun-Yen Wu** and I. Charles Ume, Georgia Institute of Technology, G. W. Woodruff School of Mechanical Engineering, Atlanta, GA 30332-0405

---Lamb waves are widely used in defect detection in thin structures. To use lasers to generate Lamb waves is beneficial due to its noncontact nature. Here, a technique called superimposed line sources is presented. The technique generates narrowband Lamb waves with a dominant wavelength by superimposing signals of line sources at the pitch corresponding to the desired wavelength. The superposition is performed in software after data are collected so that it permits flexibility of selecting desired wavelength afterwards. By selecting the dominant wavelength in signals, signal complexity is reduced and the speeds and frequencies of wave modes with the selected wavelength can be determined through dispersion curves. The knowledge of speeds and frequencies of narrowband Lamb wave modes permits identification and time-of-flight analysis of each wave mode in applications. Continuous wavelet transform is used to transform signals into time-frequency domain to identify each mode. To investigate the defect detection ability of the technique, finite element simulations and experiments of surface-breaking notches with different dimensions are conducted. Reflection and transmission coefficients are calculated for fundamental wave modes. Good agreement is found between the simulations and experiments and the result of coefficients with respect to defect and sample dimensions will be shown.

Relations Between Material Properties in Metals and Laser Ultrasonic Signals

---**Magnus Falkenström** and Martin Engman, Swerea KIMAB, Box 55970, 102 16 Stockholm

---For the last year the main research focus at Swerea KIMAB have been concentrated on industrial application for in-process characterization of metals. In this presentation our recent results correlating laser ultrasonic signals to microstructure in steel and brass of different geometries will be presented. In a couple of ongoing projects we strive in particular to find good relations between ultrasound signals and material properties like yield strength and phase constituents. For example in hot rolled low alloyed steels the dependence of the ultrasound signals to the anisotropy in the materials shows good correlation with the yield strength.

Laser Ultrasonics for Detection of Elastic Nonlinearity Using Collinear Mixing of Surface Acoustic Waves

---**Steve D. Sharples**, Theodosia Stratoudaki, Rob Ellwood, Ian J. Collison, Matt Clark and Mike G. Somekh, University of Nottingham, Electrical Systems & Optics Research Division, Nottingham, United Kingdom

---The inherent material nonlinearity of many materials leads to deviation from Hooke's law, as the elastic moduli are not constant under applied stress. Acoustic waves traveling in the material are also sensitive to changes in the elastic moduli, and this sensitivity can be used as a metric of intrinsic material nonlinearity. As static stressing of a component is in most cases impractical, an alternative technique, explored here, is to use a large amplitude surface acoustic wave (SAW) "pump" to generate stresses which propagate along the surface of a sample. A laser generated high frequency tone burst SAW "probe" is co-propagated with the pump, and is subject to the same stress as it propagates; the stress will be determined by both the height of the pump and the relative position of the probe with respect to the pump, which we can adjust. This collinear mixing results in a small change in the velocity of the probe wave, which is detected using another laser. By relating the change of velocity to the applied stress, a measure of the material's intrinsic nonlinearity can be obtained. We present quantitative measurements relating to material characterization, and implications for its use in damage detection are discussed.

Laser Induced Shock Waves for Adhesive Bond Testing

---Zhowei Gu, Mathieu Perton, Silvio E. Kruger, Alain Blouin, Daniel Levesque, and **Jean-Pierre Monchalin**, Industrial Materials Institute, National Research Council of Canada, Boucherville, Quebec, Canada; Andrew Johnston, Institute for Aerospace Research, National Research Council of Canada, Ottawa, Ontario, Canada

---Adhesive bonding of structural components presents many practical advantages when compared to other joining methods, but its application for critical components is limited by the absence of reliable nondestructive methods that can assure the bond strength of the joint. In this paper, a method based on shock waves produced by a pulsed laser is applied to the evaluation of bond strength of two plates joined with different adhesives. A shock wave produced by an energetic short laser pulse can cause a delamination when it propagates through the adhesive/plate interface. Different values of laser pulse energies can be used to probe the adhesion strength. A good joint will be unaffected by a certain level of shock wave stress whereas a weaker one (kissing bond) will be damaged. The method is made quantitative and in-situ by optically measuring the sample surface velocity with a Doppler or velocity interferometer. Interferometer signals give a signature of well-bonded and disbanded interfaces. The velocity interferometer signals can moreover be correlated with numerical simulation to obtain an estimate of the bond strength. Results show that the proposed test is able to differentiate bond quality. In addition, laser-ultrasonic measurements made on shocked samples confirmed that weak bonds are revealed by the shock wave method. The proposed testing approach may help a broad adoption of adhesive bonding throughout the aerospace industry and its use for joining primary aircraft structures.

Session 21

SESSION 21

CIVIL STRUCTURES

B. Koehler, Chairperson
Chafee 277

1:30 PM **Guided Wave Propagation in Solid Structures of Arbitrary Cross-Section Coupled to Infinite Solid Media**
---**K. Qi**[1,2] and G. Zhao[1], [1]Intelligent Automation, Inc., Rockville, MD 20855; J. L. Rose[2], [2]The Pennsylvania State University, Department of Engineering Science and Mechanics, University Park, PA 16802

1:50 PM **Nondestructive Inspection of Trunnion Bearing Pins**
---B. Story, **S. Hurlebaus**, and G. Fry, Zachry Department of Civil Engineering, Texas A&M University, College Station, TX 77843

2:10 PM **Capacitive Probe Modelling by DPSM Technique**
---**T. Bore** and F. Taillade, Laboratoire Central des Ponts et Chaussées, Division Mesures & Instrumentations, 75015 Paris, France; D. Placko, Ens Cachan, Satie, 94230 France; M. Himbert, CNAM, INM, Saint Denis, 93210 France

2:30 PM **Study and Applications of a Multi MR Sensor System to Detect Corrosion in Suspension Cables**
---**V. Torres**, S. Quek, and P. Gaydecki, The University of Manchester, Electrical and Electronic Engineering, Manchester, United Kingdom

2:50 PM **An Efficient Algorithm for Stiffness Identification of Truss Structures Through Distributed Local Computation**
---**G. Zhang** and R. Burgueño, Michigan State University, Department of Civil and Environmental Engineering, East Lansing, MI 48824-1226; N. G. Elvin, City College of New York, Mechanical Engineering Department, New York, NY 10014

3:10 PM ***Break***

3:30 PM **Control and Data Acquisition of Automated Multi-Sensor Systems in Civil Engineering**
---**J. H. Kurz** and G. Dobmann, Institut Zerstörungsfreie Prüfverfahren (IZFP), Saarbrucken, Germany; M. Stoppel and A. Taffe, Federal Institute for Materials Research and Testing (BAM), Berlin

3:50 PM **Nuclear Containment Vessel Inspection Using an Array of Guided Wave Sensors for Damage Localization**
---**A. C. Cobb** and J. L. Fisher, Southwest Research Institute, Mechanical and Materials Engineering Division, 6220 Culebra Road, San Antonio, TX 78238

4:10 PM **An Algorithm to Generate Images Showing the Position and Arrangement of Steel Bars from a Magnetic Field Imaging Camera (mFIC)**
---P. Gaydecki and **L. Heathcote**, University of Manchester, School of Electrical and Electronic Engineering, Manchester, United Kingdom

4:30 PM **Diffuse Ultrasound Measurements in Concrete**
---**F. Deroo**, J.-Y. Kim, and K. G. Sabra, Georgia Institute of Technology, School of Civil & Environmental Engineering, Atlanta, GA 30332; L. J. Jacobs, Georgia Institute of Technology, School of Civil & Environmental Engineering, and Woodruff School of Mechanical Engineering, Atlanta, GA; J. Qu, Georgia Institute of Technology, Woodruff School of Mechanical Engineering, Atlanta, GA 30332

4:50 PM **Characterization of Microcrackings in Mortars Using Nonlinear Acoustic Techniques**
---**J. Chen**, A. R. Jayapalan, J.-Y. Kim, K. E. Kurtis, and L. J. Jacobs, School of Civil and Environmental Engineering, Georgia Institute of Technology, 790 Atlantic Drive, Atlanta, GA 30332-0355

Guided Wave Propagation in Solid Structures of Arbitrary Cross-Section Coupled to Infinite Solid Media

---**Kevin Qi**[1,2] and George Zhao[1], [1]Intelligent Automation, Inc., Rockville, MD 20855; Joseph L Rose[2], [2]The Pennsylvania State University, Department of Engineering Science and Mechanics, University Park, PA 16802

---Semi-Analytical Finite Element (SAFE) method has been proved to be effective in calculating wave propagation in a waveguide of arbitrary cross-section. However, the conventional SAFE method is not suitable for waveguides coupled to unbounded domain. In this paper, infinite elements are introduced into the SAFE method to analyze the dispersion curves for structures embedded in infinite media. Special shape functions are constructed in the infinite elements to make wave displacements and stresses decay with dimension. The effectiveness of the infinite element based absorbing boundary is illustrated with examples.

Nondestructive Inspection of Trunnion Bearing Pins

---Brett Story, **Stefan Hurlebaus**, and Gary Fry, Zachry Department of Civil Engineering, Texas A&M University, College Station, TX 77843

---Currently, there are several issues plaguing the railroad bridge infrastructure in the United States. These structures are aging and reaching the end of their original design life while simultaneously experiencing increases in train speed, axle load, and train length. As a result of reaching the end of their original design lives, special attention must be given to evaluate the effects of deterioration such as corrosion and fatigue. This research project investigates the integrity of trunnion bearing pins using ultrasonic techniques that (1) minimize disassembling of the bearing, (2) minimize the lock time of the bridge, and (3) are nondestructive. The proposed technique uses an ultrasonic probe to inspect the bearing pin from the center hole as well as an ultrasonic transducer to inspect the pins from their faces. The results of this research show that the proposed method is capable of detecting discontinuities in the bearing pin such as the keyholes.

Capacitive Probe Modelling by DPSM Technique

---**Thierry Bore** and Frederic Taillade, Laboratoire Central des Ponts et Chaussées, Division Mesures & Instrumentations, 75015 Paris, France; Placko Dominique, Ens Cachan, Satie, 94230, France; Himbert Marc, CNAM, INM, Saint Denis, 93210 France

---Lots of bridges use external post-tensioned, during its construction or as a process of strengthening the structure. The steels wire rope are generally placed in a duct made of high density polyethylene (PEHD), where the residual space is filled under high pressure with cement paste or with oil wax. Since many years, the managers have been confronted to a recrudescence of breakings of elementary strand, or even the entire duct, in zone non protected by the cement, particularly in the presence of water or air. So as to keep watch on the post- tensioned duct, a capacitive probe has been developed at the Laboratoire Central des Ponts et Chaussées in France near Paris: the wire electrodes are placed at the surface of the duct form a capacitor of which the capacity will vary with the nature of the materials in the duct. The modelization of the problem has been realized with the Distributed Points Source Method technique (DPSM): a semi-analytical technique based on the superposition of a basic point source problem. Calculations have been made on a typical post- tensioned duct and compared to finite elements calculation. Moreover, the laboratory have several test duct: comparisons between measurements and calculus have been realized.

Study and Application of a Multi MR Sensor System to Detect Corrosion in Suspension Cables

---**V. Torres**, S. Quek, and P. Gaydecki, The University of Manchester, Electrical and Electronic Engineering, Manchester, United Kingdom

---Aging and deterioration of the main functional parts in civil structures is one of the biggest problems that private and governmental institutions, dedicated to operate and maintain such structures, are facing now days. In the case of relatively old suspension bridges, problems emerge due to corrosion and break of wires in the main cables. Decisive information and a reliable monitoring and evaluation are factors of great relevance required to prevent significant or catastrophic damages caused to the structure, and more importantly, to people. The main challenge for the NDE methods of inspection arises in dealing with the steel wrapping barrier of the suspension cable, which main function is to shield, shape and hold the bundles. The following work, presents a study of a multi-magnetoresistive sensors system aiming to support the monitoring and evaluation of suspension cables at some of its stages. Modelling, signal acquisition, signal processing, experiments and the initial phases of implementation are presented and discussed widely.

An Efficient Algorithm for Stiffness Identification of Truss Structures Through Distributed Local Computation

---**Gang Zhang** and Rigoberto Burgueño, Michigan State University, Department of Civil and Environmental Engineering, East Lansing, MI 48824-1226; Niell G. Elvin, City College of New York, Mechanical Engineering Department, New York, NY

---This paper presents an efficient stiffness identification technique for truss structures based on distributed local computation. Sensor nodes on each element are assumed to collect strain data and communicate only with sensors on neighboring elements. This can significantly reduce the energy demand for data transmission and the complexity of transmission protocols, thus enabling a simplified wireless implementation. Element stiffness parameters are identified by simple low order matrix inversion at a local level, which reduces the computational energy, allows for distributed computation and makes parallel data processing possible. The proposed method also permits addressing the problem of missing data or faulty sensors. Numerical examples, with and without missing data, are presented and the element stiffness parameters are accurately identified. The computation efficiency of the proposed method is n2 times higher than previously proposed global damage identification methods.

Control and Data Acquisition of Automated Multi-Sensor Systems in Civil Engineering

---**Jochen H. Kurz** and Gerd Dobmann, Institut Zerstörungsfreie Prüfverfahren (IZFP), Saarbrucken, Germany; Markus Stoppel and Alexander Taffe, Federal Institute for Materials Research and Testing (BAM)

---A combination of different non-destructive test methods is often necessary to receive reliable results for material characterization, flaw detection and the determination of component specific geometry parameters. Regarding structures of concrete thickness measurements are combined with flaw detection. Furthermore, additional information about reinforcement and tendon ducts is needed. Therefore, a multi-sensor measurement approach is required with a high degree of automation. Otherwise a time consuming succession of manual measurements has to be performed. A modular control and data acquisition approach will be described and the application to two different automated measurement devices will be shown. These are results from two collaborative projects dealing with the development of an automobile robot system and a highly flexible scanner system. These different applications are based on a similar kernel allowing the modular use of different contact and non-contact sensors. Therefore, continuous and point measurement devices can be combined and multiple sensor combinations are posible. This measurement approach leads to results in form of point data and time series. Furthermore, the coordinates of each measurement can be device dependent. Therefore, a flexible analysis concept is needed. Since often only a combination of several methods will lead to significant results the fusion of the analysed data must also be possible. Several aspects as well as limits and future trends concerning analysis and also flexible data storage will be discussed.

Nuclear Containment Vessel Inspection Using an Array of Guided Wave Sensors for Damage Localization

---**Adam C. Cobb** and Jay L. Fisher, Southwest Research Institute, Mechanical and Materials Engineering Division, 6220 Culebra Road, San Antonio, TX 78238

---Nuclear power plant containments are typically both the last line of defense against the release of radioactivity to the environment and the first line of defense to protect against intrusion from external objects. As such, it is important to be able to locate any damage that would limit the integrity of the containment itself. Typically, a portion of the containment consists of a metallic pressure boundary. This pressure vessel encloses the reactor primary circuit; it is made of thick steel plates welded together. Furthermore, the vessel is lined with concrete and partially buried, limiting areas that can be visually inspected for corrosion damage. This study presents a strategy using low frequency (<50 kHz) guided waves to find corrosion-like damage several meters from the probe in a mock-up of the containment vessel. A magnetostrictive sensor (MsS) is scanned across the circumference of the vessel, acquiring waveforms at a fixed interval. A beam forming strategy is used to localize the defects, allowing greater accuracy when compared to a typical B-scan strategy. Experimental results are presented for a variety of damage types and orientations, demonstrating the efficacy of this technique to localize damage smaller than the ultrasonic wavelength.

An Algorithm to Generate Images Showing the Position and Arrangement of Steel Bars from a Magnetic Field Imaging Camera (mFIC)

---Patrick Gaydecki and **Lydia Heathcote**, University of Manchester, School of Electrical and Electronic Engineering, Manchester, United Kingdom

---The University of Manchester has developed and built a real time magnetic field imaging camera (mFIC) based on solid state sensors. It is a 2D array of 35x33 magneto-inductive sensors, placed within a large coil which carries a DC current. Outputs from several rows of sensors are routed to a sub-master controller and all sub-masters route to a master-controller responsible for data coordination and signal pre-processing. The data are sent to a computer via a USB interface and the images generated and displayed at a rate of several frames per second. A statistical algorithm has been developed to ascertain the location and orientation of steel rebars derived from the raw data captured by a magnetic field imaging camera (Mfic). The algorithm is used to generate an image showing the position, quantity and arrangement of the bars.

Diffuse Ultrasound Measurements in Concrete

---**Frederik Deroo**, Jin-Yeon Kim, and Karim G. Sabra, Georgia Institute of Technology, School of Civil & Environmental Engineering, Atlanta, GA 30332; Laurence J. Jacobs, Georgia Institute of Technology, School of Civil & Environmental Engineering, and Woodruff School of Mechanical Engineering, Atlanta, GA; Jianmin Qu, Georgia Institute of Technology, Woodruff School of Mechanical Engineering, Atlanta, GA 30332

---Heterogeneities in concrete caused by the random distribution of aggregate in the cement-paste matrix lead to the strong scattering of ultrasound waves at wavelengths on the order of the aggregate. Use of these high frequencies is necessary to detect damage at an early stage, something that is not possible with conventional ultrasonic methods. The ultrasound energy density in that regime can be described by the diffusion equation. The objective of this research is to develop a quantitative understanding of the effects of additional scattering sources, such as small cracks in the cement-paste matrix, on the parameters of the diffusion equation, the diffusion and the dissipation coefficients. Experimentally measured ultrasonic waves are processed using diffusion theory to determine the diffusivity and the dissipation, as a function of frequency. The samples employed are made of a Portland cement-paste matrix and regular aggregate, such as gravel and sand. The results will provide a basic understanding of repeatability and consistency of measurements, with an emphasis on the nondestructive evaluation of concrete.

Characterization of Microcrackings in Mortars Using Nonlinear Acoustic Techniques

---**Jun Chen**, Amal R. Jayapalan, Jin-Yeon Kim, Kimberly E. Kurtis, and Laurence J. Jacobs, School of Civil and Environmental Engineering, Georgia Institute of Technology, 790 Atlantic Drive, Atlanta, GA 30332-0355

---Experimental techniques based on nonlinear acoustics are developed to characterize the progress of microcracking in mortar materials. The microcracking is induced by alkali-silica reaction, a chemical reaction in cement-based materials, and these microcracks grow cumulatively throughout a 14-day experimental duration. The cumulative microcracking is quantitatively recorded by advanced petrographic techniques. Nonlinear acoustic parameters are defined in experimental techniques that are used to represent the amount of microcracking of mortar samples. In addition, conventional linear measurements such as pulse velocity (to calculate the Young's modulus) are also conducted in a parallel manner with the progressive microcracking of the samples. Through a comparison between the defined nonlinear and linear acoustic parameters, the developed nonlinear acoustic technique is found to be much more sensitive to the occurrence and further progress of microcrackings in mortars. The variation of nonlinear parameters also is in good agreement with the recorded microcracking index in petrographic analyses. The results of this work indicate that the developed nonlinear techniques could be highly effective and reliable experimental tools for the general characterization of defects in concrete materials.

Session 22

SESSION 22

NDE FOR CORROSION, PLASTIC DEFORMATION, AND FRACTURE

K. Balasubramaniam, Chairperson

CBLS 010

1:30 PM **Monitoring of General Corrosion of Plain Carbon Steel by Means of Acoustic Emission**
---**N. Parida**, MST Division, National Metallurgical Laboratory, Jamshedpur 831007, India

1:50 PM **Non-Contact Acousti-Thermal Signatures of Plastic Deformation in Ti-6Al-4V**
---**J. T. Welter**, M. P. Blodgett, and K. V. Jata, Air Force Research Laboratory, Wright-Patterson Air Force Base, Dayton, OH 45469-0120; N. Schehl and S. Sathish, University of Dayton Research Institute, 300 College Park, Dayton, OH 45469-0120; J. Malott, SOCHE, Miami Valley Research Park, 3155 Research Blvd. Suite 204, Dayton OH 45469-0120

2:10 PM **Detection and Prediction of Creep-Damage of Copper Using Nonlinear Acoustics Technique**
---V. Jitendra, **K. Balasubramaniam**, and R. Prakash, Centre for Non destructive Evaluation, Department of Mechanical Engineering, Indian Institute of Technology Madras, Chennai-36, India

2:30 PM **Nonlinear Acoustics and Microstructural Evolution During Creep in Cr-Mo-V Steel**
---**T. Ohtani** and T. Ogawa, Shonan Institute of Technology, Department of Mechanical Engineering, Fujisawa, Kanagawa, Japan

2:50 PM **Monitoring Fatigue Crack Growth in Multi-Layered Tensile Specimens Using Guided Ulrasonic Waves**
---**E. Kostson** and P. Fromme, Department of Mechanical Engineering, University College London, London WC1E 7JE, United Kingdom

3:10 PM ***Break***

3:30 PM **Identifying Fracture Origin in Ceramics by Combination of Nondestructive Testing and Discrete Element Analysis**
---**R. Senapati** and J. Zhang, The University of Texas at El Paso, Industrial Engineering Department, El Paso, TX 79968

3:50 PM **Eddy Current Probe Impedance Due to Edge Cracks**
---**J. R. Bowler**[1] and T. Theodoulidis[2], [1]Center for NDE and Department of Electrical and Computer Engineering, Iowa State University, Ames, IA 50011; [2]Department of Mechanical Engineering of the University of Western Macedonia, Kozani, Greece

Monitoring of General Corrosion of Plain Carbon Steel by Means of Acoustic Emission
---**Narayan Parida**, MST Division, National Metallurgical Laboratory, Jamshedpur 831007, India

---Acoustic emission technique has recently been emerged as a direct non-intrusive technique for corrosion monitoring of storage tank bottom in oil industries. Presently it is being used to establish tank floor condition in order to help make decision on tank maintenance timing and priority. The active corrosion taking place at the tank bottom during service could generate acoustic emission signals. Detection, location and characterization of these acoustic emission signals would evaluate the integrity of the storage tanks. The presently adopted procedure of AE testing of tank bottom is as follows: AE monitoring is conducted with tank filled with its regular product, which is allowed to sit for a minimum of twelve hours prior to the test. It includes the use of several sensors mounted on the tank wall at least one meter above the bottom to enable planar source location within the entire tank floor area. The test is usually carried out for one hour and based on the level of acoustic emission activity generated within one hour test period the tank floor condition is graded. This grading is probably based on experience. There is no scientific data presently available in the open literature to predict the condition of a storage tank. A systematic study is, therefore, required for scientific understanding of this problem, which will include characterization of AE signals generated due to active corrosion and identification of various corrosion processes taking place at the tank bottom. This paper presents the characterization of AE signals generated during uniform corrosion taking place in plain carbon steel representing tank bottom material. The characterization has been made for acidic, neutral and basic solutions. The results show that there is linear relationship between weight loss and AE activity.

Non-Contact Acousto-Thermal Signatures of Plastic Deformation in Ti-6Al-4V
---**John T. Welter**, Mark P. Blodgett, and Kumar V. Jata, Air Force Research Laboratory, Wright-Patterson Air Force Base, Dayton, OH 45469-0120; Norm Schehl and Shamachary Sathish, University of Dayton Research Institute, 300 College Park, Dayton, OH 45469-0120; Jerry Malott, SOCHE, Miami Valley Research Park, 3155 Research Blvd. Suite 204, Dayton OH 45469-0120

---Plastic deformation introduces changes in a material which include increases in: dislocations, strains, residual stress, and yield stress. However, these changes have a very small impact on the material properties such as elastic modulus, conductivity and ultrasonic wave velocity. This is due to the fact that interatomic forces govern these properties and they are not affected by plastic deformation to any large degree. This is evident from the changes in electrical resistance and ultrasonic velocity in plastically deformed and virgin samples is very small and can only be determined by highly controlled experiments. Except for X-ray diffraction, there are no widely accepted direct nondestructive methods for measuring strain and the residual stress. This paper presents an application of the non-contact acousto-thermal signature (NCATS) NDE methodology to detect plastic deformation in flat dog bone Ti-6Al-4V samples. Results of the NCATS measurements on samples subjected to incremental amounts of plastic deformation are presented. The maximum temperature attained by the sample due to acoustic excitation is found to be sensitive to the amount of plastic strain. It is observed that the temperature induced by acoustic excitation increases to a peak followed by a decrease to failure. The maximum temperature peak occurs at plastic strains of 12-14%. A correlation is observed between the peak in maximum temperature rise and the strain at the experimentally determined ultimate tensile strength. A microstructure based explanation for this will be presented. The results are discussed in reference to using this technique for detection and evaluation of plastic deformation.

Detection and Prediction of Creep-Damage of Copper Using Nonlinear Acoustics Technique

---Valluri Jitendra, **Krishnan Balasubramaniam**, and Raghu Prakash, Centre for Non destructive Evaluation, Department of Mechanical Engineering, Indian Institute of Technology Madras, Chennai-36, India

---This paper describes the nonlinear acoustic technique for characterization of material degradation and remaining life assessment of crept sample of copper 99.98 % pure. Specimens of this material were subjected to creep testing at different stress levels. Creep tests were periodically interrupted at different creep life fractions to conduct transmission ultrasonic tests and then analyzing receiving amplitude in the frequency domain, here in frequency domain we observed harmonics and also extract static displacement component. For all of the experiments, no noticeable change in longitudinal velocity in the same specimens with change of degradation was observed. Finally, we observe that nonlinear response enhanced where the damage is more locally accumulated and it is confirmed by the metallography, also we correlated the nonlinear response with time based creep life fraction, from this result we can able to predict remaining life of material systems.

Nonlinear Acoustics and Microstructural Evolution During Creep in Cr-Mo-V Steel

---**Toshihiro Ohtani** and Tomonori Ogawa, Shonan Institute of Technology, Department of Mechanical Engineering,Fujisawa, Kanagawa, Japan

---A nonlinear acoustic measurement is studied for creep damage evaluation. An electromagnetic acoustic transducer (EMAT) magnetostrictively couples to a surface-shear-wave resonance along the circumference of a cylindrical specimen during the creep of Cr-Mo-V steels. The excitation of the EMAT at half of the resonance frequency caused a standing wave to contain only the second-harmonic component, which was received by the same EMAT for determining the second-harmonic amplitude. This measured surface-wave nonlinearity showed a peak at 30% and a minimum at 50% of the total life. We interpreted these phenomena in terms of dislocation mobility and restructuring, with support from scanning electron microscope (SEM) and transmission electron microscope (TEM) observations. This noncontact resonance-EMAT measurement can monitor the evolution of surface-shear-wave nonlinearity throughout creep life and has a potential to assess damage advance and predict the creep life of metals.

Monitoring Fatigue Crack Growth in Multi-Layered Tensile Specimens Using Guided Ultrasonic Waves

---**E. Kostson** and P. Fromme, Department of Mechanical Engineering, University College London, London WC1E 7JE, United Kingdom

---Varying loading conditions of aircraft lead to stress concentration at fasteners, connecting multi-layered components, where fatigue cracks can develop. This contribution presents a study of the excitation of guided ultrasonic wave modes in multi-layered tensile specimens and their application for monitoring fatigue crack growth at fastener holes in the 2nd layer of such structures. The model multi-layered structure investigated consists of two adhesively bonded aluminum plate-strips. Semi-analytical Finite element (SAFE) calculations show that multiple guided wave width modes can propagate below the cut-off frequency of higher order thickness modes. The lowest flexural width mode is similar to the A0 mode in an infinite plate with relative constant amplitude across the width. 3D Finite-Element (FE) simulations were performed to study the selective excitation of this mode. Experimentally this was done by bonding multiple piezoelectric discs to the surface of the specimen. Fatigue experiments were carried out and the sensitivity of the guided wave mode to monitor fatigue crack growth in the 2nd layer of the model structure was investigated. Changes in the amplitude of the ultrasonic signal due to fatigue crack growth show good agreement with 3D FE simulations.

Identifying Fracture Origin in Ceramics by Combination of Nondestructive Testing and Discrete Element Analysis

---**Rajeev Senapati** and Jianmei Zhang, The University of Texas at El Paso, Industrial Engineering Department, El Paso, TX 79968

---Advanced ceramic materials have been extensively applied in aerospace, automobile and other industries. However, the reliability of the advanced ceramics is a major concern because of the brittle nature of the materials. In this paper, combination of nondestructive testing and numerical modeling Discrete Element Method (DEM) is proposed to identify the fracture origin in ceramics. The nondestructive testing – laser scattering technology is first performed on the ceramic components to reveal the machining-induced damage such as cracks and the material-inherent flaws such as voids, then followed by the four point bending test. DEM software package PFC2D is used to simulate the four point bending test and try to identify where the fractures start. The numerical representation of the ceramic materials is done by generating a densely packed particle system using the specimen genesis procedure and then applying the suitable microparameters to the particle system. Simulation of four point bending test is performed on materials having no defects, materials having manufacturing-induced defects like cracks, and materials having material-inherent flaws like voids. The initiation and propagation of defects is modeled and the mean contact force on the loading ball is also plotted. The simulation prediction results are well in accordance with the nondestructive testing results.

Eddy Current Probe Impedance Due to Edge Cracks

---**John R. Bowler**[1] and T. Theodoulidis[2], [1]Center for NDE and Department of Electrical and Computer Engineering, Iowa State University, Ames, IA 50011; [2]Department of Mechanical Engineering of the University of Western Macedonia, Kozani, Greece

---A numerical scheme has been used to calculate eddy current coil signals due to edge cracks. The calculation reflects that of a typical scattering problem in which the incident field is found first, then the perturbed field. An efficient way of finding the flaw field is to start with a representation of the field of a point flaw in the form of a current dipole. Then the field of an extensive defect is expressed as a supposition of current dipoles. In the case of a crack, this can be done using a distribution of current dipoles over the surface of the crack. The main innovation of the current work is that the dipole field is determined for a point source near a corner. Consequently, only the flaw region is made discrete in the when flaw signal is calculated. We consider two cases of planar cracks at a right angled corner formed at the intersection of a vertical and horizontal surface. In the first case, the crack is in a plane parallel to the vertical surface and bounded by the horizontal surface. This is the transverse crack. In the second case it is perpendicular to and bounded by both horizontal and vertical surfaces. This is the longitudinal crack. The names stem from the fact that we choose a reference direction normal to the vertical surface and designate cracks as transverse if the crack plane is perpendicular to this direction and longitudinal if the preferred direction is parallel to the crack plane. The approach allows numerical estimates of the probe signal to be calculated using boundary or volume elements. Here, a boundary element calculation has been used to determine the crack field. The coil response is then calculated from the crack field.---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.

Session 23

SESSION 23

NDE IN DESIGN, MANUFACTURING, AND PROCESS CONTROL

M. Kreutzbruck, Chairperson
Chafee 273

1:30 PM **Ultrasonic Immersion C-Scan Imaging Technique: A Tool for Evaluating & Optimizing EMS Parameters for Continuously Cast Steel Billet Quality**
---**M. Raj**, J. Haldar, P. P. Sahoo, S. K. Choudhary, and J. C. Pandey, Tata Steel Ltd., Jamshedpur, Jharkhand, India 831 001

1:50 PM **Evolution of the Ultrasonic Inspection Requirements of Heavy Rotor Forgings Over the Last Decades**
---**J. L. Vrana**, K. P. Bailey, R. P. Angal, and P. J. Zombo, Siemens Energy, MC Q3-031, 4400 N. Alafaya Trail, Orlando, FL 32826; A. Zimmer, Saarschmiede GmbH Freiformschmiede, Bismarkstraße 57-59, D-66333 Völklingen, Germany; U. Büchner and W. Herinrich, Siemens Energy, Huttenstraße 12, D-10553 Berlin, Germany; A. Buschmann, Siemens Energy, Mellinghofer Str. 55, D-45473 Mülheim an der Ruhr, Germany

2:10 PM **Development of Ultrasonic Inspections of Heavy Rotor Forgings Over the Last Decades**
---**A. Zimmer**, J. Meiser, and N. Blaes, Saarschmiede GmbH Freiformschmiede, Bismarkstraße 57-59, D-66333 Völklingen, Germany; J. Vrana, Siemens Energy, MC Q3-031, 4400 N. Alafaya Trail, Orlando, FL 32826

2:30 PM **Electric Real-Time Wire Bond Quality Control**
---R. Kurppa[1], H. Seppänen[1,2], A. Meriläinen[1], M. Oinonen[3], and **E. Haeggström**[1,2], [1]University of Helsinki, Department of Physics, Helsinki, Finland; [2]Helsinki Institute of Physics, Helsinki, Finland; [3]University of Helsinki, Dating Laboratory, Helsinki, Finland

2:50 PM **Ultrasonic Process Monitoring Technology for Tank Mixing of Solids Suspensions**
---**K. M. Denslow**, M. S. Greenwood, G. P. Morgan, R. A. Pappas, D. F. Hopkins, L. J. Kirihara, C. J. Flynn, B. K. Hatchell, and P. A. Meyer, Pacific Northwest National Laboratory, Physical and Chemical Sciences Division, Richland, WA 99354

3:10 PM ***Break***

3:30 PM **Using Matrix Transducer for Ultrasonic Evaluation of Screw-Sheet Projection Welds**
---A. Ambroziak and **M. Korzeniowski**, Wroclaw University of Technology, Mechanical Department, Wroclaw, Poland; R. Gr. Maev and F. Severin, University of Windsor, Physics Department, Windsor, Ontario, Canada; A. Denisov, Tessonics Inc., Windsor, Ontario, Canada

3:50 PM **Real-Time Ultrasonic Expulsion Detection and Indentation Measurement in Resistance Spot Welds**
---R. Gr. Maev, A. M. Chertov, and **A. Karloff**, University of Windsor, Physics Department, Institute for Diagnostic Imaging Research, Windsor, Ontario, Canada

4:10 PM **In-Line Ultrasonic Investigation of Spot Weld Quality Using Multi-Transducer Set-Up**
---**P. Kustroń**, J. Kocimski, A. M. Chertov, S. Titov, and R. Gr. Maev, University of Windsor, Physics Department, Institute for Diagnostic Imaging Research, Windsor, Ontario, Canada;
P. Kustroń, J. Kocimski, and A. Ambroziak, Wroclaw University of Technology, Mechanical Department, Institute of Production Engineering and Automation, Welding Division, Wroclaw, Poland

4:30 PM **Portfolio of Potential Strategies in Aeronautic Maintenance**
---**S. Rolet**, EADS France, Innovation Works-Structural Health Engineering, Toulouse, France

4:50 PM **Nondestructive Evaluation of Aerospace Parts Using Process Compensated Resonant Testing (PCRT)**
---**S. Singh**, NDT Engineering, M & PE, Honeywell Aerospace, Phoenix, AZ 85034; L. Jauriqui and T. Sloan, Vibrant Corporation, 3801 Academy Parkway NE, Albuquerque, NM 87109; D. Piotrowski, Delta Air Lines, Technical Operations, Atlanta, GA 30320

Ultrasonic Immersion C-Scan Imaging Technique: A Tool for Evaluating & Optimizing EMS Parameters for Continuously Cast Steel Billet Quality

---**Manish Raj**, J. Haldar, P. P. Sahoo, S. K. Choudhary, and J. C. Pandey, Tata Steel Ltd., Jamshedpur, Jharkhand, India 831 001

--- Ultrasonic C-scan images obtained through an automatic computerized multi-scan immersion ultrasonic system has been used for as a tool for evaluating and obtaining optimum electromagnetic stirrer (EMS) parameters i.e. current and frequency, installed at LD#1 CC#1 billet caster, TATA STEEL Ltd., India. The ultrasonic amplitude and positional data were integrated and controlled by a PC-based ultrasonic equipment. The defect size and area in C-scan image were calculated automatically by labeling and clustering algorithm, of which results showed a good correlation to the condition of actual defects. Continuously cast steel billet slices of low carbon (LC Grade-A) and high carbon (HC Grade-A) were selected for experimental trials. The experiments conducted with various current and frequency combinations revealed that in general, quality of billets improved with increasing EMS current in all grades of steel considered in the present work. The most significant improvement was found at 280 ampere EMS current and frequency 3.5 Hz. Beyond this there was only a marginal improvement in the billet quality as well as equiaxed zone. Based on the experimental observations, it is recommended to operate EMS at 280A current and EMS frequency should not increase beyond 4 Hz in the plant.

Evolution of the Ultrasonic Inspection Requirements of Heavy Rotor Forgings Over the Last Decades

---**J. L. Vrana**, K. P. Bailey, R. P. Angal, and P. J. Zombo, Siemens Energy, MC Q3-031, 4400 N. Alafaya Trail, Orlando, FL 32826; A. Zimmer, Saarschmiede GmbH Freiformschmiede, Bismarkstraße 57-59, D-66333 Völklingen, Germany; U. Büchner and W. Herinrich, Siemens Energy, Huttenstraße 12, D-10553 Berlin, Germany; A. Buschmann, Siemens Energy, Mellinghofer Str. 55, D-45473 Mülheim an der Ruhr, Germany

---Heavy rotor forgings for land based power generation turbines are inspected ultrasonically. Several decades ago the first inspections were conducted using manual, straight beam, contact transducers with simple, non-descript reporting requirements. The development of ultrasonic inspection capabilities, the change of design engineer requirements, improvements of design engineer calculations, experience with the operation of turbines, experience with the inspcetion technology, and propability of detection drove the change to the current day inspection requirements: sizing technologies were implemented, detection limits were lowered, angle and pitch catch scans were introduced, automated equipment for the inspection was required. Due to all those changes model based sizing techniques, like DGS, and modern ultrasonic techiques, like phased array, could be introduced globally. This paper describes this process over the last decades and presents an outlook for tomorrow.

Development of Ultrasonic Inspections of Heavy Rotor Forgings Over the Last Decades
---**A. Zimmer**, J. Meiser, and N. Blaes, Saarschmiede GmbH Freiformschmiede, Bismarkstraße 57-59, D-66333 Völklingen, Germany; J. Vrana, Siemens Energy, MC Q3-031, 4400 N. Alafaya Trail, Orlando, FL 32826

---All types of heavy forgings that are used in energy machine industry, rotor shafts as well as discs, retaining rings etc. are subject to extensive nondestructive inspections before delivery. Due to the availability of the parts in simple shapes, these forgings are well suited for volumetric inspections using ultrasound. In the beginning, these inspections were carried out manually, using straight beam probes and analogue equipment. Higher requirements in reliability, efficiency and safety in the machines have lead to higher requirements for the ultrasonic inspection in the form of more scanning directions, higher sensitivity demands and improved documentation. This and the increasing use of high alloy materials for ever growing parts, increase the need for more and more sophisticated methods for testing the forgings. Angle scans and sizing technologies like DGS have been implemented, and for more than 15 years now, mechanized and automated inspections have gained importance since they allow better documentation as well as easier evaluation of the recorded data using different views, projections or tomography views. The latest major development has been the availability of phased array probes to increase the flexibility of the inspection systems. Many results of the ongoing research in ultrasonics have not been implemented yet. Today's availability of fast computers, large and fast data storage allows to save RF inspection data and apply sophisticated signal processing methods. For example linear diffraction tomography methods like SAFT permit 3D reconstruction of UT data, simplifying sizing and locating of defects as well as for improving SNR, a method that has been under development for many years. Such methods are still to be implemented in the steel industry. This paper describes the development of the ultrasonic inspection of heavy forgings from the beginning up to today at the example of Saarschmiede and gives an outlook over the current progression.

Electric Real-Time Wire Bond Quality Control
---Risto Kurppa[1], H. Seppänen[1,2], Antti Meriläinen[1], Markku Oinonen[3], and **Edward Haeggström**[1,2], [1]University of Helsinki, Department of Physics, Helsinki, Finland; [2]Helsinki Institute of Physics, Helsinki, Finland; [3]University of Helsinki, Dating Laboratory, Helsinki, Finland

---We present a real-time nondestructive electrical method for wire bond process control and microelectric wire bond strength prediction. We measure, during the ultrasonic bonding process, the contact resistance (CR) of the wire bond. A custom-built setup measures the CR between the bond wire and the bond pad at 10MHz sampling rate. Several bond development phases are visible in the real-time CR signal: Touchdown, surface cleaning, contact development and achieving the fully developed bond. We show that the CR signal of the most critical wire bond process phases, surface cleaning and contact development can be used to quantitatively estimate the contact area and thus predict the pull force development of the contact. We propose the method for real-time wire bond quality monitoring. We envision that the method can provide feedback for automatic bond process parameter tuning during the bonding process.

Ultrasonic Process Monitoring Technology for Tank Mixing of Solids Suspensions

---**Kayte M. Denslow**, Margaret S. Greenwood, Gerald P. Morgan, Richard A. Pappas, Derek F. Hopkins, Leslie J. Kirihara, Connor J. Flynn, Brian K. Hatchell, and Perry A. Meyer, Pacific Northwest National Laboratory, Physical and Chemical Sciences Division, Richland, WA 99354

---During scaled testing in support of the Hanford Waste Treatment and Immobilization Plant (WTP), three advanced ultrasonic process monitoring technologies developed at DOE Pacific Northwest National Laboratory (PNNL) were utilized during geometrically scaled mixing/mobilization testing to perform non-disruptive, real-time measurements to satisfy the following measurement requirements: a. Measure the vertical solids distribution inside the mixing vessel; b. Determine when solids off-bottom suspension has been achieved; c. Measure solids accumulation on the vessel bottom. The three ultrasonic technologies applied were an attenuation method for solids concentration, an Ultrasonic Doppler velocimeter for particle suspension and a pulse-echo method to measure the boundary between mobilized and non-mobilized solids. The complementary measurements from all three systems were performed in real time, and these data were used to assess mixing performance under broad ranges of test conditions. The tests provided measurements of: critical mixer parameters for complete solids suspension, the solids concentration profile, the opaque peak solids cloud height as a function of geometric parameters, operating parameters and simulant properties. The test data were used to develop new mixing models for both complete suspension velocity and solids concentration near the tank bottom to predict full-scale performance WTP mixing system designs.

Using Matrix Transducer for Ultrasonic Evaluation of Screw-Sheet Projection Welds

---Andrzej Ambroziak and **Marcin Korzeniowski**, Wroclaw University of Technology, Mechanical Department, Wroclaw, Poland; Roman Gr. Maev and Fedar Severin, University of Windsor, Physics Department, Windsor, Ontario, Canada; Alexey Denisov, Tessonics Inc., Windsor, Ontario, Canada

---Ultrasonic testing of spot welds joined by resistance spot welding is commonly used in automotive industry. Commercially produced by Tessonics Inc., RSWA (Resistant Spot Weld Analyzer) device was developed for nondestructive evaluation of the nugget size of the resistant spot welds. It provides a good performance for standard spot welds and precise measurement of a nugget diameter. The idea was to try to use 2D array system based on RSWA platform and adapt it for a specific purpose which is testing projection welds screw-sheet. The preliminary studies on applying matrix array transducer for estimation quality of screw-sheet and nut-sheet projection welds were performed. The preliminary studies on applying matrix array transducer for estimation quality of screw-sheet and nut-sheet projection welds. Current array covers a round area of 10 mm in diameter and projection weld is 20 mm in diameter of screw. Therefore, the acoustic image of the whole projection weld is obtained by overlapping of several individual scans. The final image was assembled from the recorded C-scans with their digital superposition.

Real-Time Ultrasonic Expulsion Detection and Indentation Measurement in Resistance Spot Welds

---R. Gr. Maev, A. M. Chertov, and **A. Karloff**, University of Windsor, Physics Department, Institute for Diagnostic Imaging Research, Windsor, Ontario, Canada

---The thickness of a resistance spot weld resulting from electrode indentation is an important quality control parameter for estimating the final nugget diameter and identifying the occurrence of expulsion. An ultrasound transducer has been installed in a welding electrode allowing for evaluation of a spot weld during welding, using echo pulses. In such a system, the unknown increase in temperature during welding increases time of flight through the weld, while geometric contraction of the plates decreases it. These opposing effects often give false representations of the true weld thickness. This paper proposes a novel method of separating these effects. This is done using signal and image processing of successive A-scans to identify the solid-liquid nugget interface, where the melting temperature of the material is known. This paper demonstrates how the final weld thickness can be determined very accurately at the point in time when the nugget completely solidifies. It can also be shown that excessive indentation accompanied by a sudden decrease in time-of-flight during welding can be used to determine if an expulsion has occurred.

In-Line Ultrasonic Investigation of Spot Weld Quality Using Multi-Transducer Set-Up

---**Paweł Kustroń**, Janusz Kocimski, Andriy M. Chertov, Sergey Titov, and Roman Gr. Maev, University of Windsor, Physics Department, Institute for Diagnostic Imaging Research, Windsor, Ontario, Canada; Paweł Kustroń, Janusz Kocimski, and Andrzej Ambroziak, Wroclaw University of Technology, Mechanical Department, Institute of Production Engineering and Automation, Welding Division, Wroclaw, Poland

---This article presents one of the most recent developments in real-time ultrasonic quality control methods for resistance spot welds. Currently used in-line system uses single-element transducer to characterize the spot weld quality. The solution presented in this paper makes another step forward towards improvement of accuracy of measurements using array of ultrasonic transducers. Spot welding process is very sensitive to various disturbances. Some of the most common are current variations, surface roughness, organic and oxide coverings, surface contaminations. These cause instabilities in the nugget growth. Such disturbances occur randomly and affect the geometry of the melted zone, it's crystallization and final shape of the welding nugget. For that reason, study of wave propagation through the growing spot weld is very important for development of in-line ultrasonic quality monitoring systems. In this paper authors present some results of in-line ultrasonic quality monitoring using multi-transducer system. It is based on 8 ultrasonic transducers placed in one line above the center of the spot weld. Such solution allows observe some geometrical properties of the nugget and possible flaws of the growing spot weld. This research provides important information about the behavior of nugget growth during spot welding including the influence of the transducer positioning on information obtained from monitoring process.

Portfolio of Potential Strategies in Aeronautic Maintenance

---**Sebastien Rolet**, EADS France, Innovation Works-Structural Health Engineering, Toulouse, France

---EADS divisions aim more and more at developing services associated to their platforms. EADS divisions, like Airbus and Eurocopter, are investigating on services associated to their platforms in order to add them value. One possible service consists in structural maintenance operation assistance, especially for NDT operations performed by the customer. EADS Innovation Works envisages three different and complementary enhanced structural maintenance categories. First category, called Enhanced NDT, improves standard NDT operation environment. This is made possible by the existence of “smart” NDT tools that are computer based and therefore able to support other functions. These functions range from local smart data processing and display to remote expert assisted operation. Second category, called Passive Sensor Network, relies on sensors permanently installed on aircraft structure. Interrogation of sensors is performed on ground and off line (while structure is not loaded except by its own weight). It can be done at arbitrary times in order to determine structure health. The aim is to give easy access to some hidden “hot spots”, to reduce human factor in structure health assessment and optimize maintenance. Third category, Structural Health Monitoring, goes a step beyond Passive Sensor Network, because interrogation units are on board the aircraft and may be connected to aircraft network. It allows on-line techniques such as acoustic emission and automatic alarm when a defect appears in the structure. This paper presents these different ways of improving structural maintenance operations in service, with their respective advantages and limitations.

Nondestructive Evaluation of Aerospace Parts Using Process Compensated Resonant Testing (PCRT)

---**Surendra Singh**, NDT Engineering, M & PE, Honeywell Aerospace, Phoenix, AZ 85034; Leanne Jauriqui and Trista Sloan, Vibrant Corporation, 3801 Academy Parkway NE, Albuquerque, NM 87109; David Piotrowski, Delta Air Lines, Technical Operations, Atlanta, GA 30320

---The current NDT methods often provide partial inspection results and require additional inspections such as focused/directed when used to inspect aerospace parts. For example, emerging SONIC IR has been found suitable to detect tight cracks (under compressive stress) when traditional PT, UT, and ET methods had limited success. Similarly, it is both time consuming and cost- prohibitive to inspect ceramic balls using UT method whereas using an alternative emerging such as Process Compensated Resonant Testing (PCRT)it is possible to inspect each ceramic ball in less than one minute. PCRT has been reported an excellent alternative to study diverse and complex aerospace parts that can’t be studied otherwise. In this study, we have used PCRT for studying structural integrity and functional performance in a wide range of aerospace parts used on various Auxiliary Power Units and Propulsion Engines. The parts include different ceramic balls, bonded parts, and blades. The PCRT is a whole body inspection and provides an assessment for structural integrity in terms of cracks, voids, shifted cores, heat treatments, etc. and performance of parts. The parts with accepted structural integrity and performance are separated from parts with manufacturing and structural and/ or material deficiencies. The results from this study show that PCRT has been found successful in sorting acceptable parts from rejected parts based on materials/structural integrity, dimensional tolerance, and functional performance or service induced defects such as micro-structural changes, cracks, inter-granular attack (IGA), and excessive wear, etc. PCRT is successful in sorting acceptable parts from those unacceptable, though it suffers from limitations. It is generally not capable of determining the type, size or location of the anomaly or cause for rejections. The pursuit of progressive improvements in the usage of PCRT, like any other NDT methods, is an on-going process.

Session 24

Session 24
SPECIAL EVENING SESSION
CBLS 100

8:00 PM Current Research at Federal Highway NDE Center

---**Frank Jalinoos**, Program Manager, FHWA NDE Center, Federal Highway Administration, Office of Infrastructure R&D, HRDI-10, 6300 Georgetown Pike, McLean, VA 22101

---Current research at FHWA NDE Center will be discussed. This includes discussions on the use of NDE technologies for inspection of steel and concrete bridges as well as structural health monitoring of transportation facilities.

THURSDAY

THURSDAY, JULY 30, 2009

	Session 25 **POD I** ***Chafee 277***	**Session 26** **Sensors and Transducers** ***CBLS 010***	**Session 27** **UT Phased Arrays I** ***CBLS 100***	**Session 28** **Model-Based Inversion** ***Chafee 273***
8:30 AM				
8:50				
9:10				
9:30				
9:50				
10:10	COFFEE BREAK			
10:30				
10:50				
11:10				
11:30				
11:50				
12:10 PM	LUNCH			

Session 29 – POSTERS – 1:30 – 3:10 PM – Memorial Union Ballroom

	Session 30 **POD II** ***Chafee 277***	**Session 31** **X-Ray and T-Ray** ***Chafee 273***	**Session 32** **NDE for Microstructure** ***CBLS 010***	**Session 33** **UT Phased Arrays II** ***CBLS 100***
3:10	COFFEE BREAK			
3:30				
3:50				
4:10				
4:30				
4:50				
5:10				
5:30	ADJOURN			

Session 25

SESSION 25
PROBABILITY OF DETECTION I
E. Lindgren, Chairperson
Chafee 277

8:30 AM **Challenges in Modeling for Probability of Detection, Location, and Characterization Determination in Aircraft**
---**E. A. Lindgren**, Air Force Research Laboratory, Materials and Manufacturing Directorate, Nondestructive Evalution Branch, WP AFB, OH 45433

8:50 AM **Development and Validation of Model Assisted Probability of Detection Method**
---**D. S. Forsyth**, Texas Research Institute Austin, NDE Division, Austin, TX 78733; J. C. Aldrin, Computational Tools, Gurnee, IL 60031; I. Gray, NDE Technologies Inc., Charlottesville, VA22911; R. B. Thompson, Iowa State University, Center for NDE, Ames, IA 50011

9:10 AM **Progress in Development of a Transfer Function for Angle Beam Ultrasonic Inspections**
---**J. D. Heebl** and E. A. Lindgren, Air Force Research Laboratory, Materials and Manufacturing Directorate, Non Destructive Evaluation Branch, Wright Patterson Air Foce Base, OH 45433

9:30 AM **A Parametric Study of Eddy Current Response for Probability of Detection Estimation**
---**W. C. Hoppe**, University of Dayton Research Institute, Structural Integrity Division, 300 College Park Avenue, Dayton OH 45469-0120

9:50 AM **Model Based POD Techniques for Enhancing Reliability of SG Inspection**
---**Y. Deng**, X. Liu, L. Udpa, and S. S. Udpa, NDE Laboratory, Department of Electrical and Computer Engineering, Michigan State University, East Lansing, MI 48824

10:10 AM ***Break***

10:30 AM **Statistical Study of ECT Detection Around Fasteners Using Simulation Based POD Curves**
---C. Reboud, **G. Pichenot**, S. Paillard, and F. Jenson, Laboratoire de Simulation et de Modélisation, CEA Saclay, DRT/DETECS/SYSSC, Bâtiment 611, Point courrier 120, 91191 Gif-sur-Yvette Cedex, France

10:50 AM **POD Generator Project: A Numerical Assessment of the Inspection of Fatigue Cracks Using TOFD**
---J. Bloom, U. Stelwagen, A. Mast, and **A. Volker**, TNO Science and Industry, Stieltjesweg 1, P.O. Box 155, 2600 AD Delft, Netherland

11:10 AM **Modeling of the Sources of Signal Fluctuations to Determine the Reliability of Ultrasonic Non-Destructive Methods**
---**F. Jenson** and E. Lakovleva, CEA, LIST, SYSSC, F-91191 Gif-sur-Yvette, France

11:30 PM ***Lunch***

Challenges in Modeling for Probability of Detection, Location, and Characterization Determination in Aircraft

---**Eric A. Lindgren**, Air Force Research Laboratory, Materials and Manufacturing Directorate, Nondestructive Evaluation Branch, WP AFB, OH 45433

---The desire to use Condition-based Maintenance to manage US Air Force Aircraft can be realized with improved nondestructive sensing methods to characterize damage. This knowledge is important to determine when maintenance is required. This includes the use of sensing methods either off-board, typically described as traditional NDE, or on-board as a component of Structural Health Monitoring. As damage characterization in an aircraft structural component typically becomes an ill-posed inverse problem, assessing the accuracy of these methods requires an expansion of typical probability of detection methods to include the additional parameters of location and size. This would be very difficult via empirical methods, which has become an additional motivating factor for incorporating modeling into the assessment of a damage characterization technique. In addition, variability in aircraft as a function of design, manufacture, maintenance, repair, modification, and usage needs to be integrated into the assessment, further complicating the model-assisted evaluation. This presentation reviews several possible approaches for addressing these challenges and discusses several advantages and disadvantages of these approaches.

Development and Validation of Model Assisted Probability of Detection Method

---**David S. Forsyth**, Texas Research Institute Austin, NDE Division, Austin, TX 78733; John C. Aldrin, Computational Tools, Gurnee, IL; Irving Gray, NDE Technologies Inc., Charlottesville, VA; R. Bruce Thompson, Iowa State University, Center for NDE, Ames, IA 50011

---TRI/Austin in collaboration with Computational Tools, NDE Technologies Inc., and the Iowa State University Center for NDE have completed a Phase I SBIR-funded program to develop and validate the technologies required to implement Model-Assisted Probability of Detection (MAPOD) for a problem set of interest to the Air Force. We will present the results of this Phase I effort. There were three primary areas of effort: assessment of available ultrasonic models for the target problem, collection of ultrasonic inspection data for model validation, and MAPOD process definition and documentation. The primary target problem is fatigue cracks nucleated at holes. This configuration potentially exists at any fastener hole, as well as other structural elements typical of aircraft design such as lugs. Numerous models, both commercially available softwares and research codes presented in the literature, were evaluated for their capability to model the relevant ultrasonic features of this class of problem. Simple specimens were constructed and inspected to generate a library of validation ultrasonic data. Finally, a software framework will be presented that provides a complete set of capabilities required for implementation of MAPOD as a more cost-efficient POD estimation method.

Progress in Development of a Transfer Function for Angle Beam Ultrasonic Inspections

---**Jason D. Heebl** and Eric A. Lindgren, Air Force Research Laboratory, Materials and Manufacturing Directorate, Non Destructive Evaluation Branch, Wright Patterson Air Foce Base, OH 45433

---A significant concern for the US Air Force (USAF) is the aging of its fleet and, subsequently, the potential for an increase in the number of inspections required to ensure the safety of these aircraft. In particular, the inspection of bolt holes at locations of high stress is a recurring inspection requirement. Typically, when not removing fasteners, a 45 degree angle beam shear wave ultrasonic (UT) inspection is used for detecting fatigue cracks at these sites. The implementation of new inspections usually requires a capability demonstration. This is commonly performed using representative damage in representative structures. It is very common to use electric discharge machined (EDM) notches to represent fatigue cracks in capability studies to decrease the time and cost of such studies. A limitation of this approach is that sensitivity will vary as a function of damage type. Therefore, a mathematical relationship needs to be developed that establishes the relationship between the responses from EDM notches and grown fatigue cracks. This will enable EDM notched samples to be used to validate new inspections. An immersion ultrasonic tank was used to perform inspections on both EDM notched samples and multiple fatigue cracked coupons using the 45 degree angle beam ultrasonic technique. Both sample sets had a range of crack dimensions. The empirical data was analyzed to develop a mathematical transfer function that correlates the amplitude response from the EDM notches with those from grown fatigue cracks.

A Parametric Study of Eddy Current Response for Probability of Detection Estimation

---**Wally C. Hoppe**, University of Dayton Research Institute, Structural Integrity Division, 300 College Park Avenue, Dayton, OH 45469-0120

---Conventional “a-hat versus a” Probability of Detection (POD) analysis uses statistical approaches to determine the best curve to explain the response of an inspection (a-hat) as a function of the defect size (a). For a linear fit, the slope, the intercept and the standard deviation of the residuals about the fit define an empirical model describing the behavior of the system to the defects in question. Historically, POD experiments have simply measured POD and have done little to understand or predict the values of these parameters. Recently, a number of studies have attempted to predict POD by modeling inspection responses from either first principles or by creating transfer functions from notches to cracks in the same material or between cracks in different materials and/or geometries. In the study reported here, historical POD data for eddy current inspections were analyzed using an extension of the “a-hat versus a” model in order to better account for known crack variables and thereby better separate system and crack factors influencing the POD parameters. Intriguing insights have been gained in the process suggesting a simplified model for POD estimation. The parametric model will be presented including results of the study and suggestions for further research.

Model Based POD Techniques for Enhancing Reliability of SG Inspection

---Y. Deng, X. Liu, L. Udpa, and S. S. Udpa, NDE Laboratory, Department of Electrical and Computer Engineering, Michigan State University, East Lansing, MI 48824

---In Eddy current systems for inspection of SG tubes in nuclear power plants its ability to detect critical flaws is quantified in terms of probability of detection (POD) and observed confidence bounds. Limitations of different nondestructive inspection techniques and inspector variability often lead to false rejections and false acceptance errors. Further, uncertainties in operational parameters, such as probe geometry, liftoff, probe wobble, material properties and flaw orientation lead to a spread in signal strength for the same nominal flaw size. Quantitative knowledge of the signal spread due to these variabilities and uncertainties in inspection parameters can help operators rationalize their decision strategy. Simulation models can serve as the means by which effects of uncertainties on signal strength are studied and trended. Once the statistical distribution of signal amplitude is established using numerical computations, the Probabilities of detection and false calls can be estimated by integrating the signal distribution within the acceptance range. Results of estimating the POD of axial ODSCCs using bobbin coil probe is conducted using a three dimensional finite element model.

Statistical Study of ECT Detection Around Fasteners Using Simulation Based POD Curves

--- C. Reboud, **G. Pichenot**, S. Paillard, and F. Jenson, Laboratoire de Simulation et de Modélisation, CEA Saclay, DRT/DETECS/SYSSC, Bâtiment 611, Point courrier 120, 91191 Gif-sur-Yvette Cedex, France

--- Eddy current testing (ECT) is widely used in aeronautics for the monitoring of riveted structures. A main objective in this application is the detection of small flaws located in the vicinity of a much bigger rivet. This paper presents the results of a statistical study carried out using the simulation software CIVA and focused on the ECT detection of flaws located around fastener. Performance of several probe configurations is assessed using probability of detection (POD) curves. The ECT configuration studied consists in a small flaw located at the bottom of a rivet that holds two non-magnetic sheets together. The time efficiency of the volume integral method used in simulation makes it well-suited to the large number of calculations required when estimating POD curves. Two POD estimations have been compared in this work: the so-called a versus â method that uses the signal amplitude and another method using binary hit/miss data. In both cases perturbations due to small lift off and tilt variations are taken into account in simulation through random distributions. The relevance of the parametric forms assumed as well as further developments regarding POD determination in CIVA are finally discussed.

POD Generator Project: A Numerical Assessment of the Inspection of Fatigue Cracks Using TOFD

---Joost Bloom, Uilke Stelwagen, Arjan Mast, and **Arno Volker**, TNO Science and Industry, Stieltjesweg 1, P.O. Box 155, 2600 AD Delft

---Risk based inspection strategies rely on detailed knowledge of the performance of inspection techniques. The objective of the "POD generator" project is to develop a numerical modeling approach to assess effectiveness of specific inspection techniques. Simulation offers flexibly and reliability at acceptable costs. Therefore numerical models have been developed and validated for accurately simulating the physics of inspection techniques. These numerical models are then used to generate quantitative probability of detection (POD) curves. In the case of ultrasonic time-of-flight-diffraction (TOFD) inspections, the human factor is included on two levels. First in the way a TOFD scan is carried out (positioning variations). And secondly, in the fact that simulated inspection results are interpreted by real operators. This paper shows the assessment of the inspection of fatigue cracks using TOFD using this numerical approach. The influence of high-low, gas inclusions and the human interpretation on the performance of the inspection was investigated by generating multiple POD-curves under different circumstances. This way we show that the numerical modeling approach is an efficient and reliable way of determining the required effort to inspect welds for fatigue cracks under different circumstances.

Modeling of the Sources of Signal Fluctuations to Determine the Reliability of Ultrasonic Non-Destructive Methods

---**Frederic Jenson** and Ekaterina Lakovleva, CEA, LIST, SYSSC, F-91191 Gif-sur-Yvette, France

---It is common practice to quantify inspection reliability in terms of the Probability Of Detection (POD) and the Probability of False Alarm (PFA). The determination of these statistical indicators is currently based on very costly and time consuming empirical studies. Physic-based models are now available to replace part of the experimental data with simulation results. This paper proposes a methodology exploiting existing modelling tools (here CIVA models) to simulate POD curves. First, the model inputs are defined using statistical distributions in place of deterministic nominal values. For more complex material-related noise and fluctuation sources, specific algorithms are proposed. For instance, ultrasonic grain noise is computed using a noise generator based on a single scattering approximation. In the next step, realistic values for the inspection output are obtained using a sampling approach. This step requires the computation of the physical model for a set of random values for the input parameters. Finally, a functional form is assumed for the POD curve and the related parameters are estimated from the simulation results. This paper also describes applications of this methodology to realistic ultrasonic inspection setups.

Session 26

SESSION 26
SENSORS AND TRANSDUCERS
A. Lhémery, Chairperson
CBLS 010

8:30 AM **Development of Corrosion Sensors for Aircraft IVHM Systems**
---**D. A. Scott**, D. C. Price, G. C. Edwards, and A. B. Batten, CSIRO Materials Science and Engineering, Lindfield, NSW, Australia; T. H. Muster, P. Corrigan, and I. S. Cole, CSIRO Materials Science and Engineering, Clayton, VIC, Australia

8:50 AM **Ultrasonic Waveguide Sensor Using a Leaky Lamb Wave for Under-Sodium Viewing**
---**Y.-S. Joo** and J.-H. Lee, Fast Reactor Development, Korea Atomic Energy Research Institute, 150-1 Dukjin-dong, Yuseong, Daejeon, Korea

9:10 AM **Pulsed Electromagnet EMAT for High Temperatures**
---**F. Hernandez-Valle** and S. Dixon, University of Warwick, Department of Physics, Coventry, West Midlands, United Kingdom

9:30 AM **Modelling of Electromagnetic Acoustic Transducers Operating on Ferromagnetic Materials**
---**R. Ribichini**, F. Cegla, and P. Cawley, Imperial College, UK Research Centre in NDE, Mechanical Engineering, London SW7 2AZ, United Kingdom; P. Nagy, University of Cincinnati, Aerospace Engineering & Engineering, Mechanics, Cincinnati, OH 45221-0070

9:50 AM **Numerical Simulation of Pulsed Meander Coil EMAT**
---R. Dhayalan, **K. Balasubramaniam**, and C. V. Krishnamurthy, Centre for Nondestructive Evaluation (CNDE), Department of Mechanical Engineering, Indian Institute of Technology Madras, Chennai-36, Tamil nadu, India

10:10 AM ***Break***

10:30 AM **Ultrasonic Crack Monitoring at High Temperatures Using SH Waves (>500°C)**
---**F. Cegla** and J. Davies, Imperial College, UK Research Centre in NDE, Mechanical Engineering, London, United Kingdom

10:50 AM **A Methodology to Extract Dimensional Information Using a Magnetic Field Imaging Camera (mFIC)**
---P. Gaydecki and **L. Heathcote**, University of Manchester, School of Electrical and Electronic Engineering, Manchester, United Kingdom

11:10 AM **Magnetostrictive Oblique Patch Array Method for Torsional Wave Based Damage Detection of a Rotating Shaft**
---**C. Park**, Seoul National University, Institute of Advanced Machinery and Design, Seoul, Korea; S. H. Cho, Korea Research Institute of Standards and Science, Center for Safety Measurement, Daejon, Korea; S. W. Han, Korea Railroad Research Institute, Railroad Safety Division, Gyeongi, Korea; Y. Y. Kim, Seoul National University, School of Mechanical and Aerospace Engineering, Seoul, Korea

11:30 AM **Planar-Solenoid Arrayed Patch-Type Magnetostrictive Ultrasonic Transducers for Plate Damage Detection**
---J. S. Lee, M. K. Lee, and **Y. Y. Kim**, Seoul National University, School of Mechanical and Aerospace Engineering and National Creative Research Initiatives Center for Multiscale Design, Seoul, Korea; B. C. Jeon, Aero Technology Research Institute, Air Force Logistics Command, Daegu, Korea; S. H. Cho, Korea Research Institute of Standards and Science, Safety Metrology Center, Daejon, Korea

11:50 AM **Issues in Mega Hertz Torsional Wave Generation in a Pipe by a Magnetostrictive Patch: Internal Reflections within a Patch**
---**H. W. Kim**, H. J. Lee, Y. E. Kwon, and Y. Y. Kim, Seoul National University, School of Mechanical and Aerospace Engineering, Seoul, Korea; S. H. Cho, Korea Research Institute of Standards and Science, Division of Industrial Metrology, Daejon, Korea

12:10 PM ***Lunch***

Development of Corrosion Sensors for Aircraft IVHM Systems

---**D. Andrew Scott**, Donald C. Price, Graeme C. Edwards, and Adam B. Batten, CSIRO Materials Science and Engineering, Lindfield, NSW, Australia; Tim H. Muster, Penny Corrigan, and Ivan S. Cole, CSIRO Materials Science and Engineering, Clayton, VIC, Australia

---A Rayleigh-wave-based sensor has been developed to measure corrosion damage in aircraft. This sensor forms an important part of a corrosion monitoring system being developed for a major aircraft manufacturer. A number of sensors monitor temperature, relative humidity, pH, and time of wetness, and their outputs are recorded and used as the inputs to a functional-based model of corrosion. This system measures the corrosion rate at the location of the sensors, and through the model predicts the corrosion rates in places of an aircraft into which no sensors may be placed â€“ cracks, rivet holes, around scratches in corrosion protection layers, and so on. Such difficult-to-access sites are often the most susceptible to corrosion. In order to calibrate this model, which yields corrosion rates rather than the integrated effect, an absolute measure of the damage is required. In this paper the development of a surface wave sensor capable of measuring accumulated damage will be described in detail. This sensor allows the system to measure material loss due to corrosion regardless of the possible loss of historical corrosion rate data, and can provide, at any stage, a benchmark for the predictive model that would allow a good estimate of the accumulated corrosion damage anywhere on an aircraft. This system may obviate the need for costly inspection of difficult-to-access places in aircraft, where presently the only way to check for corrosion is by periodic dismantling and reassembly.

Ultrasonic Waveguide Sensor Using a Leaky Lamb Wave for Under-Sodium Viewing

---**Young-Sang Joo** and Jae-Han Lee, Fast Reactor Development, Korea Atomic Energy Research Institute, 150-1 Dukjin-dong, Yuseong, Daejeon, Korea

---A plate-type ultrasonic waveguide sensor using a leaky Lamb wave has been developed for the under-sodium viewing of a reactor core and in-vessel structures of a sodium-cooled fast reactor (SFR). An A0 Lamb wave mode is utilized in the waveguide sensor for the single mode generation and the effective radiation capability in a fluid. A radiation beam steering technique is presented which is achieved by the frequency tuning of the excitation pulse in the frequency range of the A0 Lamb wave mode which the group velocity is not dispersive and the phase velocity is dispersive. The long distance propagation ability and C-scan imaging performance have been demonstrated successfully by experimental feasibility tests of the waveguide sensor.

Pulsed Electromagnet EMAT for High Temperatures

---**Francisco Hernandez-Valle** and Steve Dixon, University of Warwick, Department of Physics, Coventry, West Midlands, United Kingdom

---We presented recently a design of EMAT that utilised a pulsed electromagnet to provide the required magnetic field for operation. This new EMAT exhibited a significant improvement in the generated ultrasonic signal amplitude and signal to noise ratio, for operation on mild steel samples at room temperature, compared to equivalent EMATs that use permanent magnets. Previous works have shown that ultrasonic measurements can be done at temperatures in excess of 800ºC using laser-EMAT or laser-laser based techniques. However, the cost of laser systems and laser safety issues can restrict the use of such techniques. For laser generation and laser detection, it can also be impractical to use these systems for long term measurements for condition monitoring applications. When using EMATs, the temperature of the magnet must be kept below the maximum operating point (typically in the range of 150-250 ºC) and the temperature of the coil must be sufficiently low to avoid damage to the coil's insulation. This usually requires water cooling. Results for using the pulsed electromagnet EMAT to generate and detect SH shear waves in mild steel at elevated temperatures are presented.

Modelling of Electromagnetic Acoustic Transducers Operating on Ferromagnetic Materials

---**Remo Ribichini**, Frederic Cegla and Peter Cawley, Imperial College, UK Research Centre in NDE, Mechanical Engineering, London SW7 2AZ, United Kingdom; Peter Nagy, University of Cincinnati, Aerospace Engineering & Engineering, Mechanics, Cincinnati, OH 45221-0070

---The contact-less nature of Electromagnetic Acoustic Transducers (EMATs) offers a series of advantages over traditional piezoelectric transducers. Among these, two of the most attractive features of EMATs are the possibility of performing high temperature inspection and the effective generation of wave-modes such as the shear horizontal (SH) in plates. However, these valuable properties are counter-balanced by a series of problems that affect EMATs, especially their relatively low signal-to-noise ratio. The implication is that full exploitation of the capabilities of EMATs needs a detailed understanding of the phenomena occurring during their operation on different samples and materials. A finite element model has been developed to allow the optimization of the transducers for specific applications. The model includes the main transduction mechanisms operating in EMATs when inspecting a ferromagnetic sample: the Lorentz force and magnetostriction. The latter phenomenon is described through an analogy with piezoelectricity and acousto-elasticity. The numerical model is used to evaluate the relative importance of the two transduction mechanisms on different materials and for different wave modes, and to develop guidelines for optimal EMAT design. Experimental data showing the behavior of EMATs on a wide range of steels is also presented, showing the typical range of magnetostriction properties encountered in practice.

Numerical Simulation of Pulsed Meander Coil EMAT

---R. Dhayalan, **Krishnan Balasubramaniam**, and C. V. Krishnamurthy, Centre for Nondestructive Evaluation (CNDE), Department of Mechanical Engineering, Indian Institute of Technology Madras, Chennai-36, Tamil nadu, India

---Electro magnetic acoustic transducers (EMATs) are now being widely investigated for non-contact non-destructive testing (NDT) of solid materials. This type of transducer can generate and/or detect ultrasound in electrically conductive or magnetic materials through the Lorentz force principle and/or magneto-elastic effects. This work describes about the Meander coil EMAT that is modeled using finite element method. A 2-D finite element model was developed to calculate the induced current inside the medium, and subsequently the Lorentz force density in the medium. The calculated Lorentz force density values are applied for simulating the transient ultrasonic wave generation within the medium. Meander coil EMATs that were designed using the model were used for experimental studies. Several case studies will be reported which include Rayleigh waves, Shear waves, Longitudinal and Lamb wave modes using pulsed mode of excitation. The experimental results were agreed well with the simulation results.

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

---**Frederic Cegla** and Jacob Davies, Imperial College, UK Research Centre in NDE, Mechanical Engineering, London, United Kingdom

---The development of shear horizontal (SH) wave transducers 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 provide 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 simulation and experimental results from an array of SH probes on a thick notched plate. Signals were acquired using a purpose built array controller and processed into images using a variation of the total focusing method (TFM). Using the system, images of thick sample plates with notches of varying depth were acquired at room temperature. Furthermore two samples containing fatigue cracks were tested and a notched specimen was then placed in a furnace at high temperature and images of the notch were acquired at elevated temperatures.

A Methodology to Extract Dimensional Information Using a Magnetic Field Imaging Camera (mFIC)

---Patrick Gaydecki and **Lydia Heathcote**, University of Manchester,School of Electrical and Electronic Engineering, Manchester, United Kingdom

---A methodology to estimate the depth and diameter of steel rebars is presented using information obtained from scans generated by a magnetic field imaging camera (mFIC). It has generated accurate dimensional information to a depth of 10 cm. The camera, developed within the University of Manchester, UK, uses a 2D array of solid-state sensors to image in real time the distribution of a static magnetic field in its vicinity. The instrument is interfaced to a conventional PC and the software provides an image refresh rate of several frames per second.

Magnetostrictive Oblique Patch Array Method for Torsional Wave Based Damage Detection of a Rotating Shaft

---**Chanil Park**, Seoul National University, Institute of Advanced Machinery and Design, Seoul, Korea; Seung Hyun Cho, Korea Research Institute of Standards and Science, Center for Safety Measurement, Daejon, Korea; Soon Woo Han, Korea Railroad Research Institute, Railroad Safety Division, Gyeongi, Korea; Yoon Young Kim, Seoul National University, School of Mechanical and Aerospace Engineering, Seoul, Korea

---Damage detection of shafts is an important task but an ultrasonic method applicable to rotating shafts has not yet been developed. In this paper, a guided-ultrasonic torsional wave approach is developed for the damage detection of a rotating shaft. The key idea of the method is to use a magnetostrictive patch array to generate and measure ultrasonic waves without direct contact with a rotating shaft. Obviously, torsional waves are preferred because they are non-dispersive. The developed transducer is composed of a magnetostrictive patch array and a solenoid by which a magnetic field is supplied to and sensed from the patch array. The patch array must be obliquely bonded to a shaft for torsional wave transduction. And for frequency tuning, the distance between each patch of the array should be the same as the wavelength corresponding to the selected operating frequency. Several experiments were conducted on rotating shafts. After checking the underlying characteristics of the transducer, the developed method was applied to the detection of a circumferential crack in a rotating shaft.

Planar-Solenoid Arrayed Patch-Type Magnetostrictive Ultrasonic Transducers for Plate Damage Detection

---Ju Seung Lee, Min Kyung Lee, and **Yoon Young Kim**, Seoul National University, School of Mechanical and Aerospace Engineering and National Creative Research Initiatives Center for Multiscale Design, Seoul, Korea; Byung Chul Jeon, Aero Technology Research Institute, Air Force Logistics Command, Daegu, Korea; Seung Hyun Cho, Korea Research Institute of Standards and Science, Safety Metrology Center, Daejon, Korea

---Beam-focused ultrasonic transducers can be efficient damage inspectors if the direction of the generated ultrasonic beam is easily varied. In this presentation, we consider recently-developed magnetostrictive patch-type guided-wave ultrasonic transducers applicable to thin-walled plates. The transducer consists of two parts: a housing hosting a frequency-tuned planar solenoid array and two permanent magnets and a thin circular magnetostrictive patch bonded onto a test plate. The housing is simply placed above the patch, so it can freely rotate and thus change the generated beam direction. Depending on the relative magnetic field directions of the dynamic magnetic field by the coil and the bias field by magnets, the guided Lamb or shear-horizontal (SH) waves are generated and measured. Here, we mainly considered the transduction of the first non-dispersive SH wave mode at 250 kHz and 360 kHz and found highly-focused beam radiation patterns along the applied dynamic field direction. The experimental finding was also confirmed by a theoretical analysis. Because the beam direction control is easy, a damaged plate can be effectively inspected only with a few transducers. A damage inspection experiment on a 0.8 mm thick aluminum plate having two 1 mm circular cracks clearly demonstrated the effectiveness of the developed transducer.

Issues in Mega Hertz Torsional Wave Generation in a Pipe by a Magnetostrictive Patch: Internal Reflections within a Patch

---**Hoe Woong Kim**, Hyung Jin Lee, Young Eui Kwon and Yoon Young Kim, Seoul National University, School of Mechanical and Aerospace Engineering, Seoul, Korea; Seung Hyun Cho Korea Research Institute of Standards and Science, Division of Industrial Metrology, Daejon, Korea

---A recent report shows that mega Hertz torsional guided waves can be successfully generated and measured in a pipe by a patch-type magnetostrictive transducer. It consists of a thin magnetostrictive patch circumferentially bonded around a pipe, a permanent magnet and a meander coil. It was found that the measured mega Hertz wave signal by the patch transducer includes extra pulses immediately following the original pulse sent by an amplifier. Because the appearance of the extra pulses makes the resulting signal analysis difficult, the reason for their appearance should be identified and a method to suppress them is needed. To achieve these goals, several experiments were conducted and an analysis model was suggested. To do so, it was observed that as the frequency becomes higher, the corresponding wavelength (about 3 mm at 1 MHz) may not be sufficiently large compared with the thickness (0.15 mm) of the used patch. Therefore, a part of the generated wave is trapped within the magnetostrictive patch of a receiving transducer so that multiple internal reflections can occur within the patch. Through this research, the internal reflection was experimentally and analytically studied and a simple method to reduce the wave trapping was suggested and tested.

Session 27

SESSION 27
UT PHASED ARRAYS I
B. Addison, Chairperson
CBLS 100

8:30 AM **Imaging of Defects in Several Complex Configurations by Simulation-Helped Processing of Ultrasonic Array Data**
---A. Fidahoussen, **P. Calmon**, Ekaterina Lakovleva, and Sylvain Chatillon, CEA, LIST, SYSSC, F-91191 Gif-sur-Yvette, France

8:50 AM **Software Tools for Automated Phased Array Application Development**
---**V. Lupien**, Acoustic Ideas, Inc., 27 Eaton Street, Wakefield, MA 01880; S. Chen, York University; El-Mahjoub Rasselkorde, TWI Ltd., United Kingdom

9:10 AM **Efficient Data Capture and Post-Processing for Real-Time Imaging Using an Ultrasonic Phased Array**
---**L. Moreau**, A. J. Hunter, B. W. Drinkwater, and P. D. Wilcox, University of Bristol, Department of Mechanical Engineering, Bristol, United Kingdom

9:30 AM **Grain Noise Reduction by Phase Coherence Imaging**
---**J. Camacho**, J. Brizuela, and C. Fritsch, Instituto de Automática Industrial, Departamento de Sistemas, Ctra. Campo Real km. 0.200, Arganda del Rey, 28500, Madrid, Spain

9:50 AM **Synthetically Focused Imaging Techniques in Simulated Austentic Steel Welds Using an Ultrasonic Phased Array**
---**G. Connolly**, M. J. S. Lowe, and A. Temple, Imperial College, UK Research Centre in NDE, Mechanical Engineering, London, UK; S. Rokhlin, The Ohio State University, Edison Joining Technology Center, Columbus, OH 43221

10:10 AM ***Break***

10:30 AM **A Model-Based Autofocus Algorithm for Ultrasonic Imaging Using a Flexible Array**
---**A. J. Hunter**, B. W. Drinkwater, and P. D. Wilcox, Dept. of Mechanical Engineering, University of Bristol, Bristol, United Kingdom

10:50 AM **Hexagonal Array Structure for 2D NDE Applications**
---J. Dziewierz, S. N. Ramadas, **A. Gachagan**, R. L. O'Leary, and G. Hayward, Centre for Ultrasonic Engineering, University of Strathclyde, Glasgow, G1 1XW United Kingdom

11:10 AM **Development of 3D Phased Array Ultrasonic Inspection System 3D Focus-UT**
---**A. Baba**, N. Kono, and S. Kitazawa, Energy and Env. Systems Lab., Hitachi Ltd., 7-2-1 Omika-cho, Hitachi-shi, Ibaraki-ken, 319-1221, Japan; M. Odakura, Hitachi Works, Hitachi-GE Nuclear Energy Ltd.,3-1-1, Saiwai-cho, Hitachi-shi, Ibaraki-ken, 317-8511, Japan; Y. Adachi, Hitachi Works, Hitachi Ltd., 3-1-1, Saiwai-cho, Hitachi-shi, Ibaraki-ken, 317-8511, Japan; O. Kikuchi, Hitachi Eng. & Service Ltd., 3-2-1, Saiwai-cho, Hitachi-shi, Ibaraki-ken, 317-0073, Japan

11:30 AM **Development of a Membrane Coupled Conformable Phased Array Inspection Capability**
---**J. Russell**, R. Long, and P. Cawley, Imperial College, UK Research Centre in NDE, Mechanical Engineering, London, United Kingdom

11:50 AM **Through Weld Ultrasonic Phased Array Inspection Using a Conformable Membrane Device**
---**R. Long**, J. Russell, and P. Cawley, Imperial College, UK Research Centre in NDE, Mechanical Engineering, London, United Kingdom

12:10 PM **Inspection of Single Crystal Aerspace Components with Ultrasonic Arrays**
---**C. J. L. Lane** and A. K. Dunhill, Rolls-Royce plc, NDE Laboratory, GP 4-1-4, Bristol BS34 7QE, United Kingdom; B. W. Drinkwater and P. D. Wilcox, University of Bristol, Dept. of Mechanical Engineering, Bristol, United Kingdom

12:30 PM ***Lunch***

Imaging of Defects in Several Complex Configurations by Simulation-Helped Processing of Ultrasonic Array Data

---Alex Fidahoussen, **Pierre Calmon**, Ekaterina Lakovleva, and Sylvain Chatillon, CEA, LIST, SYSSC, F-91191 Gif-sur-Yvette, France

---Advanced ultrasonic array techniques such as full matrix acquisitions provide considerable amount of data making possible by the use of suitable processing algorithms enhanced capability of defects imaging and therefore improved localization and sizing. In general the processing algorithms consist in a coherent summation of signals (synthetic focusing) based on a time of flight inverse matching method. This approach is often limited by the capabilities of the forwards models used in the matching process. In this communication we present imaging algorithms which have been connected to forwards models allowing to deal with realistically complex configurations. Forwards models give access not only to theoretical times of flight but also to amplitude information which can be used in the reconstruction. The performances of the algorithms are evaluated both on simulated and experimental results. We show in particular examples of results obtained on complex geometries and on defects detected by multiple ultrasonic paths (tip diffraction, corner effect, mode conversions).

Software Tools for Automated Phased Array Application Development

---**Vincent Lupien**, Acoustic Ideas, Inc., 27 Eaton Street, Wakefield, MA 01880; Stephen Chen, York University; El-Mahjoub Rasselkorde, TWI Ltd., United Kingdom

---Despite their impressive capabilities, today's software modeling tools for NDE are still limited to predicting wave phenomena given known transducers and inspection approaches. We believe the NDE community needs tools that design transducers and inspection approaches automatically. We have been developing such a tool, called Probe Designer, for the past several years and the tool has reached sufficient maturity for its first few commercial sales this year. We will present progress on Probe Designer including the ability automatically to design phased array transducers for use with multiple geometries, to design element subdivision patterns for transducers with constrained shapes, and to select the best transducer from a catalog of existing transducers. In addition we will discuss the use of recently developed Locust Swarm Optimization techniques to effectively zero in on optimal solutions when the search space is erratic or noisy.

Efficient Data Capture and Post-Processing for Real-Time Imaging Using an Ultrasonic Phased Array

---**L. Moreau**, A. J. Hunter, B. W. Drinkwater, and P. D. Wilcox, University of Bristol, Department of Mechanical Engineering, Bristol, United Kingdom

---Over the past few years, ultrasonic phased arrays have shown good potential for non-destructive testing (NDT), thanks to high resolution imaging algorithms that allow the characterization of defects in a structure. Many algorithms are based on the full matrix capture, obtained by firing each element of an ultrasonic array independently, while collecting the data with all elements. Because of the finite sound velocity in the specimen, two consecutive firings must be separated by a minimum time interval. Therefore, more elements in the array require longer data acquisition times. Moreover, if the array has N elements, then the full matrix contains N2 temporal signals to be processed. Because of the limited calculation speed of current computers, a large matrix of data can result in rather long post-processing times. In an industrial context where real-time imaging is desirable, it is crucial to reduce acquisition and/or post-processing times. This paper investigates methods designed to reduce acquisition and post-processing times. To reduce data capture duration, limited transmission cycles are used, while post-processing times are reduced using the sparse TFM or wavenumber algorithm, and demodulation of the data to baseband. Results are presented so that a compromise can be made between acquisition time, post-processing time and image quality.

Grain Noise Reduction by Phase Coherence Imaging

---**Jorge Camacho**, Jose Brizuela, and Carlos Fritsch, Instituto de Automática Industrial, Departamento de Sistemas, Ctra. Campo Real km. 0.200, Arganda del Rey, 28500, Madrid, Spain

---Weak flaws detection and sizing is especially difficult in solids presenting structural noise. Several methods and algorithms have been developed in the past to address this problem. On the other hand there is a growing interest on using phased array technology to get real-time images to improve flaw detection and characterization. However, in spite of the higher spatial diversity provided by phased arrays, grain noise blurs images. In extreme cases, flaws are not detected at all. This work presents a new approach where a phase coherence operator is included in the beamforming process to achieve a significant reduction of scattering noise in images. It modifies the beamformer output as a function of the phase diversity of the aperture data for every range. After application of focusing delays, the grain noise shows high phase diversity, being suppressed by the phase coherence operator, while the higher phase coherence of flaws keep their indications. Experimental verification shows a good agreement with theory. High signal-to-noise ratio improvement is achieved, providing a very simple tool to grain noise reduction in real time with phased arrays.

Synthetically Focused Imaging Techniques in Simulated Austentic Steel Welds Using an Ultrasonic Phased Array

---**George Connolly**, Michael J. S. Lowe, and Andrew Temple, Imperial College, UK Research Centre in NDE, Mechanical Engineering, London, UK; Stanislav Rokhlin, The Ohio State University, Edison Joining Technology Center, Columbus, OH

---In austenitic steel welds employed in safety-critical applications, detection of defects that may propagate during service or may have occurred during welding is particularly important. However, ultrasonic rays are known to deviate in austenitic welds due to material anisotropy and inhomogeneity. In this study, synthetically focused imaging techniques are applied to the echoes received by phased arrays in order to reconstruct images of the interior of a simulated austenitic steel weld, with application to sizing and location of simplified defects. Using a ray-tracing approach through a previously developed weld model, we briefly describe and then apply three focusing techniques. Results generated via both ray-tracing theory and finite element simulations will be shown.

A Model-Based Autofocus Algorithm for Ultrasonic Imaging Using a Flexible Array

---**Alan J. Hunter**, Bruce W. Drinkwater, and Paul D. Wilcox, Department of Mechanical Engineering, University of Bristol, Bristol, United Kingdom

---Autofocus is a methodology for estimating and correcting errors in the assumed parameters of an imaging algorithm. It provides improved image quality and, therefore, better defect detection and characterization capabilities. In this paper, we present a new autofocus algorithm developed specifically for ultrasonic non-destructive testing and evaluation. Here, we consider the estimation and correction of errors in the assumed element positions for a flexible ultrasonic array coupled to a specimen with an unknown surface profile. However, the algorithm can, in principle, be modified for use with any imaging parameters, e.g., for imaging within an inhomogeneous and/or anisotropic medium, such as austenitic weld material. When an image is not too severely distorted due to inadequate knowledge of the imaging parameters (which is the case in many practical situations), it is often possible to isolate and characterize features in the corrupted image, particularly if some prior information about the specimen geometry is known. Using a reversible imaging algorithm, one can isolate these features in the echo data. Then, by comparing the echo data with a model of the feature, the errors in the assumed parameters can be inferred. We describe this approach for point and planar image features and present experimental results from a flexible array prototype.

Hexagonal Array Structure for 2D NDE Applications

---Jerzy Dziewierz, Sivaram N. Ramadas, **Anthony Gachagan**, Richard L. O'Leary, and Gordon Hayward, Centre for Ultrasonic Engineering, University of Strathclyde, Glasgow, G1 1XW United Kingdom

---The application of 2D phased array technology is currently restricted by the channel limitation associated with commercial phased array controller instrumentation. This constraint is problematic as the resultant small array aperture results in a reduced beam steering capability and negates many of the advantages of 2D arrays for volumetric inspection. This work has used a combination of simulation and experimentation to evaluate the advantages offered by utilizing a hexagonal shaped array element in a 2D NDE array structure. The active material is a 1-3 connectivity piezoelectric composite structure incorporating triangular shaped pillars – each hexagonal array element comprising six triangular pillars. A combination of PZFlex and COMSOL has been used to simulate the behavior of this device microstructure, for operation around 3MHz, with unimodal behavior and low levels of mechanical cross-coupling predicted. Furthermore, the application of hexagonal array elements enables the array aperture to increase by 13%, compared to a conventional orthogonal array matrix and hence will provide enhanced volumetric coverage. Prototype array configurations have been manufactured and demonstrate good corroboration of the theoretically predicted mechanical cross-coupling between adjacent array elements (~18dB). Finally, the pulse-echo performance of this 2D array structure has been evaluated for operation into a steel test block.

Development of 3D Phased Array Ultrasonic Inspection System 3D Focus-UT

---**Atsushi Baba**, Naoyuki Kono, and So Kitazawa, Energy and Environmental Systems Laboratory, Hitachi Ltd., 7-2-1 Omika-cho, Hitachi-shi, Ibaraki-ken, 319-1221, Japan; Mitsuru Odakura, Hitachi Works, Hitachi-GE Nuclear Energy Ltd.,3-1-1, Saiwai-cho, Hitachi-shi, Ibaraki-ken, 317-8511, Japan; Yuji Adachi, Hitachi works, Hitachi Ltd., 3-1-1, Saiwai-cho, Hitachi-shi, Ibaraki-ken, 317-8511, Japan; Osamu Kikuchi, Hitachi Engineering & Service Ltd., 3-2-1, Saiwai-cho, Hitachi-shi, Ibaraki-ken, 317-0073, Japan

---Various industrial fields have used the ultrasonic phased array inspection system. For instance, power plants have used this system to maintain their reliability. The phased array is advantageous because it improves efficiency by imaging the inside of the test subject. This inspection image is obtained by the electronic scanning of focused ultrasonic beam using phased array sensor. We have developed a 3 dimensional volume inspection technology to make further efficiency and accuracy improvements in ultrasonic inspection. This study presents the innovative three dimensional phased array inspection system "3D Focus-UT" for 3D volume inspection. This system employee: (1) 3D ray-trace simulator to set-up the delay time for the elements in the array sensor and the delay pattern for 3D volume scanning. (2) High sensitivity phased array equipment, that has a 256CH of pulsar/receiver to drive/receive a 2D matrix array sensor simultaneously. (3) High-speed 3D data processing software. The software converts 3D volumetric inspection data into 3D voxel data in order to display 3D inspection image. The images could be used to evaluate the crack location and crack size. The results of 3D volume inspection obtained by 3D Focus-UT would be presented.

Development of a Membrane Coupled Conformable Phased Array Inspection Capability

---**Jonathan Russell**, Robert Long, and Peter Cawley, Imperial College, UK Research Centre in NDE, Mechanical Engineering, London, United Kingdom

---A membrane coupled conformable phased array device is under development to improve the inspection of components with irregular surface geometry. This device uses a conventional linear phased array, which is coupled to the surface of the component under test via a water path encapsulated by a low loss rubber membrane. The membrane coupled device has recently been updated to provide improved beam forming, reduced internal noise and an integrated irrigation system. An enhanced inspection system has also been developed that allows the rapid acquisition and processing of scanned full matrix capture (FMC) inspection data. Results obtained from the inspection of a stainless steel pipe weld with the weld cap in place will be presented along with simulated results. This work demonstrates that a practical inspection of a component with complex surface geometry using phased arrays with FMC is now achievable. Results also show that this approach delivers significant improvements in terms of inspection speed, accuracy and flexibility.

Through Weld Ultrasonic Phased Array Inspection Using a Conformable Membrane Device

---**Robert Long**, Jonathan Russell, and Peter Cawley, Imperial College, UK Research Centre in NDE, Mechanical Engineering, London, United Kingdom

---We are developing phased array inspection of welded pipes found typically in the nuclear industry. A challenging inspection that we would like to perform is to provide a specular reflection off a defect requiring ultrasonic waves to propagate across the irregular weld-cap profile, and through the structurally complex weld material that can disturb ultrasonic wave propagation. Our solution is the development of a conformable phased array membrane device now in its third generation, the modelling of the test scenario using the CIVA software, acquisition of full matrix capture and processing the data ourselves. This presentation reports on improvements made to ultrasonically measuring the surface profile and the utilization of these measurements for updating delay laws. Simulated direct wave, through weld inspections obtained with the CIVA software are compared to the experimental results.

Inspection of Single Crystal Aerospace Components with Ultrasonic Arrays

---**Christopher J. L. Lane** and Anthony K. Dunhill, Rolls-Royce plc, NDE Laboratory, GP 4-1-4, Bristol BS34 7QE, United Kingdom; Bruce W. Drinkwater and Paul D. Wilcox, University of Bristol, Department of Mechanical Engineering, Bristol, United Kingdom

---Single crystal metal alloys are used extensively in the manufacture of jet engine components for their excellent mechanical properties at elevated temperatures. The increasing use of these materials and demand for longer operational life and improved reliability motivates the requirement to have capable NDE methods available. Ultrasonic arrays are well established at detecting sub-surface defects, however these methods are not currently suitable to the inspection of single crystal components due to their high elastic anisotropy causing directional variation in ultrasonic waves. In this paper a model of wave propagation in anisotropic material is used to correct an ultrasonic imaging algorithm and is applied to single crystal test specimens. The orientation of the crystal in a specimen must be known for this corrected-algorithm; therefore a crystal orientation method is also presented that utilizes surface skimming longitudinal waves under a 2D array. The work detailed in this paper allows an ultrasonic 2D array to measure the orientation of a single crystal material and then perform accurate volumetric imaging to detect and size defects.

Session 28

SESSION 28
MODEL BASED INVERSION
J. Aldrin, Chairperson
Chafee 273

8:30 AM **Voxel-Based Inverse Methods**
---**H. A. Sabbagh**, R. Kim Murphy, and E. H. Sabbagh, Victor Technologies, LLC, PO Box 7706, Bloomington, IN 47407-7706

8:50 AM **Eddy-Current Inversion and Estimation Metrics for Evaluating Thermal Barrier Coatings**
---**H. A. Sabbagh**, R. K. Murphy, and E. H. Sabbagh, Victor Technologies, LLC, Bloomington, IN 47401; J. Nyenhuis, Purdue University, Department of Electric and Computer Engineering, West Lafayette, IN 47906; J. C. Aldrin, Computational Tools, Gurnee, IL 60031; J. Knopp, Air Force Research Laboratory (AFRL/MLLP), Wright-Patterson AFB, OH 45433

9:10 AM **Reconstructing the Back of a Defect from Its Mirror Image**
---**T. Hutt** and F. Simonetti, Imperial College, UK Research Centre in NDE, Mechanical Engineering, London, United Kingdom

9:30 AM **Inverse Modeling of Volumetric Ultrasonic Thermal Excitation**
---J. T. Welter and M. P. Blodgett, Air Force Research Laboratory, Metals, Ceramics and NDE Division, 2230 Tenth St., Wright Patterson AFB, Dayton, OH 45433-7817; **S. A. Martin,** NDE Computational Consultants, Dublin, OH 43017-8530; S. Sathish, University of Dayton Research Institute, 300 College Park, Dayton, OH 45469-0127

9:50 AM **Sensitivity Analysis of Inverse Methods in Eddy Current Pit Characterization**
---**J. C. Aldrin**, Computational Tools, Gurnee, IL 60031; H. A. Sabbagh, R. K. Murphy, and E. H. Sabbagh, Victor Technologies LLC, Bloomington, IN 47407-7706; J. S. Knopp, U.S. Air Force Research Laboratory, Wright-Patterson AFB, OH 45433-7817

10:10 AM ***Break***

10:30 AM **Three Dimensional Defect Reconstruction Using Substructure-Frontal Method**
---**X. Liu**, Y. Deng, L. Udpa, and S. S. Udpa, NDE Laboratory, Department of Electrical and Computer Engineering, Michigan State University, East Lansing, MI 48824

10:50 AM **Simultaneous Estimation of Electrical and Thermal Properties from Tone Burst Eddy Current Thermography (TBET) Data**
---B. Narayanan, N. Ganesan, C. V. Krishnamurthy, and **K. Balasubramaniam**, Center for Non Destructive Evaluation and Department of Mechanical Engineering, Indian Institute of Technology Madras, Chennai- 600 036, India

11:10 AM ***Lunch***

Voxel-Based Inverse Methods

---**Harold A. Sabbagh**, R. Kim Murphy, and Elias H. Sabbagh, Victor Technologies, LLC, PO Box 7706, Bloomington, IN 47407-7706

---Voxel-based inversion algorithms differ from the more familiar model-based algorithms in that they do not rely on an a priori estimate of the nature of the anomalous region. Thus, one does not attempt to define a few parameters that model the anomaly, but rather one reconstructs the conductivity distribution of the anomaly voxel-by-voxel throughout the entire region of the anomaly. This makes these algorithms much more powerful than the model-based algorithms, but they also require more data, since one is reconstructing a full three-dimensional anomaly. A simple example is a one-dimensional layer model, in which one might attempt to assign a conductivity to each of a number of layers that span the anomalous region. Two other examples of voxel-based inversion algorithms will be presented, and results that demonstrate the ability to reconstruct complex regions will be shown.

Eddy-Current Inversion and Estimation Metrics for Evaluating Thermal Barrier Coatings

---**Harold A. Sabbagh**, R. Kim Murphy, and Elias H. Sabbagh, Victor Technologies, LLC, Bloomington, IN 47401; John Nyenhuis, Purdue University, Department of Electric and Computer Engineering, West Lafayette, IN; John C. Aldrin, Computational Tools, Gurnee, IL 60031; Jeremy Knopp, Air Force Research Laboratory (AFRL/MLLP), Wright-Patterson AFB, OH 45433

---The nondestructive evaluation (NDE) of high-temperature coatings is one of the important factors in achieving a high-level of structural integrity in advanced gas turbines. In this paper we successfully demonstrate that sophisticated eddy-current techniques incorporating model-based inverse methods can be utilized to measure the thickness and remaining-life of high-temperature coatings. To further assure the performance of these inverse methods, several estimation metrics, including Fisher Information, Cramer-Rao Lower Bound (CRLB), covariance, and singular-value decomposition (SVD), are introduced. The connections and utility of these metrics are illustrated in the design of eddy-current methods for estimating layer thickness, conductivity and probe liftoff.

Reconstructing the Back of a Defect from its Mirror Image

---**Timothy Hutt** and Francesco Simonetti, Imperial College, UK Research Centre in NDE, Mechanical Engineering, London, United Kingdom

---A significant problem in imaging of defects in thick plates is the limited field of view afforded by a linear ultrasound array. This frequently results in inaccurate and incomplete reconstructions. These could be improved by using a second array on the back of the plate to improve the range of insonification directions, however this is not practical in most cases. Instead it is proposed that reflections from the back wall could be utilized as additional probing waves. These reflections give rise to multiply scattered signals that arrive after the direct reflection from the back wall. Traditionally they are discarded, however they encode useful information about the scatterer that can be used to improve the scatterer reconstruction. We have incorporated prior knowledge of the component geometry by modifying the Green's function of the inverse scattering methods in order to take the back wall reflections into account. While accurate sizing is not possible with current beamforming methods, especially in the range direction, the use of modern inverse scattering methods with the back wall reflection data allows accurate sizing in all directions. In this paper we illustrate the theoretical framework of the proposed method and present reconstructions from both synthetic and experimental data. We discuss practical considerations including array calibration and model parameter uncertainty.

Inverse Modeling of Volumetric Ultrasonic Thermal Excitation

---John T. Welter and Mark P. Blodgett, Air Force Research Laboratory, Metals, Ceramics and NDE Division, 2230 Tenth St., Wright Patterson AFB, Dayton, OH 45433-7817; **Steven A. Martin,** NDE Computational Consultants, Dublin, OH 43017-8530; Shamachary Sathish, University of Dayton Research Institute, 300 College Park, Dayton, OH 45469-0127

---Traditional thermography is based upon thermal loading of a specimen by a boundary surface heat load. A more recent advance involves the use of volumetric heat generation to provide the thermal load. This method can be used in the traditional manner, which uses the transient response to determine thermal material properties or to locate material defects. Since the volumetric heat generation process can be a function of the state of the material, this can enable the use of thermal responses to evaluate non-thermal material properties. In this case an inverse problem arises where the internal heat generation distribution must be ascertained from the time-temperature response curves at surface or internal measurement points. The case of a one dimensional layer with known convective boundary conditions and internal heat generation with unknown spatial distribution and known excitation period is investigated. It is desired to use the time-temperature curves both during and after the excitation period to determine the internal heat generation function. A solution approach for this inverse problem is investigated.

Sensitivity Analysis of Inverse Methods in Eddy Current Pit Characterization

---**John C. Aldrin**, Computational Tools, Gurnee, IL 60031; Harold A. Sabbagh, R. Kim Murphy, and Elias H. Sabbagh, Victor Technologies LLC, Bloomington, IN 47407-7706; Jeremy S. Knopp, U.S. Air Force Research Laboratory, Wright-Patterson AFB, OH 45433-7817

---Research into inverse methods for flaw characterization using eddy current data has been explored; however, progress has been limited due to issues concerning robustness of inverse method schemes to the expected variability with real measurements. In this paper, a sensitivity analysis is performed for the case study problem of characterizing pits in tubing to quantify the impact of potential sources for variation on the inverse method performance. The impact to changes in NDE model, the inversion algorithm design, and experiment conditions was explored with respect to the accuracy and repeatability of the inversion results. Concerning the inversion process, the calibration of simulated impedance calculations with voltage measurement data, the use of noise filters, the feature extraction algorithm design, and the model-based inversion scheme were found to be statistically significant to achieve good results. In addition to inverting pit depth and pit diameter, it was also found that the scan step size must be included in the inversion problem, due to significant variation of scan speed. Repeated runs were found to be one of the greatest sources of variation in the inversion results, although it was not considered excessive. Lastly, variance in model probe dimensions did not adversely affect inversion performance.

Three Dimensional Defect Reconstruction Using Substructure-Frontal Method

---**Xin Liu**, Yiming Deng, Lalita Udpa, and Satish S. Udpa, NDE Laboratory, Department of Electrical and Computer Engineering, Michigan State University, East Lansing, MI 48824

---This paper introduces a model-based approach to reconstruct the three-dimensional defect profiles using nondestructive inspection signals from EC-GMR sensors. The method uses a substructure-frontal finite element (SFFE) forward model to simulate the underlying physics and a local search algorithm to solve the inverse problem by minimizing the cost function. The advantage of the SFFE method is that it divides the whole solution domain into two substructures and only the region of interest (ROI) with dramatic material changes will be updated in each iterative step. Since the number of elements inside the ROI is very small compared with the number of elements in the entire mesh, the computational effort needed in both LU factorization and coefficient matrix assembling is reduced. Therefore, the computational cost will be reduced significantly to make the inversion very efficient. This paper presents the results of SFFE implementation, which confirm the validity and merits of the approach.

Simultaneous Estimation of Electrical and Thermal Properties from Tone Burst Eddy Current Thermography (TBET) Data

---B. Narayanan, N. Ganesan, C. V. Krishnamurthy, and **K. Balasubramaniam**, Center for Non Destructive Evaluation and Department of Mechanical Engineering, Indian Institute of Technology Madras, Chennai- 600 036, India

--- In many situations, it is often required to determine the deterioration in the material properties due to ageing, or to find the unknown properties of a given virgin material. In the present work, an attempt is made to determine simultaneously the electrical conductivity and the components of thermal conductivity of a given anisotropic sample using inversion techniques from the observed temperature data in eddy current thermography. In literature, methods are available to determine the electrical and thermal parameters separately. In this paper a Genetic Algorithm (GA) based inversion method is proposed to determine simultaneously the electrical conductivity and thermal conductivity (k) values along and across the fibers of a given anisotropic material from the time- temperature data obtained from the eddy current thermography. The method consists of solving the forward problem of eddy current heating for getting the temperature data and then using the inversion technique by Genetic Algorithm to arrive at the material properties such as electrical conductivity and thermal conductivity (k11, k22) simultaneously. The forward problem is solved by taking a 2D model using COMSOL 3.2 multi physics software and inversion is done using Genetic Algorithm tool box in MATLAB. Different trials are carried out initially with simulated temperature data without and with noise and then with experimental data.

Session 29

Thursday, July 30, 2009

SESSION 29 – POSTERS

MATERIALS PROPERTIES, SPOT WELDS, SIGNAL PROCESSING TECHNIQUES, NDE FOR MATERIALS, NDE APPLICATIONS, VARIOUS TECHNIQUES, BIO MATERIAL APPLICATIONS, AND EDUCATION

Memorial Union Ballroom

1:30 PM

Materials Properties

Elasticity Characterization of Precipitates in USC Steel Using Ultrasonic Atomic Force
---**C. S. Kim**, T. S. Park, and I. K. Park, Mechanical Engineering, Seoul National University of Technology, Seoul, South Korea; S. S. Lee, Korea Research Institute of Standard and Science, Daejon, South Korea

Quantitative Ultrasound Characterization of Silicon Carbide Mirrors
---**A. R. Portune** and R. A. Haber, Rutgers the State University of New Jersey, Department of Materials Science and Engineering, Piscataway, NJ 08854

Ultrasonic Lamb Wave Tomography of Non-Uniform Interfacial Stiffness Between Contacting Solid Bodies
---**A. Balvantin** and A. Baltazar, Centro de Investigacion y Estudios Avanzados del Instituto Politecnico, Nacional, Robotics and Advanced Manufacturing Program, Saltillo, Coahuila, Mexico; J.-Y. Kim, Georgia Institute of Technology, Woodruff School of Mechanical Engineering, Atlanta, GA 30332

Creep Characterization of Turbine Blade Material by Ultrasonic NDE Technique
---**C. S. Kim** and C. J. Lissenden, The Pennsylvania State University, Engineering Science and Mechanics, University Park, PA 16802; I. K. Park, Seoul National University of Technology, Mechanical Engineering, Seoul, South Korea

Characterization of Silicon Surface after Hydrophilic and Hydrophobic Treatment by Atomic Force Microscopy
---**X. Xi**, S. Maghsoudy-Louyeh, and B. R. Tittmann, Department of Engineering Science and Mechanics, Penn State University, University Park, PA 16802

Surface Roughness Study of Selected Materials Using Atomic Force Microscopy
---**S. Maghsoudy-Louyeh**, H. S. Ju, and B. R. Tittmann, The Pennsylvania State University, Department of Engineering Science & Mechanics, University Park, PA 16802

Characterization of Microstructural Changes in Coarse Ferritic-Perlitic Stainless Steel Through the Statistical Fluctuation and Fractal Analyses of Barkhausen Noise
---L. R. Padovese, Universidade de Sao Paulo, Departamento de Engenharia Mecanica, Sao Paulo, SP, Brazil; F. E. da Silva, **E. P. Moura**, and L. L. Gonçalves, Universidade Federal do Ceara, Departamento de Engenharia Metalurgica e de Materiais, Fortaleza, CE, Brazil

Inspection of Laser Welds with Acoustic Microscope
---R. Gr. Maev and **F. M. Severin**, Institute for Diagnostic Imaging Research, Physics Department, University of Windsor, 401 Sunset Avenue, Windsor, Ontario, N9B 3P4, Canada

Study of Aging Effects in 2205 Duplex Stainless Steel Using Thermoelectric Power Measurement
---**N. Ortiz-Lara**, A. Ruiz, H. Carreón and A. Medina, Institute of Metallurgical Researches of the UMSNH, Morelia, Michoacán, México; U. Gonzalez-Zavala and A. Sánchez-Castillo, Department of Mechanical Engineering of the UMSNH, Morelia, Michoacán, México

Detection of Anomalous Machining Damages in Inconel 718 and Ti 6-4 by Eddy Current Technqiues
---**C. C. H. Lo** and N. Nakagawa, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

Spot Welds

Real Time Ultrasonic Aluminum Spot Weld Monitoring System
---R. Gr. Maev, A. M. Chertov, and **W. Perez Regalado**, University of Windsor, Physics Department, Institute for Diagnostic Imaging Research, Windsor, Ontario, Canada

Finite Element Modeling of Wave Propagation During In-Line Ultrasonic Monitoring of Spot Welds
---**J. Kocimski**, P. Kustroń, and A. Ambroziak, Wroclaw University of Technology, Mechanical Department, Institute of Production Engineering and Automation, Welding Division, Wroclaw, Poland; J. Kocimski, P. Kustroń, A. Karloff, W. Perez Regalado, A. M. Chertov, and R. Gr. Maev, University of Windsor, Physics Department, Institute for Diagnostic Imaging Research, Windsor, Ontario, Canada

Signal Processing Techniques

An Improved Processing Algorithm for Guided Wave Phased Array in Plate Structures
---**H.-S. Kwon**, S.-H. Cho, and S.-S. Lee, Korea Research Institute of Standards and Science, P.O. Box 102, Yuseong, Daejeon 305-600, Korea; J.-Y. Kim, School of Civil and Environmental Engineering, Georgia Institute of Technology, Atlanta, GA 30332

Acoustic Emission Signal Processing Based on Wavelet Analysis for Grinding Process
---**J. Yang**, S.-Z. Xu, Z.-N. Zhang, and J.-C. Cheng, Key Laboratory of Modern Acoustics, MOE, and Institute of Acoustics, Nanjing University, Nanjing 210093, Jiangsu Province, P. R. China; X.-X. Liu, Hiecise Machines Co, Ltd., Kunshan 215337, Jiangsu Province, P. R. China

A Preemphasis Technique to Broaden the Usable Frequency Range in Time Delay Spectrometry Systems
---**P. M. Gammell**, Gammell Applied Technologies, LLC, Exmore, VA 23350; S. Maruvada, Y. Liu, and G. R. Harris, U.S. Food and Drug Administration, Center for Devices and Radiological, Health, Ultrasonics Laboratory, Silver Spring, MD 20903

Lamb Wave Pipe Coating Disbond Detection and Assessment Using the Dynamic Wavelet Fingerprinting Technique
---**M. K. Hinders** and J. P. Bingham, Department of Applied Science, College of William and Mary, Williamsburg, VA 23187-8795

NDE for Materials

NDE Residual Stress – New Technique
---**E. Curto**, R&D Vicenza (Italy), Via E.di Velo, 84, 36100, Italy

Dislocation Detection Through Harmonic Generation
---**B. T. Reinhardt**, K. Boudreau, M. Kropf, and B. Tittmann, Pennsylvania State University, Department of Engineering Science and Mechanics, State College, PA 16802

Nonlinear Parameters for a Diagnosis of Micro-Scale Cracks Using a Nonlinear Resonant Ultrasound Spectroscopy (NRUS)
---**Y.-M. Cheong** and M. K. Alam, Nuclear Materials Research Division, Korea Atomic Energy Research Institute, Yusong P. O. Box 105, Daejon, 305-600, Korea

Study on the Structural Variation of Rare Earth Doped Titanium Dioxide from Wet Gel to Nanocrystals by Photoacoustic Spectroscopy
---H. Wang, **Y. Yang**, W. Chen, X. Liu, and S. Zhang, Key Laboratory of Modern Acoustics, Institute of Acoustics, Nanjing University, Nanjing, Jiangsu, China (PRC)

Evaluation of Fatigue Degradation Using Nonlinear Ultrasonics
---**K.-Y. Jhang**, Hanyang University, Seoul, South Korea; T.-H. Lee and I. Choi, Graduate School of Hanyang University, Seoul, South Korea

NDE Applications

CSI Helsinki: SWLI in Forensic Science: Comparing Tool Marks of Diagonal Cutting Pliers
---P. K. Ahvenainen, K. Hanhijarvi, and **E. Haeggstrom**, Electronics Research Unit, Department of Physics, University of Helsinki, P. O. Box 64, FIN-00014, Finland; I. V. Kassamakov, Department of Micro and Nanosciences, Helsinki University of Technology, P. O. Box 3500, FI-02015 TKK, Finland; J. Aaltonen, Helsinki Institute of Physics, University of Helsinki, P. O. Box 64, FIN-00014, Finland; K. Kokko and T. Reinikainen, National Bureau of Investigation, Forensic Laboratory, Vantaa, Finland

Real-Time Examination for Mines on Ship Hulls Using Rayleigh-Lamb Waves
---**M. K. Hinders** and J. P. Bingham, Department of Applied Science, College of William and Mary, Williamsburg, VA 23187-8795; A. Friedman, Solers, Inc. Sensor Technology Division, 3811 North Fairfax Drive, Suite 950, Arlington, VA 20155

Detection of Mine Roof-Fall Precursers in Microseismic Signals
---**M. K. Hinders** and C. A. Bertoncini, Departments of Applied Science and Physics, College of William and Mary, Williamsburg, VA 23187-8795

Acoustic Parametric Array for Identifying Standoff Targets
---**M. K. Hinders** and K. E. Rudd, Department of Applied Science, College of William and Mary, Williamsburg, VA 23187-8795

Various Techniques

Comparative Analysis of Selected Eddy Current Transducers for Titanium Alloy Evaluation
---**T. Chady**, R. Sikora, P. Baniukiewicz, and P. Lopato, West Pomeranian University of Technology, Department of Electrical and Computer Engineering, Szczecin, Poland

Matrix Eddy Current Probes for Molten Metal Level Measuring
---I. V. Terekhin[1] and **A. D. Pokrovskiy**, Moscow Power Engineering Institute (MPEI TU), Krasnjkazarmennaya str., 111250; A. N. Sorokin, Company, Techno-UP, Moscow

Limitation of Measurable Defect Thickness of the Wall Thinned Pipe Using Speckle Shearing Interferometry
---K. Kim and **H. Jung**, Department of Mechanical Design Engineering, Chosun University, 375 Seoseok-Dong, Dong-Gu, Gwangju, 501-759, Korea; H. Chang, Laser Center, Chosun University, 375 Seoseok-Dong, Dong-Gu, Gwangju, 501-759, Korea; D. Hong, Division of Precision Mechanical Engineering, Chonbuk National University, 664-14 1Ga Duckjin-Dong, Duckjin-Gu, Jeonju, Jeonbuk, 561-756, Korea; M. Choi, Korea; Research Institute of Standard and Science (KRISS), P. O. Box 102, Yuseong, Daejeon, 305-600, Korea

Crack Modeling for Radiography
---**T. Chady** and L. Napierala, West Pomeranian University of Technology in Szczecin, Szczecin, Department of Electrical Engineering, st. Sikorskiego 37, 70-313 Szczecin, Poland

Development of an Underwater Radiography Inspection System for Inspection of Flexible Risers
---**P. I. Nicholson** and E. Rasselkorde, TWI Technology Centre Ltd., ECM2, Heol Cefn Gwrgan, Margam, Port Talbot SA13 2ZE, Wales, United Kingdom

Magnetic Response Field of Spherical Defects within Conductive Components
---**M. Kreutzbruck**, H.-M. Thomas, C. Casperson, R. Sickert, and R. BÃhm, Federal Institute for Materials Research and Testing, Nondestructive Testing Department, 12205 Berlin, Germany

Energy Propagation in Anisotropic Material
---**E. L. Roetman**, Embry-Riddle Aeronautical University, Whidbey Island Center, Oak Harbor, WA 98249

Wave Properties of Direct Deposit Piezoelectric Sensors for Structural Health Monitoring Applications
---**N. J. Cusolito**[1], J. K. Na[2], and J. L. Blackshire[1], [1]Air Force Research Lab (AFRL/RXLP), Wright Patterson AFB, OH 45433; [2]University of Dayton Research Institute, Dayton, OH 45469

Bio Material Applications

A Deformable Template Model with Feature Tracking for Automated IVUS Segmentation
---P. Manandhar and **C. H. Chen**, Bioengineering Program and ECE Department, University of Massachusetts Dartmouth, Electrical and Computer Engineering, 285 Old Westport Road, N. Dartmouth, MA 02747-2300

Ultrasonic Radiation Force for Debubbling Blood
---**M. K. Hinders** and C. A. Campbell, Departments of Applied Science and Physics, College of William and Mary, Williamsburg, VA 23187-8795

Ultrasonographic Detection of Tooth Flaws
---**M. K. Hinders** and C. A. Bertoncini, Departments of Applied Science and Physics, College of William and Mary, Williamsburg, VA 23187-8795; S. R. Ghorayeb, Hofstra University, Biomedical Sciences and Electrical Engr. Divisions, 104 Weed Hall, Hempstead, NY 11549

Ultrasonographic Periodontal Probing Depth Determination via Pattern Classification
---**M. K. Hinders** and C. A. Bertoncini, Departments of Applied Science and Physics, College of William and Mary, Williamsburg, VA 23187-8795

Photoacoustic Nondestructive Evaluation and Imaging of Caries in Dental Samples
---**T. Li** and R. J. Dewhurst, Photon Science Institute, University of Manchester, Manchester, M13 9PL, United Kingdom

Detection of Damage in Silicon Wafers and Biomaterials
---**S. H. Kurra** and J. Zhang, The University of Texas at El Paso, Department of Industrial Engineering, El Paso, TX 79902

Education

The Dynamic Model of Professional Competence Forming for Non-Destructive Testing Students
---**A. G. Protasov**, National Technical University of Ukraine “KPI”, NDT Department, Box 1760, 37 Prospect Peremohy Street, Kiev, 03056, Ukraine

3:10 PM ***Break***

Materials Properties

Elasticity Characterization of Precipitates in USC Steel Using Ultrasonic Atomic Force Microscopy

---**Chung Seok Kim**, Tae Sung Park, and Ik Keun Park, Mechanical Engineering, Seoul National University of Technology, Seoul, South Korea; Seung Seok Lee, Korea Research Institute of Standard and Science, Daejon, South Korea

---Mechanical properties in various precipitation hardening alloys, such as aluminum base and iron base alloys, are derived through controlled precipitation of different intermetallic phases. Advanced ferritic 12Cr steel is based on tempered martensite and their high temperature strength is sustained by precipitation hardening of MX, M23C6, and Laves (Fe2W, Fe2Mo) phases. Therefore, the elasticity characterization of precipitate is important to study strength mechanism in precipitation hardening alloys. The ultrasonic atomic force microscope has been developed in order to enhance the characterization technology for nano-scale surface combining ultrasonic property to atomic force microscope. This UAFM technique enables elasticity imaging due to the physical properties on the heterogeneous surface in addition to the novel topography of surface height in the nano-surface layer. In this study, we measure the Young's modulus of precipitates in ultra supercritical steel by using the ultrasonic atomic force microscope.

Materials Properties

Quantitative Ultrasound Characterization of Silicon Carbide Mirrors

---**Andrew R. Portune** and Rich A. Haber, Rutgers the State University of New Jersey, Department of Materials Science and Engineering, Piscataway, NJ 08854

---Silicon carbide mirrors and mirror blanks were characterized by multiple ultrasound characterization techniques in order to locate any subsurface flaws. The presence of any heterogeneities detriments the optical and thermal properties of the mirror,causing the material to behave poorly in a mirror application. A 10MHz linear phased array probe was compared versus single transducer analysis at 20MHz, 75MHz, and 125MHz. While the phased array probe had the advantage of speed and electronic beam control, the smaller wavelengths of the single transducers enabled a more detailed understanding of sample homogeneity. Amplitude measurements were used to locate abnormalities in the top surface and bottom surface reflected signal peaks. Elastic property maps were formed to determine if any abnormalities caused changes in the local Young's modulus or Poisson ratio. Acoustic spectroscopy was performed where abnormalities were found in order to ascertain whether the frequency dependency of the attenuation could provide any insight into the precise nature of the flaw. This study illustrates the advantages and disadvantages to several types of ultrasound characterization for silicon carbide mirrors and mirror blank materials.

Materials Properties

Ultrasonic Lamb Wave Tomography of Non-Uniform Interfacial Stiffness Between Contacting Solid Bodies

---**Antonio Balvantin** and Arturo Baltazar, Centro de Investigacion y Estudios Avanzados del Instituto Politecnico, Nacional, Robotics and Advanced Manufacturing Program, Saltillo, Coahuila, Mexico; Jin-Yeon Kim, Georgia Institute of Technology, Woodruff School of Mechanical Engineering, Atlanta, GA 30332

---In this work, the interfacial stiffness between two contacting solid bodies is determined using the ultrasonic Lamb wave tomography. An ultrasonic measurement setup based on cross-hole tomography that uses broadband transducers is presented. The time-frequency representation (TFR) is employed to accurately identify the arrival time and frequency contents of the transmitted wave modes. Experiments are carried out on an aluminum plate where the flat end of a solid aluminum bar is pressed perpendicular to the surface; then, the level and distribution of the interfacial stiffness is controlled by applied force on the bar. The tomographic reconstructions are performed during repeated loading cycles. Finally, reconstructed tomographic images of the contact area versus applied pressure are obtained. The method presented has potential applications to determine the loss of contact in mechanically joined structural components.

Materials Properties

Creep Characterization of Turbine Blade Material by Ultrasonic NDE Technique

---**Chung Seok Kim** and Cliff J. Lissenden, The Pennsylvania State University, Engineering Science and Mechanics, University Park, PA 16802; Ik Keun Park, Seoul National University of Technology, Mechanical Engineering, Seoul, South Korea

---The IN738 alloy has been used for gas turbine blade at high temperature because of prominent high temperature mechanical properties such as creep, oxidation and corrosion. This alloy is mainly strengthened by a large amount of γ' ($Ni_3(Al,Ti)$) precipitates. However, directional coarsening is a practical problem in this alloy since nickel based superalloys with a high volume fraction of γ' precipitates used for turbine blade applications. The effects of microstructures during creep on the ultrasonic properties have been investigated for nickel based superalloy. The cuboidal γ' precipitates in the solution heat treated material became coarsened preferentially in the direction perpendicular to the applied stress axis as creep time increased. The length of γ' precipitates increased with creep time, while the width increased slightly. The increase in the ultrasonic attenuation and nonlinearity with increasing creep time was discussed with the increase in the equivalent size of γ' precipitates, which was closely related to the scattering and distortion of ultrasonic wave. It is suggested that the ultrasonic attenuation and nonlinearity can be potentials for diagnosis of creep damage in nickel based superalloy.

Materials Properties

Characterization of Silicon Surface after Hydrophilic and Hydrophobic Treatment by Atomic Force Microscopy

---**Xiaoning Xi**, Sahar Maghsoudy-Louyeh, and Bernhard R. Tittmann, Department of Engineering Science and Mechanics, Penn State University, University Park, PA 16802

---The surface properties of silicon are key parameters to the success of the silicon direct bonding technique in the semiconductor industry. Here we report on the evaluation of the hydrophilicity of silicon surfaces by atomic force microscopy (AFM) after different surface treatments were carried out: wet chemical etching and thermal oxidation methods. Both OH-treated and thermally-treated silicon surfaces show a quick increase in adhesion forces when located in an environment of 10% to 40% relative humidity. This humidity range most effectively facilitates the hydrophilic direct-bonding process. However, HF-treated silicon surfaces show negligible change in adhesion forces with a change in relative humidity. Theoretical models are used to explain the interaction between the AFM tip and the sample surface. The roughness change of the silicon surfaces treated via different methods is also investigated to provide suggestions for surface processing during direct bonding.

Materials Properties

Surface Roughness Study of Selected Materials Using Atomic Force Microscopy

---**Sahar Maghsoudy-Louyeh**, Hyeong Sick Ju, and Bernhard R. Tittmann, The Pennsylvania State University, Department of Engineering Science & Mechanics, University Park, PA 16802

---Hydrophilicity/hydrophobicity is often used to identify the chemical properties of a material surface, which can be characterized by the water contact angle. This research conducted a systematic study of the correlation between surface roughness and hydrophilicity/hydrophobicity of materials by Atomic Force Microscopy (AFM). The surface topography was observed on the different cross sections of materials representing silicates, phylo-silicates, calcites, and carbon. On the basis of the topographic image analysis of AFM, the root-mean square (RMS) roughness was calculated. The results show that the contact angle increases from 2° to 110° with increasing RMS roughness from about 5 to 5000 Angstroms. Both experimental and theoretical results are reported.

Materials Properties

Characterization of Microstructural Changes in Coarse Ferritic-Perlitic Stainless Steel through the Statistical Fluctuation and Fractal Analyses of Barkhausen Noise

---Linilson R. Padovese, Universidade de Sao Paulo, Departamento de Engenharia Mecanica, Sao Paulo, SP, Brazil; Francisco E. da Silva, **Elineudo P. Moura**, and Lindberg L. Gonçalves, Universidade Federal do Ceara, Departamento de Engenharia Metalurgica e de Materiais, Fortaleza, CE, Brazil

---This work aims to identify the changes in the microstructure of ferritic-pearlitic stainless steel, through the statistical fluctuation and fractal analyses of Barkhausen noise. The samples studied were obtained from pipes of steam pressure vessel, and presented coarse ferritic-pearlitic phases before degradation. Due to temperature effects, two different microstructures were obtained from pearlite that has partially and completely transformed to spheroidite. The statistical fluctuations of the Barkhausen signals are obtained by means of Hurst and detrended-fluctuation analyses, and the fractal analyses are carried out by applying the minimal cover and box-counting techniques to the signals. The curves obtained for the statistical fluctuations and fractal analyses, as functions of the time window, were processed by using pattern classification techniques such as principal-component analysis and Karhunen-Loève expansion. Approximately a 100% success rate has been reached for the classification of the different microstructures, for a larger set of events obtained within the bootstrap replication scheme.

Materials Properties

Inspection of Laser Welds with Acoustic Microscope

---Roman Gr. Maev and **Fedar M. Severin**, Institute for Diagnostic Imaging Research, Physics Department, University of Windsor, 401 Sunset Avenue, Windsor, Ontario, N9B 3P4, Canada

---The high frequency ultrasound imaging technique was applied for quality control of different kinds of laser welds originated in automotive production. Linear lap joints and C-shaped stitch welds on 1 mm zinc-coated steel sheets were examined as well as cylindrical butt welds for massive steel parts. Three-dimensional data cube were acquired on Tessonics AM 1103 pulse-echo scanning acoustic microscope with 25, 50 and 100 MHz spherically focused lenses. These data were processed to determine the basic parameters of joints and to estimate its overall quality. High resolution images of C- and B-scans represents welds seam geometry. The procedures of signal processing were optimized for spatial resolution in conditions of multiple re-reflections. Different types of defects (pinholes, porosity, cracks, lack of fusion) were detected and classified on acoustical images. The results were used as a basis for development of specialized instrumentation for inspection of automotive body parts and powertrain assemblies in industrial environment.

Materials Properties

Study of Aging Effects in 2205 Duplex Stainless Steel Using Thermoelectric Power Measurement

---**N. Ortiz-Lara**, A. Ruiz, and H. Carreón, Institute of Metallurgical Researches of the UMSNH, Morelia, Michoacán, México; U. Gonzalez-Zavala and A. Sánchez-Castillo, Department of Mechanical Engineering of the UMSNH, Morelia, Michoacán, México

---Thermoelectric power (TEP) measurements have been used as an effective method for evaluating the metallurgical state of various alloys. In the steel industry, some fabrication processes promote phase transformation and second phase precipitations which affect the material properties. Assessment of mechanical properties is critical in order to ensure quality of components. This work was conducted in order to evaluate the influence of the aging state of 2205 duplex stainless steel on TEP values. Commercial 2205 duplex steel was isothermally aged at 650 °C 700 °C and 900 °C at different aging times. TEP measurement technique was applied as a non destructive assessment technique to characterize the aging kinetics of the aged 2205 duplex stainless steel, hardness Rockwell (RC) and Charpy impact test were preformed to observe the effect of aging time on the specimens. Metallographic analysis was used to monitor phase transformation and sigma phase precipitation caused by the spinodal decomposition process of ferrite into secondary austenite and sigma phase. Results indicate that that the TEP is sensitive to gradual microstructural changes produced by the aging treatments.

Materials Properties

Detection of Anomalous Machining Damages in Inconel 718 and Ti 6-4 by Eddy Current Technqiues

---**C. C. H. Lo** and N. Nakagawa, Center for NDE, Iowa State University, 1915 Scholl Road, Ames, IA 50011

---This paper reports on an eddy current (EC) study aimed at detecting anomalous machining damages in Inconel 718 and Ti 6-4 samples, including (i) surface discontinuities such as re-depositing of or chips onto the machined surface, and (ii) microstructural damages manifested as a white or amorphous surface layer typically tens of microns thick. A series of pristine and artificially damaged coupons were studied by EC scans using a differential probe operated at 2 MHz to detect discontinuous surface anomalies, and by swept high frequency EC (SHFEC) measurements from 1 MHz to 65 MHz using proprietary detection coils to detect surface microstructural damages. A high frequency operation is needed for the latter in order to achieve sufficiently small skin depths in Inconel 718 and Ti 6-4 due to their low conductivities. In general, the EC c-scan data from machine-damaged surfaces show spatial variations with larger rms fluctuations than those from the undamaged surfaces. In some cases, the c-scan images exhibit characteristic bipolar indications in good spatial correlation with surface anomalies revealed by optical microscopy and laser profilometry. Results of the SHFEC measurements indicated a reduced surface conductivity of the damaged surfaces compared to the undamaged surfaces of the same coupon.---This material is based in part upon work supported by the Federal Aviation Administration under Contract #DTFA03-98-D-00008, Delivery Order #0036, and supported in part by the Air Force Research Laboratory under contract # FA8650-04-C-5228 at Iowa State University Center for NDE.

Spot Welds

Real Time Ultrasonic Aluminum Spot Weld Monitoring System

---R. Gr. Maev, A. M. Chertov, and **W. Perez Regalado**, University of Windsor, Physics Department, Institute for Diagnostic Imaging Research, Windsor, Ontario, Canada

---Aluminum alloys pose several properties that make them one of the most popular engineering materials: they have excellent corrosion resistance, and high weight-to-strength ratio. Resistance spot welding of aluminum alloys is widely used today but oxide film and aluminum thermal and electrical properties make spot welding a difficult task. Electrode degradation due to pitting, alloying and mushrooming decreases the weld quality and adjustment of parameters like current and force is required. To realize these adjustments and ensure weld quality, a tool to measure weld quality in real time is required. In this paper, a real time ultrasonic non-destructive evaluation system for aluminum spot welds is presented. The system is able to monitor nugget growth while the spot weld is being made. This is achieved by interpreting the echoes of an ultrasound transducer located in one of the welding electrodes. The transducer receives and transmits an ultrasound signal at different times during the welding cycle. Valuable information of the weld quality is embedded in this signal. The system is able to determine the weld nugget diameter by measuring the delays of the ultrasound signals received during the complete welding cycle. The article presents the system performance on aluminum alloy AA6022.

Spot Welds

Finite Element Modeling of Wave Propagation During In-Line Ultrasonic Monitoring of Spot Welds

---**Janusz Kocimski**, Paweł Kustroń, and Andrzej Ambroziak, Wroclaw University of Technology, Mechanical Department, Institute of Production Engineering and Automation, Welding Division, Wroclaw, Poland; Janusz Kocimski, Paweł Kustroń, Anthony Karloff, Waldo Perez Regalado, Andriy M. Chertov, and Roman Gr. Maev, University of Windsor, Physics Department, Institute for Diagnostic Imaging Research, Windsor, Ontario. Canada

---This article presents the problem of ultrasonic wave's propagation in multilayer media. Using the Finite Element Method (FEM) a simulation of wave propagation was developed for real time quality control of spot welds. The simulation allows see factors affecting wave propagation during the welding process. FEM analysis is a very good way to understand the influence of temperature distribution and indentation on the time of flight (TOF) through the weld. This article presents a comparison between FEM simulations and experimental results. The analysis indicates a correlation with experimental data, which confirms that the models were prepared correctly and that certain simplifications had no significant influence on the results. FEM modeling is a very good technique which helps optimize the welding system geometry (for example shape of the electrode) and to visualize the behaviour of ultrasonic wave propagation inside chosen elements of the welding set-up.

Signal Processing Techniques

An Improved Processing Algorithm for Guided Wave Phased Array in Plate Structures

---**Hyu-Sang Kwon**, Seung-Hyun Cho, and Seung-Seok Lee, Korea Research Institute of Standards and Science, P.O. Box 102, Yuseong, Daejeon 305-600, Korea; Jin-Yeon Kim, School of Civil and Environmental Engineering, Georgia Institute of Technology, Atlanta, GA 30332

---This paper describes a general approach for processing data from an omni-directional guided wave transducer array for the inspection of damage in a large plate structure. A basic phased array algorithm is presented that can be applied to any array geometry. The beamforming is the method in which the signals from different sensors are delayed-and-summed and the summed signal amplitude is maximized by adjusting the delay at each sensor. The result is that the phase-coherent line coincides with the incoming wave front from which the wave front shape is determined. Since, in a circular array which is preferred due to its omni-directionality, the array geometry is not coincident with the wave front, its beam pattern suffers from high sidelobe levels. A compensating weighting vector is proposed that reduces the sidelobes and thus improve the inspection performance. In particular, the beam steering algorithm is derived for guided waves on a plate, and the corresponding beam pattern to the array shape is obtained. The processing algorithm proposed is validated through numerical simulations and experiments. These results demonstrate the usefulness of the proposed method in the guided wave phased array.

Signal Processing Techniques

Acoustic Emission Signal Processing Based on Wavelet Analysis for Grinding Process Monitoring

---**Jing Yang**, Shui-Zhu Xu, Zhong-Ning Zhang, and Jian-Chun Cheng, Key Laboratory of Modern Acoustics, MOE, and Institute of Acoustics, Nanjing University, Nanjing 210093, Jiangsu Province, P. R. China; Xiang-Xiong Liu, Hiecise Machines Co, Ltd., Kunshan 215337, Jiangsu Province, P. R. China

---It is believed that the acoustic emission (AE) signals contain potentially valuable information for grinding wheel and workpiece conditions during automatic grinding process. However, AE signals produced in the grinding zone are usually much more complicated and it is difficult to obtain enough effective information directly from raw measurement signals. This paper presents an efficient feature extraction method of AE signals based on wavelet analysis for grinding process monitoring system. The approximation and detail coefficients at all resolutions are obtained at different scales according to the discrete wavelet transform. The energy of each decomposed component is computed and all of these energy features form the feature vectors of AE signals. Dominant features can be chosen and threshold values can be set in order to identify the changes of different grinding conditions. Feasibility of this method is demonstrated by various conditions in the grinding experiments.

Signal Processing Techniques

A Preemphasis Technique to Broaden the Usable Frequency Range in Time Delay Spectrometry Systems

---**Paul M. Gammell**, Gammell Applied Technologies, LLC, Exmore, VA 23350; Subha Maruvada, Yunbo Liu, and Gerald R. Harris, U.S. Food and Drug Administration, Center for Devices and Radiological, Health, Ultrasonics Laboratory, Silver Spring, MD 20903

---Time Delay Spectrometry (TDS) measures the frequency response of a system by applying a swept frequency source and using a tracking receiver to select only those signals that have the desired time delay. Due to the greater time-bandwidth product, this approach provides considerable signal-to-noise improvement over Fourier transform techniques. With all ultrasonic techniques the response of the transducers and the corresponding signal-to-noise considerations limit the usable frequency range. Since the TDS source is swept in frequency, the spectral content can be tailored to partially compensate for this loss of response due to the transducers. To that end, a preemphasis option has been designed for use with TDS systems. This option consists of a variable gain amplifier together with an arbitrary waveform generator that is synchronized with the frequency sweep of the TDS system. For attenuation measurements the frequency range over which useful data can be obtained in highly attenuating materials is extended. For substitution calibration of hydrophones, removing the response of the source transducer provides a wider range of data of high accuracy. Additionally, the spectral response can be adjusted so that a display of the raw data shows the hydrophone response directly, without requiring correction for the transducer response.

Signal Processing Techniques

Lamb Wave Pipe Coating Disbond Detection and Assessment Using the Dynamic Wavelet Fingerprinting Technique

---**Mark K. Hinders** and Jill P. Bingham, Department of Applied Science, College of William and Mary, Williamsburg, VA 23187-8795

---This talk describes combined experiments and simulations to automate the extraction of ultrasonic guided wave mode arrivals in order to gain quantitative information about large-diameter pipeline coatings. The dynamic wavelet fingerprint technique (DWFT) is used to show differences between unknown coatings as well as to identify the presence of delamination and grinding flaws within the Lamb wave propagation path. Combined with complex multi-layered models to help interpret the guided wave feature changes, this extraction algorithm can be used for the detection of hidden flaws under a variety of protective coatings without having to disturb the coating or pipeline flow. High-resolution supercomputer simulations are developed using the elastodynamic finite integration technique (EFIT) accounting for the 3D interaction of realistic Lamb wave beams with finite-sized coating delaminations.

NDE for Materials

NDE Residual Stress — New Technique
---**Ennio Curto**, R&D Vicenza (Italy), Via E.di Velo, 84, 36100, Italy

---This type of non-destructive method NDT provides the possibility to measure residual stress and the effect of the service load with an impact device and a vibration measurement sensor. Introduction: Internal stresses are to be considered as the following: 1) Operational strains referring to loads that the material is subject and calculated 2) Residual stresses in the material caused by heat treatments or stresses caused by welding, forging, casting, etc. The new technique is able to measure the applied load and residual stress that are balanced on the surface of the material, and in a relatively large volume, at times even the same size as the entire structures. This stress is part of the metal's elasticity field and has a three axis spatial orientation. Description: Impact with the metallic surface results an elastic deformation energy. Ed = Ei – (Ek + Ep); Ei = Impact energy Ek = Kinetic energy; Ed = elastic deformation energy Ep = plastic deformation energy + lost energy; Ed = ½ K dx^2 = ½ m ω^2 dx^2 K = constant elastic material (stiffness); Behavior elastic metals, due to new discovery.

NDE for Materials

Dislocation Detection Through Harmonic Generation
---**Brian T. Reinhardt**, Kate Boudreau, Matt Kropf , and Bernhard Tittmann, Pennsylvania State University, Department of Engineering Science and Mechanics, State College, PA 16802

---The goal of ultrasonic nondestructive evaluation is to characterize material defects before failure. In the fatigue mode, dislocations tend to nucleate and generate stress concentrations, which lead to failure. Recent research has indicated that nonlinear harmonic generation can be used to distinguish between materials of high and low dislocation densities. This research reports nonlinear harmonic generation measurements to locate areas of dislocation densities in copper bars. The copper bars were subjected to flexural fatigue, over increasing fatigue cycles. The bars were scanned periodically to track dislocation density evolution up to the point of failure. We show that this technique provides improved early detection for critical components of failure.

NDE for Materials

Nonlinear Parameters for a Diagnosis of Micro-Scale Cracks Using a Nonlinear Resonant Ultrasound Spectroscopy (NRUS)
---**Yong-Moo Cheong** and Mohammad Khurshed Alam, Nuclear Materials Research Division, Korea Atomic Energy Research Institute, Yusong P. O. Box 105, Daejon, 305-600, Korea

---The damage produces a nonlinear stress-strain relationship and the nonlinearity can be measured by increasing excitation amplitudes. The more damage, the larger is the level of a nonlinearity, and it can be used to for diagnosis of micro-cracks. Nonlinear Resonant Ultrasound Spectroscopy (NRUS) can investigate and analyze the amplitude dependence of certain resonance frequencies and uses this information to quantify the degree of nonlinearity and diagnose the micro-cracks. The amount of non-linearity is highly correlated to the damaged state of the material. In this study a feasibility of NRUS for a diagnosis of micro-scale cracks are investigated. A shift of resonance frequency as a function of driving voltage or strain is chosen as a nonlinear parameter to correlate the micro-cracks or damage. In addition we found a normalized resonance pattern also reflects the nonlinearity and the normalized patterns of intact sample and cracked sample were compared and analyzed.

NDE for Materials

Study on the Structural Variation of Rare Earth Doped Titanium Dioxide from Wet Gel to Nanocrystals by Photoacoustic Spectroscopy
---Haiyan Wang, **Yuetao Yang**, Wansong Chen, Xiaojun Liu, and Shuyi Zhang, Key Laboratory of Modern Acoustics, Institute of Acoustics, Nanjing University, Nanjing, Jiangsu, China (PRC)

---In this work, erbium ion doped titanium dioxide (Er3+ - TiO2) nanocrystals were prepared by a sol-gel method. The structural variation of TiO2 nanocrystals powders heated at different temperatures were investigated using Er3+ as a probe by means of photoacoustic (PA) spectroscopy, X-ray diffraction (XRD) and thermal analysis (DSC-TGA). The results showed that during the heat treatment, as the water and ethanol in the samples vaporized further, the condensation and polymerization reaction went on deeply. The PA absorption bands of f-f transitions of Er3+ ion were used to interpret the structural change of the samples. It was found that nephelauxetic effect (1-β) of Er3+ ion increased as the temperature increasing, and the PA branching vector of the hypersensitive transition increased too. However, after heat treatment over 900°C the nephelauxetic effect (1-β) of Er3+ ion decreased. The unusual spectrum change was discussed in relation to the phase transition from anatase to rutile of the Er3+-ion-doped TiO2 nanocrystals. It was also approved that the variation of photoacoustic absorbtion edges can be used to evaluate the quality of TiO2 nanocrystal.

NDE for Materials

Evaluation of Fatigue Degradation Using Nonlinear Ultrasonic

---**Kyung-Young Jhang**, School of Mechanical Engineering, Hanyang University, Seoul, South Korea; Tae-Hun Lee and Ikhwang Choi, Graduate School of Hanyang University, Seoul, South Korea

---A study about evaluating rotating bar fatigue and tensile fatigue in SUS316L specimen using nonlinear ultrasonic was reported. The nonlinearity of ultrasonic can be estimated by relative nonlinearity parameter that is defined by the ratio of fundamental and second harmonic wave amplitude. For experiment, a measurement system with contact transducers was constructed. Two types of SUS316L specimen were used in experiments : one was rotating bar fatigue specimen and another was tensile fatigue specimen. The former has cylindrical shape and was used to observe the change of nonlinearity parameter while the fatigue was accumulated in a specimen. The latter is a plate-shaped specimen and was used to confirm the change of nonlinearity parameter in the spot where the stress concentration was occurred. Measured nonlinear parameter showed strong correlation with damage level of fatigue.

NDE Applications

CSI Helsinki: SWLI In Forensic Science: Comparing Tool Marks of Diagonal Cutting Pliers

---Patrik K. Ahvenainen, Kalle Hanhijarvi, and **Edward Haeggstrom**, Electronics Research Unit, Department of Physics, University of Helsinki, P. O. Box 64, FIN-00014, Finland; Ivan V. Kassamakov, Department of Micro and Nanosciences, Helsinki University of Technology, P. O. Box 3500, FI-02015 TKK, Finland; Juha Aaltonen, Helsinki Institute of Physics, University of Helsinki, P. O. Box 64, FIN-00014, Finland; Kurt Kokko and Tapani Reinikainen, National Bureau of Investigation, Forensic Laboratory, Vantaa, Finland

---Main contribution: We show that Scanning White Light Interferometry (SWLI) rapidly and nondestructively provides relevant 3D images with sub-micron range depth resolution for forensic tool mark comparison. Comparison microscopes are commonly used in forensic laboratories, where experts compare 2D images qualitatively. Confocal microscopes offer 3D imaging but are slow and employ high-power coherent light that may damage sensitive samples. SWLI solve these problems by enabling rapid nondestructive three-dimensional (3D) surface profiling relevant to forensic science. Cutting tools leave characteristic marks that can connect a set of tool marks to an individual tool. As proof of principle we imaged cut copper wire (2.1±0.1 mm diameter). Ten wire pieces were soldered onto a test printed circuit board (PCB). The test samples were cut with cutting pliers into (10±1) mm pieces maintaining a predefined blade orientation. A particular part of the blades was used for the cutting. Both 2D and 3D images were obtained by SWLI (2.5x magnification). For the 2D images the microscopic striation patterns in different samples were compared. 3D images of the cut profile obtained at the same position in the cut surface in different samples were compared. The results show that SWLI non-destructively gather quantitative 3D information that allows a more complete and objective forensic examination of tool marks.

NDE Applications

Real-Time Examination for Mines on Ship Hulls Using Rayleigh-Lamb Waves

---**Mark K. Hinders** and Jill P. Bingham, Department of Applied Science, College of William and Mary, Williamsburg, VA 23187-8795; Adam Friedman, Solers, Inc. Sensor Technology Division, 3811 North Fairfax Drive, Suite 950, Arlington, VA 20155

---This talk describes the use of ultrasonic guided waves for identifying the mass loading due to underwater limpet mines on ship hulls. The Dynamic Wavelet Fingerprint Technique (DFWT) is used to render the guided wave mode information in two-dimensional binary images because the waveform features of interest are too subtle to identify in time domain. The use of wavelets allows both time and scale features from the original signals to be retained, and image processing can be used to automatically extract features that correspond to the arrival times of the guided wave modes. For further understanding of how the guided wave modes propagate through the real structures, a parallel processing, 3D elastic wave simulation is developed using the finite integration technique (EFIT). This full field, technique models situations that are too complex for analytical solutions, such as built up 3D structures. The simulations have produced informative visualizations of the guided wave modes in the structures as well as mimicking directly the output from sensors placed in the simulation space for direct comparison to experiments. Results from both drydock and in-water experiments with dummy mines are also shown.

NDE Applications

Detection of Mine Roof-Fall Precursers in Microseismic Signals

---**Mark K. Hinders** and Crystal A. Bertoncini, Departments of Applied Science and Physics, College of William and Mary, Williamsburg, VA 23187-8795

---The goal of our work is to provide a wireless web of communication nodes and microseismic sensors that allow trapped miners to communicate with rescue personnel on the surface as well as provide warning for both impending roof fall and danger of mining into adjacent water-filled vacancies. In this study, we have shown that fuzzy classification techniques can simplify the problem of judging seismic magnitude significantly. In particular, the fuzzy classification methods we describe can be used not only to measure seismic activity but to predict roof falls. The features selected for classification include those specific to the shape of the waveform as well as features related to spectral source parameters. The k-means clustering technique resolved significant events and motivated the calibration of the Roof Fall Index. Events with a Roof Fall Index above 30 are shown to predict roof falls by as much time as several hours to a few days, which could be used to mitigate mining hazards.

NDE Applications

Acoustic Parametric Array for Identifying Standoff Targets

---**Mark K. Hinders** and Kevin E. Rudd, Department of Applied Science, College of William and Mary, Williamsburg, VA 23187-8795

---This talk presents an integrated simulation method for investigating nonlinear sound beams and 3D acoustic scattering from any combination of complicated objects. A standard finite-difference simulation method is used to model pulsed nonlinear sound propagation from a source to a scattering target via the KZK equation. Then, a parallel 3D acoustic simulation method based on the finite integration technique is used to model the acoustic wave interaction with the target. Any combination of objects and material layers can be placed into the 3D simulation space to study the resulting interaction. Several example simulations are presented to demonstrate the simulation method and 3D visualization techniques. The combined simulation method is validated by comparing experimental and simulation data and a demonstration of how this combined simulation method assisted in the development of a nonlinear acoustic concealed weapons detector is also presented.

Various Techniques

Comparative Analysis of Selected Eddy Current Transducers for Titanium Alloy Evaluation

---**Tomasz Chady**, Ryszard Sikora, Piotr Baniukiewicz, and Przemyslaw Lopato, West Pomeranian University of Technology, Department of Electrical and Computer Engineering, Szczecin, Poland

---Titanium alloy based details due to their mechanical properties continue to be in extensive use in various structures (mainly aerospace, automotive and petro-chemical industrial applications). In this paper comparative study of various types of eddy current NDT transducers was done. Probes of absolute, differential and array configurations were constructed and analyzed. Finite Element Method (FEM) models were made. Two and three dimensional numerical analysis were done in order to find the best type and configuration of the proposed transducers. An influence of titanium alloy heterogeneity (changes of conductivity in the vicinity of the surface) on detection abilities were also investigated. The measurements of titanium alloy 7 mm thick plates with artificial defects (EDM notches) in case of all proposed configurations were made. Multi-frequency excitation and acquisition were utilized. Based on FEM numerical analysis and measurements results, probability of flaws detection (having various depth and size) was evaluated. The highest sensitivity configuration and type of transducer were selected.

Various Techniques

Matrix Eddy Current Probes for Molten Metal Level Measuring

---I. V. Terekhin[1] and **A. D. Pokrovskiy**, Moscow Power Engineering Institute (MPEI TU), Krasnjkazarmennaya str., 111250; A. N. Sorokin, Company, Techno-UP, Moscow

---This paper demonstrates the application of matrix eddy current probe for molten metal level measuring during continuous casting in small section molds. Currently, for an estimation of metal level in small section molds, different radioactive probes are commonly used. But these probes are known as potentially dangerous and have slag sensitivity. We have developed a computer electromagnetic field model of the matrix eddy current probe. In this model, we also considered the particularities of the temperature distribution in mold volume, which is depended on metal level. The eddy current probe measures the molten metal level through a copper mold with a wall thickness of 8 – 20 mm. Its measurement accuracy is approximately 5 mm. Static and dynamic characteristics of the matrix eddy current probe have been determined during a series of tests. The test results have been used to validate and supplement the results of computer and laboratory simulation, helping to improve the operational capability of the matrix eddy current probe. Our tests demonstrated that basic technical characteristics of the matrix eddy current probe are comparable to those of the radioactive probe. Additionally, there is no slag influence on the matrix eddy current probe signal.

Various Techniques

Limitation of Measurable Defect Thickness of the Wall Thinned Pipe Using Speckle Shearing Interferometry

---Kyeongsuk Kim and **Hyunchul Jung**, Dept. of Mechanical Design Engineering, Chosun University, 375 Seoseok-Dong, Dong-Gu, Gwangju, 501-759, Korea; Hoseob Chang, Laser Center, Chosun University, 375 Seoseok-Dong, Dong-Gu, Gwangju, 501-759, Korea; Dongpyo Hong, Division of Precision Mechanical Engineering, Chonbuk National University, 664-14 1Ga Duckjin-Dong, Duckjin-Gu, Jeonju, Jeonbuk, 561-756, Korea; Manyong Choi, Korea; Research Institute of Standard and Science (KRISS), P.O.Box 102, Yuseong, Daejeon, 305-600, Korea

---The limitation of measurable defect thickness of the wall thinned pipe using speckle shearing interferometry is presented. Some parameters such as length, width, and thickness of a defect can be considered to detect a wall thinned defect in a pipe. Among others, measuring the thickness of a defect is important for preventing an accident in the piping system. Speckle shearing interferometry is one of the optical non-destructive testing methods and can measure a defect inside and/or outside of a pipe. In experiment, ASTM A106 Gr.B pipes are used as specimen and the internal pressure loading is provided. For acquiring the deformation distribution along the center line of the longitudinal direction and the radial direction on the defect area accurately, the numerical shape compensation technique and deformation reconstruction algorithm which was developed in previous study are used. When the width of the wall thinning defect is constant and the length and thickness of the defect is varied, the deformation distributions of each cases are compared each other. From the result, when the minimum defect thickness is (t_nom)/8, the deformation distribution cannot be measured accurately even though the length of the defect is changed.

Various Techniques

Crack Modeling for Radiography

---**Tomasz Chady** and Lech Napierala, West Pomeranian University of Technology in Szczecin, Szczecin, Department of Electrical Engineering, st. Sikorskiego 37, 70-313 Szczecin, Poland

---Computer simulation is a powerful tool, which usefulness is hard to overestimate. Having a computer model of real-life object is usually highly advantageous, as it provides convenient and cheap way to test it's behaviour in different situations. Non-destructive testing is by no means an exception to this – three-dimensional model of a defect would be invaluable in many applications. In this paper, the possibility of obtaining such a model of a crack from radiographic image is discussed. Method for storing crack in a number of two-dimensional matrices, as well algorithm for their reconstruction into a three -dimensional object is presented. Also the possibility of using iterative algorithm for matching simulated crack to a real-life radiographic image is discussed. Proposed algorithm works in a following way: Firstly, the image of crack is analyzed. Information about amount of branches, their length, width etc. is extracted. Basing on this data, a three-dimensional model of a crack is computed. This crack is then subtracted from a model of solid object, x-rayed with x-ray simulation tool and compared with original. With respect to results of comparison, crack's model is modified, and x-rayed again. With each step of this procedure difference between real-life and simulated radiograms is minimized.

Various Techniques

Development of an Underwater Radiography Inspection System for Inspection of Flexible Risers

---**P. I. Nicholson**, E. Rasselkorde, TWI Technology Centre Ltd., ECM2, Heol Cefn Gwrgan, Margam, Port Talbot SA13 2ZE, Wales, United Kingdom

---Flexible risers are used for supplying oil from the deep sea to the offshore platforms and Floating Production Storage and Offloading (FPSO) vessels. The pipes are flexible in order to accommodate the sea motion of the FPSO and are therefore subject to mechanical stress over their 10-30 year lifetime. Flexile risers comprise a number of layers of steel and polymer that have a complex structure and some of the layers are shielded by others making Non Destructive Testing particularly difficult. There is currently no method of examining, in situ, the underwater risers and flow lines to ensure their continued reliable high-integrity operation. This paper presents the design and development of a new underwater radiography inspection system prototype for inspection of flexible risers. A prototype system has been implemented by developing a gamma source and a marinised digital flat panel detector. Radiographic images of the internal walls of flexible risers are imaged both in and out of water using the double wall single image radiography technique.

Various Techniques

Magnetic Response Field of Spherical Defects within Conductive Components
---**M. Kreutzbruck**, H.-M. Thomas, C. Casperson, R. Sickert, and R. BÃhm, Federal Institute for Materials Research and Testing, Nondestructive Testing Department, 12205 Berlin, Germany

---The determination of magnetic distortion fields caused by inclusions hidden in a conductive matrix using homogeneous current flow needs to be addressed in multiple tasks of electromagnetic non-destructive testing and materials science. This includes a series of testing problems such as the detection of tantalum inclusions hidden in niobium plates, metal inclusion in a nonmetallic base material or porosity in aluminum laser welds. Unfortunately, easy tools for an estimation of the defect response fields above the sample using pertinent detection concepts are still missing. In this study the Finite Element Method (FEM) was used for modeling spherically shaped defects and an analytical expression developed for the strength of the response field including the conductivity of the defect and matrix, the sensor-to-inclusion separation and the defect size. Finally, the results were adapted to Eddy Current Testing problems, in which the skin effect was taken into consideration for an appropriate estimation of the signal strength.

Various Techniques

Energy Propagation in Anisotropic Material
---**Ernest L. Roetman**, Embry-Riddle Aeronautical University, Whidbey Island Center, Oak Harbor, WA 98249

---The elastodynamic wave propagation problem has been formulated and discussed as a first order system of equations and general remarks about dissipation and energy transport have been reported in the literature with some discussion for isotropic material. Formulations of dissipation effects in this setting are seen to be transparent and their relation to traditional formulations are investigated. A detailed formulation of the equations determining energy transport and wave attenuation for anisotropic material is given. The energy balance at an interface is investigated in general and for a representative material to exhibit the robustness of the methods and to illustrate the specific effects to expect due to the anisotropy.

Various Techniques

Wave Properties of Direct Deposit Piezoelectric Sensors for Structural Health Monitoring Applications

---**Nicholas J. Cusolito**[1], Jeong K. Na[2], and James L. Blackshire[1]; [1]Air Force Research Lab (AFRL/RXLP), Wright-Patterson AFB, OH 45433; [2]University of Dayton Research Institute, Dayton, OH 45469

---Recent developments of Sol-Gel based direct deposited lead-zirconate-titanate (PZT) piezoelectric transducers prompted an investigation into the consistency of their sensing characteristics. Five samples were evaluated to determine if the manual manufacturing process inherently creates behavioral differences from sensor to sensor. This includes the complexity involved in precisely applying the Sol-Gel based PZT layer in a uniform and consistent thickness when deposited on the aluminum test plates. Tests characterizing the transducers under investigation include resonate frequency measurements, harmonic distortion, damping characteristics, and their energy distribution over the active area of the sensors. Results indicate that the sensors, which were initially designed to operate between 5 MHz and 10 MHz, meet this specification and vary by no more than 2 MHz among samples. The transducer oscillated only two cycles after an impulse was applied. A 40 dB drop in amplitude from the fundamental frequency of each specimen was consistently measured by the third harmonic peak. Laser interferometer measurements determined that the amplitude distribution across the active area of the material deposited remained relatively uniform among the sensors. Despite the minor physical differences incurred during their fabrication, the transducers displayed consistent properties, which can be improved upon further. The transducers could be a viable option for current low profile transducer applications, especially considering they enable elimination of the need to use ultrasonic coupling agents. A Lithium Niobate single crystal transducer element and a commercial off-the-shelf transducer are compared for their ultrasonic properties.

Bio Material Applications

A Deformable Template Model with Feature Tracking for Automated IVUS Segmentation

---Prakash Manandhar and **Chi Hau Chen**, Bioengineering Program and ECE Department, University of Massachusetts Dartmouth, Electrical and Computer Engineering, 285 Old Westport Road, N. Dartmouth, MA 02747-2300

---Intravascular Ultrasound (IVUS) has been established as a useful tool for diagnosis of coronary heart disease (CHD). Recent developments have opened the possibility of using IVUS to create a 3D map from which preventative prediction of CHD can be attempted. Segmentation of IVUS images is an important step in this process. However reliable automated segmentation has been elusive, in part because of the variety of image features that are invariably present in the image that distract from the main segmentation objectives. Active contour models (ACM)s have been used successfully for automated segmentation of IVUS images. However, the accuracy of the segmentation is still not adequate for clinical use. Here we describe a new approach of a constrained deformable template model (DTM) that improves on the standard ACM algorithm by (1) detecting other distracting image features (2) using tracking algorithms to obtain a better estimate of the positions of these features (3) including the knowledge of these positions to eliminate distortions in the ACM due to these features. In addition, semantic constraints are built into the DTM so that computational time is not wasted in improbable segmentation results. Our results show that this is a promising approach to achieving fully automated segmentation with accuracy comparable to manual segmentation.

Bio Material Applications

Ultrasonic Radiation Force for Debubbling Blood

---**Mark K. Hinders** and Cara A. Campbell, Departments of Applied Science and Physics, College of William and Mary, Williamsburg, VA 23187-8795

---In this work we investigate the removal of emboli from cardiopulmonary bypass circuits via acoustic radiation force. Unless removed by a combination of filters and active debubblers, emboli can be a significant source of cognitive deficit for those undergoing heart surgery. There are a variety of mathematical models in the literature describing acoustic radiation force, but a lingering question remains how important viscosity of the blood and/or embolus is to the process. We have implemented both inviscid linear and viscous non-linear models for radiation force on a sphere immersed in a fluid. These models allow for prediction of radiation force as a function of embolus size and frequency in order to identify the optimal frequency for clinical use. The models were run for various material combinations relevant to cardiac surgery: an air bubble in blood and a lipid embolus in blood. When the viscosity of the scatterer and/or surrounding fluid is large, the two models yield different results as expected, but for the clinical emboli removal application the inviscid model is adequate given the inherent uncertainty in the knowledge of material parameters and the significant additional computation effort required to include viscosity.

Bio Material Applications

Ultrasonographic Detection of Tooth Flaws

---**Mark K. Hinders** and Crystal A. Bertoncini, Departments of Applied Science and Physics, College of William and Mary, Williamsburg, VA 23187-8795; Sleiman R. Ghorayeb, Hofstra University, Biomedical Sciences and Electrical Engr. Divisions, 104 Weed Hall, Hempstead, NY 11549

---The goal of our work is to adapt pulse-echo ultrasound into a high resolution imaging modality for early detection of oral diseases and for monitoring treatment outcome. In this talk we discuss our preliminary results in the detection of: demineralization of the enamel and dentin, demineralization or caries under and around existing restorations, caries on occlusal and interproximal surfaces, cracks of enamel and dentin, calculus, periapical lesions, etc. In vitro immersion tank experiments are compared to results from a handpiece which uses a compliant delay line to couple the ultrasound to the tooth surface. High-resolution computer simulations of the propagation of ultrasound in teeth, as well as the interaction of waves with flaws, are used to interpret experimental results. The dynamic wavelet fingerprint pattern classification algorithms are used to identify and delineate echographic features that correspond to the flaws of interest in teeth. Because the waveform echoes are complex, it is necessary to automatically interpret the signals via artificial intelligence, in order to make the clinical measurement simple to use and realtime. The immersion tank and free-hand data, combined with the computer simulations, are used as the training set for tuning the classifier.

Bio Material Applications

Ultrasonographic Periodontal Probing Depth Determination Via Pattern Classification

---**Mark K. Hinders** and Crystal A. Bertoncini, Departments of Applied Science and Physics, College of William and Mary, Williamsburg, VA 23187-8795

---Periodontal disease, commonly known as gum disease, affects millions of people. The current method of detecting periodontal pocket depth is painful, invasive, and inaccurate. As an alternative to manual probing, the Ultrasonographic periodontal probe is being developed to use ultrasound (US) echo waveforms to measure periodontal pocket depth, which is the main measure of periodontal disease. Wavelet transforms and pattern classification techniques are used in artificial intelligence routines that can automatically detect pocket depth. The main pattern classification technique used here, called a binary classification algorithm, compares test objects with only two possible pocket depth measurements at a time and relies on dimensionality reduction for the final determination. The method correctly identifies up to 90% of the US probe measurements within the manual probe's tolerance.

Bio Material Applications

Photoacoustic Nondestructive Evaluation and Imaging of Caries in Dental Samples

---**Teng Li** and Richard J. Dewhurst, Photon Science Institute, University of Manchester, Manchester, M13 9PL, United Kingdom

---Recently photoacoustic (PA) imaging has been extended as a new modality for non-invasive medical diagnosis and visualization. In photoacoustic imaging, the stress induced local deformation generates ultrasound that propagates through the sample. For the non-invasive photoacoustic measurement, induced temperature and pressure rises within biotissues should not cause physical damage to the tissue. For example, temperature rises within live human teeth above 5º C will cause pulpal necrosis. Therefore, several simulations based on the thermoelastic effect have been applied to predict temperature and pressure fields within samples. Predicted temperature levels are below corresponding safety limits, but care is required to avoid nonlinear absorption phenomena. Furthermore, samples have been studied to show good resolution imaging in both soft and hard tissue. For example, our 2-D imaging results using tissue phantoms based in PVA showed that a feature with diameter of 50 μm can be imaged to a depth of about 1.0 cm in turbid material. Moreover, 2-D and 3-D imaging results from post-mortem human teeth showed that the PA technique can be used to image human teeth caries. This may be the first time that examination of caries has been demonstrated by photoacoustic imaging techniques.

Bio Material Applications

Detection of Damage in Silicon Wafers and Biomaterials

---**Sri Harsha Kurra** and Jianmei Zhang, The University of Texas at El Paso, Department of Industrial Engineering, El Paso, TX 79902

---Nondestructive testing (NDT) has become an increasingly vital factor in the effective conduct of research, development, design and manufacturing. Only with the appropriate use of nondestructive testing techniques, the benefits of advanced materials science can be fully realized. NDT has a wide range of industrial applications and various methods and techniques are employed to perform the nondestructive testing. The current work aims to demonstrate the nondestructive testing technique applied to detect the subsurface damage in Silicon nitride and also to generate a flowchart to determine the most suitable nondestructive evaluation techniques in biomaterials based on their working mechanism and applications. A flowchart has been drawn based on the review of the current non destructive testing techniques in biomaterials. The results obtained from the nondestructive testing of silicon nitride are discussed along with the steps that are to be followed in non destructive testing of biomaterials.

Education

The Dynamic Model of Professional Competence Forming for Non-Destructive Testing Students

---**Anatoliy G. Protasov**, National Technical University of Ukraine “KPI”, NDT Department, Box 1760, 37 Prospect Peremohy Street, Kiev, 03056, Ukraine

---This paper is devoted to the problem of Non-Destructive Testing (NDT) specialist training. NDT is a complex specialty. Specialists have to acquire knowledge from different directions of engineering. Students study from physics of surface, electromagnetic field, optics, acoustics, and thermal physics to nucleus physics. Besides, they have to know how to use electronics (microprocessors, microcontrollers), programming, and signal processing technique to design NDT automatic system. So, preparation of the NDT engineers has distinctive features as compared with common engineer preparation. It is proposed dynamic model of professional competence forming for NDT students when they study at the university. The process of professional competence development consists of three stages according to this model. The first stage is devoted to diagnosis of student creative ability. It directs to eliminate factors, which block the development of students’ creative thinking. The second stage is used for forming stimulus- productive, heuristic, and creative levels of creative activity. The last one is used for stimulation of diagnostic, cognitive, and methodical activity of future specialists. The proposed model is allowed to form a high level of students’ professional competence, which help them to become proficient in the future profession.

Session 30

SESSION 30
PROBABILITY OF DETECTION II
E. Lindgren, Chairperson
Chafee 277

3:30 PM **Analysis of Variance for Probability of Detection Estimation with Transfer Function**
---**Y. Guo**, Siemens Energy, Inc., 4400 Alafaya Trail, Orlando, FL 32826

3:50 PM **Modeling of Sensor Tilt in Eddy Current — GMR Inspection and Its Use in POD Estimation**
---**G. Yang**, L. Udpa, S. Udpa, and Z. Zeng, Michigan State University, East Lansing, MI 48823

4:10 PM **Automatic Crack Detection Algorithm for Vibrothermography Sequence-of-Image Data**
---**M. Li** and W. Q. Meeker, Center for Nondestructive Evaluation and Department of Statistics, Iowa State University, Ames, IA 50011; S. D. Holland, Center for NDE and Department of Aerospace Engineering, Iowa State University, Ames, IA 50011

4:30 PM **A POD Model for Acoustic Emission — Discussion and Status**
---**A. A. Pollock**, MISTRAS Group Inc., Physical Acoustics Corporation, Princeton Junction, NJ 08550

4:50 PM **Quantitative NDI Integration with Probabilistic Fracture Mechanics for the Assessment of Fracture Risk in Pipelines**
---**J. H. Kurz**, D. Cioclov, G. Dobmann, and C. Boller, Institut Zerstörungsfreie Prüfverfahren (IZFP), Saarbrucken, Germany

5:10 PM **Model-Assisted Probabilistic Reliability Assessment for Structural Health Monitoring Systems**
---**J. C. Aldrin**, Computational Tools, Gurnee, IL, 60031; E. A. Medina, Radiance Technologies, Inc., Wright-Patterson AFB, OH 45433; E. A. Lindgren, C. Buynak, and M. Derriso, U.S. Air Force Research Laboratory, Wright-Patterson AFB, OH 45433

Analysis of Variance for Probability of Detection Estimation with Transfer Function

---**Yan Guo**, Siemens Energy, Inc., 4400 Alafaya Trail, Orlando, FL 32826

---Probability of Detection (POD) is an important quality metric for nondestructive evaluation on many applications such as aerospace, air force, power generation, constructions. A POD assessment methodology becomes the standard approach which estimated a 95% confidence level probability of detection curve from artificial flaws. Transfer function is a valid approach, because of its improved cost and expected performance, to transfer the POD estimation from the specimens with artificial flaws to the reality with the advantages of providing rapid response and broad applications. However, the variances from the real defects, NDE applications, and inspectors are important in the in determination of transfer functions. This paper will discuss the breakdown variances on POD estimations with transfer function and the analysis of tube to flange sealing welds on gas turbine combustor by ultrasonic inispection will be presented.

Modelling of Sensor Tilt in Eddy Current — GMR Inspection and Its Use in POD Estimation

---**Guang Yang**, Lalita Udpa, Satish Udpa, Zhiwei Zeng, Michigan State University, East Lansing, MI 48823

---An eddy current (EC)- giant magneto-resistive (GMR) inspection system comprising a multiple-line coil eddy current source and the GMR sensor that measures the normal component of magnetic field is proposed for detecting deep embedded flaws in multilayer structures. The performance of probe is affected significantly by sensor tilt. The sensitivity of the probe for detection of defects is studied with an aim to determining the probability of detection (POD) of critical subsurface flaws. A novel $\boldsymbol{A}_r,\boldsymbol{V}$-$\boldsymbol{A}_r$ formulation is presented for efficiently modelling the scan with a tilted sensor. The major advantage of this formulation is the elimination of the need for re-meshing at each coil position during a scan. The quantitative effect of probe tilt in terms of the resultant POD is demonstrated by considering a simple Aluminium plate of thickness 2.54mm. An 8mm diameter flat bottom hole is introduced on the bottom surface. The depth of the machined defect is varied systematically and signals generated using the multi-line coil sensor are predicted using the computational model. The sensor tilt is also varied from 0^0 to tilted 5^0 to generate the spread in signal parameters to be used in the estimation of the POD curves.

Automatic Crack Detection Algorithm for Vibrothermography Sequence-of-Image Data

---**Ming Li** and William Q. Meeker, Center for Nondestructive Evaluation and Department of Statistics, Iowa State University, Ames, IA 50011; Stephen D. Holland, Center for NDE and Department of Aerospace Engineering, Iowa State University, Ames, IA 50011

---Vibrothermography (Sonic IR, thermosonics) is a technique for finding cracks through frictional heat given off in response to vibration. Vibrothermography provides a sequence of infrared images as output of the inspection process. A fast and accurate automatic crack-detection algorithm for the sequence-of-image data will greatly increase the productivity of vibrothermography method. Matched filtering is a technique widely used in signal detection, and it is the optimal linear filter to maximize the signal to noise ratio in the presence of additive stochastic noise. Based on key features from images of known cracks, we can construct a three-dimensional matched filter to detect cracks from the vibrothermography data. In this paper, we evaluate the matched filter developed from a vibrothermography inspection sequence-of-images. The probability of detection for the matched filter detection algorithm is then compared with the probability of detection for a simpler detection algorithm that is based on a scalar measure of the amount of heat generated in an inspection. Our results show the matched filter algorithm provides improved detection capability when a flaw signature is known approximately.

A POD Model for Acoustic Emission - Discussion and Status

---**Adrian A. Pollock**, MISTRAS Group Inc., Physical Acoustics Corporation, Princeton Junction, NJ 08550

---Mathematical representations of the sequential stages of acoustic emission generation, propagation, sensing and signal processing were combined with familiar flaw growth theory, to give estimates of Probability of Detection (POD). This model does not address noise problems or human factors, but it gives a rather comprehensive treatment of mechanical stress stimulating flaws to produce AE signals above detection thresholds. Wave attenuation in large structures, and AE amplitude distribution effects are among the many variables included. The model was first applied to fatigue cracks growing according to the Paris law. It was later applied to crack initiation at weld undercut. The greatest current need is for practical field projects to get values for some of the input settings, and in general to prove the validity and limitations of this approach. Meanwhile, the model readily generates comparative data across a wide range of test variables. In AE test design, it is being used to explore the effects of changing sensor layout or changing the duration of in-service monitoring. One ultimate goal for this model would be to predict how long an AE system must monitor a structure in order to receive signals from significant flaws, reliably.

Quantitative NDI Integration with Probabilistic Fracture Mechanics for the Assessment of Fracture Risk in Pipelines

---**Jochen H. Kurz**, Dragos Cioclov, Gerd Dobmann, and Christian Boller, Institut Zerstörungsfreie Prüfverfahren (IZFP), Saarbrucken, Germany

---In the context of probabilistic paradigm of fracture risk assessment in structural components a computer simulation rationale is presented which has at the base the integration of Quantitative Non-destructive Inspection and Probabilistic Fracture Mechanics. In this study the static failure under static loading is assessed in the format known as Failure Assessment Diagram (FAD). The fracture risk is evaluated in probabilistic terms. The superposed probabilistic pattern over the deterministic one is implemented via Monte-Carlo sampling. The probabilistic fracture simulation yields a more informative analysis in terms of probability of failure. An important feature of the PVrisk software is the ability to simulate the influence of the quality and reliability of non-destructive inspection (NDI). It is achieved by integrating, algorithmically, probabilistic FAD analysis and the Probability of Detection (POD). The POD information can only be applied in a probabilistic analysis and leads to a refinement of the assessment. By this means, it can be ascertained the decrease of probability of failure when POD-characterized NDI is applied. Therefore, this procedure can be used as a tool for inspection based life time conceptions. In this paper results of sensitivity analyses are presented with the aim to outline, in terms of non-failure probabilities, the benefits of applying NDI, in various qualities, in comparison with the situation when NDI is lacking. A better substantiation is enabled of both the component reliability management and the costs-effectiveness of NDI timing.

Model-Assisted Probabilistic Reliability Assessment for Structural Health Monitoring Systems

---**John C. Aldrin**, Computational Tools, Gurnee, IL, 60031; Enrique A. Medina, Radiance Technologies, Inc., Wright-Patterson AFB, OH; Eric A. Lindgren, Charles Buynak, and Mark Derriso, U.S. Air Force Research Laboratory, Wright-Patterson AFB, OH 45433

---The lack of accepted validation protocols is a significant barrier to successful implementation of structural health monitoring (SHM) systems. Before the potential of SHM systems as enablers of condition-based maintenance and prognostic strategies can be realized, it is necessary for the performance of these systems to be validated in terms of their sensitivity with respect to the variables that they intend to monitor, their robustness with respect to benign changes in their operating environment, and their reliability over their expected useful life. This paper describes a model-assisted probabilistic reliability assessment methodology which consists of proposed statistical metrics of reliability for SHM systems used for damage detection, localization, and sizing, and a protocol designed for using empirical and simulated data for characterizing SHM methods in terms of the proposed statistical metrics, including uncertainty analysis. A multi-scale approach to the model-assisted evaluation is presented that attempts to minimize the number of samples, the length of time for testing, and the degree of full-scale testing required for obtaining statistically meaningful characterization results. The feasibility of applying this approach to typical sensing methods found in SHM systems is explored, and additional challenges concerning modeling efforts and uncertainty propagation are addressed.

Session 31

SESSION 31

X-RAY AND T-RAY

G.-R. Jaenisch and H. I. Ringermacher, Co-Chairpersons
Chafee 273

3:30 PM **Simulation of Electron Transport**
---M. Zhukovsky and M. Skachkov, Keldysh Institute for Applied Mathematics, Moscow, Russia; A. Deresch, **G.-R. Jaenisch**, and C. Bellon, BAM (Federal Institute of Materials Research and Testing), Division VIII.3 Radiology, Berlin, Germany

3:50 PM **Simulation and Experimental Verification of X-Ray Spectra**
---A. Deresch, **G.-R. Jaenisch**, and C. Bellon, BAM (Federal Institute of Materials Research and Testing), Division VIII.3 Radiology, Berlin, Germany; A. Warrikhoff, rtw Röntgentechnik Dr., Warrikhoff, Neuenhagen, Germany

4:10 PM **Micro-Structured Optical Fiber for X-Ray Detection**
---**S. L. DeHaven**, NASA Langley Research Center, Nondestructive Evaluation Sciences Branch, Hampton, VA 23681

4:30 PM **New Developments in Digital Radiographic Techniques: A Simulation Tool for Scattering Imaging**
---**A. Bonnin**, P. Duvauchelle, V. Kaftandjian, and J.Giot, INSA – Laboratoire CNDRI, Bât St Exupéry, 25 Av Jean Capelle, 69621 Villeurbanne, France

4:50 PM **Terahertz Subwavelength Structures for Sensing and NDE**
---A. Heifetz, **N. Gopalsami**, H.-T. Chien, and A. Raptis, Argonne National Laboratory, Nuclear Engineering Division, Argonne, IL 60439

5:10 PM **Production Process Monitoring of Multilayered Materials Using Time-Domain Terahertz Gauges**
---**D. Zimdars**, I. Duling, G. Fichter, and J. White, Picometrix LLC., Ann Arbor, MI 48104

Simulation of Electron Transport

--- Mikhail Zhukovsky and Mikhail Skachkov, Keldysh Institute for Applied Mathematics, Moscow, Russia; Andreas Deresch, **Gerd-Ruediger Jaenisch**, and Carsten Bellon, BAM (Federal Institute of Materials Research and Testing), Division VIII.3 Radiology, Berlin, Germany

---A method of efficiently calculating transport of electrons when injected into atomic matter with some initial energy is discussed. In contrast to neutral particles, movement of electrons and other charged particles within atomic matter is governed to a large extent by Coulomb scattering, resulting in a large number of individual interactions. The method based on novel model of grouped trajectories is developed without using multiple scattering theory. Corresponding statistical algorithm gives possibility to achieve high computational speed as well as accuracy. The method can be used to acquire different distributions of electron characteristics, namely energy, direction of movement, position within and point of ejection from the object. Ionization, excitation and radiative energy losses of the electrons are considered via a combined stopping power.

Simulation and Experimental Verification of X-ray Spectra

---Andreas Deresch, **Gerd-Ruediger Jaenisch**, and Carsten Bellon, BAM (Federal Institute of Materials Research and Testing), Division VIII.3 Radiology, Berlin, Germany; Alexander Warrikhoff, rtw Rontgentechnik Dr., Warrikhoff, Neuenhagen, Germany

---A model is discussed which describes the generation of X-rays in conventional tubes using tabulated Bremsstrahlung energy spectra depending on three variables: the target atomic number, the incident electron kinetic energy, and the fraction of energy radiated. The constructed model includes technical tube parameters like kilovoltage, target material and target angle to also account for self-absorption in the target, as well as radiographic parameters like filtering. Additionally a parameter-free description of the characteristic radiation is included in the model. With the help of the simulation tool the influence of parameters can be separately studied. The validity of the proposed model is shown by measurements. This research is supported by the German Federal Ministry of Economics and Technology under contract MNPQ transfer II D 5-30/06.

Micro-Structured Optical Fiber for X-Ray Detection

---**Stanton L. DeHaven**, NASA Langley Research Center, Nondestructive Evaluation Sciences Branch, Hampton, VA 23681

---A novel scintillating optical fiber is presented using a composite micro-structured quartz optical fiber. Scintillating materials are introduced into the multiple inclusions of the fiber. This creates a composite optical fiber having quartz as a cladding with an organic scintillating material core. Light is guided by total internal reflection within the scintillating material. The visible light generated inside the fiber by x-rays is detected using photomultiplier equipment. Two different types of sensors were fabricated, one with a liquid scintillator introduced into the inclusions, and the other contains a crystalline scintillating material. These materials have similar energy absorption characteristics however an x-ray generates more photons when absorbed by the crystal than when absorbed by the liquid. X-ray detection using these fibers is compared to a collimated cadmium telluride (CdTe) detector over an energy range from 10 to 40 keV. Results show a good correlation between the fiber count rate trend and that of the CdTe detector.

New Developments in Digital Radiographic Techniques: A Simulation Tool for Scattering Imaging

---**A. Bonnin**, Ph. Duvauchelle, V. Kaftandjian and J. Giot, INSA – Laboratoire CNDRI, Bât St Exupéry, 25 Av Jean Capelle, 69621 Villeurbanne, France

---This paper focus on a simulation tool used to compute X-ray imaging technique and the last developments with the calculation of the scattering. In particular, it allows evaluating the scattered contribution on a transmission detector but also simulating scattering technique as Compton or Rayleigh tomography. The simulation code named VXI (Virtual X-Ray Imaging), which is developed at the CNDRI laboratory, can simulate a wide range of X-ray imaging techniques. Based on a ray tracing algorithm, VXI is a deterministic code allowing to simulate, in particular, the Compton and Rayleigh scattering. Although VXI takes into account, for now, only the first order scattering, it presents the real advantage to obtain quality images and especially faster than Monte-Carlo methods. In addition, as the algorithm is deterministic, simulated images contain no photon noise. Afterwards, we can then test different noise levels representing various experimental conditions, without needing to perform the whole calculation. The computation of scattering radiation is based on a 3D sampling of the object where each voxel behaves as a secondary source. The algorithm uses the classical Klein-Nishina and Thomson modeling including the incoherent scattering function and the form factor. The algorithm performs a double ray tracing: from the source to each voxel, then from each voxel to each detector pixel. During the presentation, we will show the possibilities of the VXI software for the X-ray scattering techniques. Several acquisition methods of Compton scattering will be shown. We will focus the presentation on security field. According to the simulated images, we will detail advantages and drawbacks of the technique and its acquisition methods.

Terahertz Subwavelength Structures for Sensing and NDE

---Alexander Heifetz, **Nachappa Gopalsami**, Hual-Te Chien, and Apostolos Raptis, Argonne National Laboratory, Nuclear Engineering Division, Argonne, IL 60439

---The ability to control and concentrate electromagnetic (em) energy in length scales much smaller than the excitation wavelength opens up new opportunities for sensing and NDE. Ordinarily em wave transmission through such structures becomes infinitesimally small as the slit opening becomes much smaller than the wavelength; however, extraordinary transmission through these structures has been observed by researchers, which is believed to be due to surface plasmonic effect. We have investigated THz subwavelength slit structures and micro apertures for sensing and NDE. In a slit structure not only are the waves transmitted through with good signal-to-noise ratio but also are found to be resonating because of the open ends. As a result, it can sense the dielectric properties of materials, which may be in gas, liquid, or solid forms, with high sensitivity and selectivity depending on the quality factor of the cavity resonance. Subwavelength aperture allows for imaging of materials with spatial resolution below the Abbe limit. To understand the electromagnetic wave propagation through subwavelength structures and to help design high quality resonators, we have performed a full wave analysis of the em fields the with finite difference time domain (FDTD) technique. Simulated responses were verified with swept-frequency cw THz waves (230-300 GHz) through 50 μm slits.

Production Process Monitoring of Multilayered Materials Using Time-Domain Terahertz Gauges

---**David Zimdars**, Irl Duling, Greg Fichter, and Jeffrey White, Picometrix LLC., Ann Arbor, MI 48104

---The results of a factory trial time-domain terahertz (TD-THz) measurement of a multilayer industrial product will be presented. The measurements will be the simultaneous overall sample, and the individual layer, thickness. In additional, the capability to detect delaminations in the material will be demonstrated. Measurements will be made while scanning across the 12 foot wide moving web sample in a factory environment. TD-THz measurements, and subsequent deconvolution and model fit calculation of material properties from the TD-THz waveforms will be presented to demonstrate system precision and accuracy. A key capability is that a non-contact measurement of the basis weight and/or thickness of multiple layers of laminated materials can be made with a single TD-THz gauge. Suitability to the production environment for the TD-THz gauge will be discussed. Other examples of layer measurements will also be presented. TD-THz gauges can measured dimensions and properties within “opaque” materials. Dielectric materials (e.g., plastic, rubber, paper, paint) are basically transparent to THz pulses. Thus inspection of a very wide range of samples, including very thick materials, is possible. Measurements of applied adhesives and coatings will also be discussed.

Session 32

SESSION 32
NDE FOR MICROSTRUCTURE
A. Lasseigne, Chairperson
CBLS 010

3:30 PM **Assessment of the State of Precipitation in Aluminum Casting A356 Alloy Using Nondestructive Microstructure Electronic Property Measurements**
---**P. Kiattisaksri**[1], K. Koenig[1], E. A. Pfeif[1], A. N. Lasseigne[2], P. F. Mendez[3], B. Mishra[1], and D. L. Olson[1], [1]Colorado School of Mines, Golden, CO 80401; [2]Generation 2 Materials Technology LLC, Firestone, CO, [3]University of Alberta, Alberta, Canada

3:50 PM **Non-Linear Analytical Modeling of Interfacial Phenomena and Nano-Size Microstructural Features to Better Correlate NDE Electronic Property Measurements to the Material State**
---**J. E. Jackson**[1], J. A. Roubidoux[2], A. N. Lasseigne[1], B. Mishra[2], and D. L. Olson[2], [1]Generation 2 Materials Technology LLC, Firestone, CO, [2]Colorado School of Mines, Golden, CO 80401

4:10 PM **Characterization of Hydrogen Content in Zircaloy-4 Nuclear Fuel Cladding Utilizing NDE Electronic Property Measurements**
---**E. A. Pfeif**[1], A. N. Lasseigne[2], K. Krzywosz[3], E. V. Mader[3], B. Mishra[1], and D.L. Olson[1], [1]Colorado School of Mines, Golden, CO 80401, [2]Generation 2 Materials Technology LLC, Firestone, CO, [3]Energy Power Research Institute, Palo Alto, CA 94303-0867

4:30 PM **Non-Contact, Nondestructive Hydrogen Content Assessment of Steel Welds**
---**K. Koenig**[1], A. N. Lasseigne[2], J. W. Cisler[1], B. Mishra[1], and D. L. Olson[1], [1]Colorado School of Mines, Golden, CO 80401, [2]Generation 2 Materials Technology LLC, Firestone, CO 80504

4:50 PM **Electrochemical Impedance Analysis of β-Titanium Alloys as Implants in Ringers Lactate Solution**
---R. Bhola, **S. M. Bhola**, B. Mishra, and D. L. Olson, Colorado School of Mines, Golden, CO 80401

5:10 PM **Thermoelectric Power Measurements (TEP) for Ageing Kinetics in PH Steels**
---**Y. Snir**[1], Y. Gelbstein[2], S. Meir[3], and A. Landau[1], [1]Nuclear Research Center Negev, Negev, Israel; [2]Ben-Gurion University of the Negev, Negev, Israel; [3]Colorado School of Mines, Golden, CO 80401

Assessment of the State of Precipitation in Aluminum Casting A356 Alloy Using Nondestructive Microstructure Electronic Property Measurements

---**P. Kiattisaksri**[1], K. Koenig[1], E. A. Pfeif[1], A. N. Lasseigne[2], P. F. Mendez[3], B. Mishra[1], and D. L. Olson[1], [1]Colorado School of Mines, Golden, CO 80401; [2]Generation 2 Materials Technology LLC, Firestone, CO, [3]University of Alberta, Alberta, Canada

---Application of nondestructive electronic property measurements, thermoelectric power coefficients and low frequency impedance to assess the strengthening of Mg-Si precipitates in aluminum A356 casting has been demonstrated. The effect of solidification and cooling time on the evolution of cast microstructures has been investigated. The results indicated the evolution of precipitation phase through over aging with increased cooling time or thickness of the cast part. The classical optimum precipitation behavior has been characterized and verified with thermal analysis, thermoelectric power, low frequency impedance, and micro hardness measurements. A proposed practice to use nondestructive electronic property measurement tools to assess aluminum casting for acceptable mechanical properties on the foundry floor after mold shake out is presented.

Non-Linear Analytical Modeling of Interfacial Phenomena and Nano-Size Microstructural Features to Better Correlate NDE Electronic Property Measurements to the Material State

---**J. E. Jackson**[1], J. A. Roubidoux[2], A. N. Lasseigne[1], B. Mishra[2], and D. L. Olson[2], [1]Generation 2 Materials Technology LLC, Firestone, CO, [2]Colorado School of Mines, Golden, CO

---When the microstructural dimension approaches nano size and/or the interfacial phase boundary achieves space-charging behavior, the traditional linear driving force and mobility terms become insufficient to describe physical observations. Generation 2 materials science, which incorporates non-linear and higher-order phenomena, is needed to provide new insight and enable the prediction of transport and phase evolution in advanced materials. This paper correlates non-linear material properties by incorporating higher-order to suggested nondestructive electronic property measurements and practices which can be used to assess thin films, surface layers, and other advanced materials that exhibit modified behaviors based on their space-charged interfacial behavior.

Characterization of Hydrogen Content in Zircaloy-4 Nuclear Fuel Cladding Utilizing NDE Electronic Property Measurements

---**E. A. Pfeif**[1], A. N. Lasseigne[2], K. Krzywosz[3], E. V. Mader[3], B. Mishra[1], and D. L. Olson[1], [1]Colorado School of Mines, Golden, CO, [2]Generation 2 Materials Technology LLC, Firestone, CO, [3]Energy Power Research Institute, Palo Alto, CA

---Nondestructive tools are being used for diverse material property assessment to increase material health awareness. The assessment of hydrogen uptake of underwater nuclear fuel clad and component materials will enable improved monitoring fuel performance. Zirconium alloys are used in nuclear reactors as fuel cladding, fuel channels, guide tubes and spacer grids, and are available for inspection in spent fuel pools during outages. With increasing reactor exposure zirconium alloys experience hydrogen ingress due to water-side corrosion that is not easily quantified without destructive hot cell examination. A novel technique to assess the amount of hydrogen and hydride formation within Zircaloy 4 materials that are submerged in spent fuel pools using Seebeck coefficient measurements and low frequency impedance spectroscopy are presented.

Non-Contact, Nondestructive Hydrogen Content Assessment of Steel Welds

---**K. Koenig**[1], A. N. Lasseigne[2], J. W. Cisler[1], B. Mishra[1], and D. L. Olson[1], [1]Colorado School of Mines, Golden, CO 80401, [2]Generation 2 Materials Technology LLC, Firestone, CO 80504

---Nondestructive low frequency impedance has been developed to determine hydrogen content in operating pipeline steel and weldments through a structural coating. A low frequency impedance measurement is essentially a non-contact resistivity measurement. Dominant scattering mechanisms such as microstructure, residual stress, and temperature introduce variability in impedance measurements. Each of these variables must be separated out to obtain a hydrogen content measurement in operating pipelines (with a structural coating) using low frequency impedance. The use of real-time low frequency impedance measurements to monitor hydrogen content as it diffuses out of a steel weldment is presented and discussed.

Electrochemical Impedance Analysis of β-Titanium Alloys as Implants in Ringers Lactate Solution

---R. Bhola, **S. M. Bhola**, B. Mishra, and D. L. Olson, Colorado School of Mines, Golden, CO 80401

---Commercially pure titanium and two β-titanium alloys, TNZT and TMZF, have been characterized using various electrochemical techniques for their corrosion behavior in Ringers lactate solution. The variation of corrosion potential and solution pH with time has been discussed. Electrochemical Impedance Spectroscopy has been used to fit the results into a circuit model. The stability of the oxides formed on the surface of these alloys has been correlated with impedance phase angles. Cyclic Potentiodynamic Polarization has been used to compute the corrosion parameters and to investigate the pitting tendency for the alloys. TMZF is found to be a better β-alloy as compared to TNZT.

Thermoelectric Power Measurements (TEP) for Ageing Kinetics in PH Steels

---**Yoav Snir**[1], Y. Gelbstein[2], S. Meir[3], and A. Landau[1], [1]Nuclear Research Center Negev, Negev, Israel; [2]Ben-Gurion University of the Negev, Negev, Israel; [3]Colorado School of Mines, Golden, CO 80401

---Most of the current practices of Nondestructive Evaluation (NDE) of materials rely on the measurement of the material response to penetrating radiation, elastic waves, electro-magnetic, or thermo-electric signals. The outgoing signals are a superposition of various interactions within the examined material that are functions of its atomic structure, microstructure and defects. Advanced NDE can be applied to sense each of the stages of microstructural evolution for specific materials. An NDE tool combined with well characterized standards can be implemented for in-situ monitoring, in-service degradation or on-line material production. The combination of various NDE techniques was proven to be sensitive to metallurgical modifications in numerous systems, including various types of steels, radiation damage, hydrogen and nitrogen miscibility in metals and microstructural modifications along weldments. In all cases the variation in the measured non-destructive signal was interrelated according to well characterized modification in the microstructure of the material. The current work demonstrates the sensitivities of Thermoelectric Power (TEP) measurements in characterizing the aging kinetics of different types of PH steels: MAR250, PH13-8Mo, PH17-7, A286. The unusually large changes in TEP values during the aging process of MAR250 was studied and reported. It seems that the basic differences between the precipitate crystallography and morphology are responsible to the large variation. It is believed that although all the current PH steels are based on precipitation of $Ni_x(Al,Ti,Mo)_y$ phases, the unique crystallographic characteristics of the η-$Ni_3(Ti,Mo)$ in a martensitic matrix is the major factor affecting the large TEP variation in the maraging steels compared to the other types of the PH steels.

Session 33

SESSION 33
UT PHASED ARRAYS II
P. Dumas, Chairperson
CBLS 100

3:30 PM **Ultrasonic Air-Coupled Inspection of Textile Materials Using Ferroelectret-Based Phased Arrays**
---**J. Ealo**, J. Camacho, F. Seco, and C. Fritsch, Instituto de Automática Industrial, Departamento de Sistemas, Ctra.camp real km 0.200, Agranda, del Rey, 28500, Madrid, Spain; J. Ealo, School of Mechanical Engineering, Universidad del Valle, Cali, Colombia

3:50 PM **Ultrasonic Inspection System for Automated Round-Bar-Testing Based on Phased Array Technique**
---D. Brackrock, G. Schenk, R. Boehm, G. Brekow, and **M. Kreutzbruck,** Federal Institute of Material Research and Testing, BAM Berlin, Germany; W. A. K. Deutsch, M. Joswig, K. Maxam, and V. Schuster, Karl Deutsch Prüf- und Messgerätebau GmbH + Co KG, 42115, Wuppertal, Germany

4:10 PM **Ultrasonic Phased Array Inspection Experiments and Modeling for an Isogrid Structural Element with Cracks**
---**D. J. Roth**[1], R. P. Tokars[1], R. E. Martin[2], R. W. Rauser[3], J. C. Aldrin[4], and E. J. Schumacher[5], [1]NASA Glenn Research Center, Cleveland, OH 44135; [2]Cleveland State University, Cleveland, OH 44115; [3]University of Toledo, Toledo, OH 2368; [4]Computational Tools, Inc., Gurnee, IL 60031; [5]Magsoft Corporation, Ballston Spa, NY 12020

4:30 PM **Monitoring Growth of Closed Fatigue Crack Using Subharmonic Phased Array**
---**Y. Ohara**, H. Endo, M. Hashimoto, Y. Shintaku, and K. Yamanaka, Tohoku University, Department of Materials Processing, Sendai, Miyagi, Japan

4:50 PM **The Characterization of Crack-Like Defects Using Ultrasonic Images**
---**J. Zhang**, B. W. Drinkwater, and P. D. Wilcox, University of Bristol, Department of Mechanical Engineering, Bristol, United Kingdom

5:10 PM **Stategies for Ultrasound Imaging Using Two-Dimensional Arrays**
---**A. Velichko** and P. D. Wilcox, University of Bristol, Department of Mechanical Engineering, Bristol, United Kingdom

Ultrasonic Air-Coupled Inspection of Textile Materials Using Ferroelectret-Based Phased Arrays

---**Joao Ealo**, Jorge Camacho, Fernando Seco, and Carlos Fritsch, Instituto de Automática Industrial, Departamento de Sistemas, Ctra.camp real km 0.200, Agranda, del Rey, 28500, Madrid, Spain; Joao Ealo, School of Mechanical Engineering, Universidad del Valle, Cali, Colombia

---Most common defects in textile manufacturing process include weaving errors (such as missing threads), oil spots and material inhomogeneities. Despite of the fact that Air-coupled Ultrasound, among others techniques, has proved useful to detect them, its use has not been widespread. The recent developments of special air-coupled transducers and the appearance of novel engineering materials, open up new possibilities of applying non-contact ultrasound to ensure quality in many textile materials. In this sense, the new cellular ferroelectric material exhibit remarkable characteristics which make it a good candidate for air-coupled ultrasonic transducers, i.e. good matching with air, good sensitivity, low cost and easiness of use and manipulation. In this work, we demonstrate the feasibility of using ferroelectric-based transducers for the inspection of woven material. A linear array of 32 elements (34mm x 110mm, pitch 3.4mm) was built for this purpose following an easy fabrication procedure recently proposed. Electronic focusing at the textile sample position allowed us to detect weaving errors and oil spots of 1 mm in through transmission mode, at normal incidence and with a good signal-to-noise ratio. A brief description of the phased array fabrication procedure and its characterization is also presented.

Ultrasonic Inspection System for Automated Round-Bar-Testing Based on Phased Array Technique

---D. Brackrock, G. Schenk, R. Boehm, G. Brekow, and **Marc Kreutzbruck,** Federal Institute of Material Research and Testing, BAM Berlin, Germany; W. A. K. Deutsch, M. Joswig, K. Maxam, and V. Schuster, Karl Deutsch Prüf- und Messgerätebau GmbH + Co KG, 42115, Wuppertal, Germany

---Within a know-how transfer project funded by the government conventional ultrasonic technique was replaced by phased array technique for automated round-bar testing. Instead of applying a great number of conventional probes to achieve acceptable volume coverage we used curved linear arrays. The benefits of phased array technique such as programmable skew angles, beamforming and beam positions, led not only to a significant decrease in inspection time, but also the number of probes could be substantially reduced. Finally, the testing parameters for a large range of bar-diameters could be adapted by software control instead of time-consuming mechanical replacement. The probe-design was carried out by a proprietary modelling program. Both the theoretical calculations as well as the latter experimental verifications revealed significant advantages of curved arrays versus the planar types. A radial oriented probe offers perfect adaption to the cylindrical shape of the specimen allowing wide variations of the sound field. Thus beam direction, beam size and beam position could be optimized with respect to a minimum of inspection cycles, as inspections have to be executed in-line during the production. A number of laboratory tests were carried out on special test components. In order to achieve an optimal performance of the reference rod we implemented three different types of reference reflectors: (i) flat-bottom-holes with diameters of 0.8 mm and 1.2 mm, (ii) side-drilled-holes with a diameter of 0.7 mm for the detection of volumetric flaws, and (iii) notches with a depth of 0.2 mm and 0.5 mm for the detection of surface-oriented defects. All laboratory tests were carried out with the COMPAS-XXL inspection system, a proprietary development of BAM.

Ultrasonic Phased Array Inspection Experiments and Modeling for an Isogrid Structural Element with Cracks

---**D. J. Roth**[1], R. P. Tokars[1], R. E. Martin[2], R. W. Rauser[3], J. C. Aldrin[4], and E. J. Schumacher[5], [1]NASA Glenn Research Center, Cleveland, OH 44135; [2]Cleveland State University, Cleveland, OH 44115; [3]University of Toledo, Toledo, OH 2368; [4]Computational Tools, Inc., Gurnee, IL 60031; [5]Magsoft Corporation, Ballston Spa, New York 12020

---In this investigation, a T-shaped aluminum alloy isogrid stiffener element used in aerospace applications was inspected with ultrasonic phased array methods. The isogrid had various crack configurations emanating from bolt holes. Computational simulation methods were used to mimic the experiments in order to help understand experimental results. The results of this study indicate that it is at least partly feasible to interrogate this type of geometry with the given flaw configurations using phased array ultrasonics. The simulation methods were critical in helping explain the experimental results.

Monitoring Growth of Closed Fatigue Crack Using Subharmonic Phased Array

---**Y. Ohara**, H. Endo, M. Hashimoto, Y. Shintaku, and K. Yamanaka, Tohoku University, Department of Materials Processing, Sendai, Miyagi, Japan

---Nonlinear ultrasound has been expected as a most promising approach to detect closed cracks. Among them, subharmonic phased array for crack evaluation (SPACE) proposed by the authors has a unique capability of selectively imaging open and closed parts. Thus far, its performance has been demonstrated in closed fatigue and stress corrosion cracks. In this study, we monitored a closed fatigue crack growth using SPACE. The fatigue crack was formed in a compact tension (CT) specimen (A7075) with a maximum stress intensity factor of 9.0 MPa•m1/2 and a minimum stress intensity factor of 0.6 MPa•m1/2. To examine the distribution of the crack depths and closure behavior in the length direction, the measurement was done at 5 positions. As a result, the crack depths in the subharmonic images were larger than those in the fundamental images at each position. Specifically, the difference was larger at near the side surface than at the center. This suggests that the crack tip was closed with higher closure stress. The percentage of the closed part was 63 % at near the surface after 48000 fatigue cycles, whereas it decreased to 20 % after 87000 cycles. Thus, we succeeded to monitor closure behavior using SPACE. We also examined the dependence of the fundamental and subharmonic images on a static tensile load which reduces the effect of the closure stress. The fundamental images changed in the stress intensity factor range of 0 to 1 MPa•m1/2, whereas the subharmonic images changed in the wider range of 0 to 2 MPa•m1/2. This suggests that the behavior at the closed parts, referred to as the area of ‘contact acoustic nonlinearity (CAN)’, was more diverse than at the linear scatterers. Thus, we found that the comparison of the fundamental and subharmonic images provides detailed information about the open and closed parts in overall cracks.

The Characterization of Crack-Like Defects Using Ultrasonic Images

---**Jie Zhang**, Bruce W. Drinkwater, and Paul D. Wilcox, University of Bristol, Department of Mechanical Engineering, Bristol, United Kingdom

---The use of ultrasonic arrays to image and size crack-like defects is an important area in non-destructive evaluation. The features in the ultrasonic data from a crack-like defect provide information about the size and orientation angle of the defect. In this paper, the characteristics of a small crack-like defect (its length less than a wavelength) were measured from its scattering coefficient matrix. The imaged features for a large crack-like defect (its length more than a wavelength) were directly used to characterize the defect through a rectangular box fitting approach. An efficient hybrid model was used to generate the full matrix of array data from samples with a defect and for a specified inspection configuration. This hybrid model combines far-field scattering coefficient matrix for defects with a ray based forward model. This model offers the potential to compile a look-up table through which defects can be classified and then sized. Good agreement was achieved between simulation and experiment results hence validating this model based approach.

Strategies for Ultrasound Imaging Using Two-dimensional Arrays

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

---Current NDE systems utilize mainly 1D arrays and so are limited to obtaining a 2D image. 2D arrays are able to ‘view’ a given defect from a range of angles leading to the possibility of obtaining characterization detail far beyond what is currently achievable. This has clear benefits as real defects and engineering structures are three-dimensional. However there are a number of problems currently restricting the application of 2D arrays to NDE. Firstly, how should 2D arrays be designed with a low enough number of elements to be practically viable? Secondly, how should the vast amount of data potentially obtainable be processed? Thirdly, given these practical limitations, what imaging and characterization performance can be achieved? This paper describes different approaches to optimize array design and possible array inspection strategies. Any scatterer can be characterized by its angular reflectivity pattern. A range of signal processing techniques for reconstructing the 3D angular reflectivity pattern of a scatterer is investigated. Results are shown that illustrate the application of the proposed techniques to modelling and experimental data.

FRIDAY

FRIDAY, JULY 31, 2009

	Session 34 **NDE for High Temperature Materials, Films, and Surfaces** ***CBLS 010***	**Session 35** **New Techniques, Instruments, and Systems** ***Chafee 273***	**Session 36** **New Applications and Techniques II** ***Chafee 277***
8:30 AM			
8:50			
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10:10	COFFEE BREAK		
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Session 34

Friday, July 31, 2009

SESSION 34

NDE FOR HIGH TEMPERATURE MATERIALS, FILMS, AND SURFACES

A. Every, Chairperson
CBLS 010

8:30 AM **Vibration Analysis of Ceramic Tiles for NDE**
---**V. Dayal** and D. K. Hsu, Center for NDE, Iowa State University, 1915 Scholl Road, Ames, IA 50011

8:50 AM **Aluminum Nitride as a High Temperature Transducer**
---**D. A. Parks**, M. M. Kropf, and B. R. Tittmann, Penn State University, Engineering Science and Mechanics, University Park, PA 16802

9:10 AM **Thick Film Sol-Gel Deposted Bismuth Titanate Lamb Wave Transducer for Temperatures Over 600 C°**
---**C. T. Searfass**, B. R. Tittmann, and D. Agrawal, Pennsylvania State University, Department of Engineering Science and Mechanics, University Park, PA 16802

9:30 AM **Local and Structural Nondestructive Evaluation of Advanced Silicon Carbide Mirrors**
---**R. W. Martin**[3], S. Sathish[3], M. P. Blodgett[1], J. T. Welter[1], S. Martin[4], and L. E. Matson[2]; [1]Air Force Research Laboratory, Metals, Ceramics and NDE Division, RXLP, 2230 Tenth Street, Wright Patterson AFB, Dayton, OH 45433-7817; [2]Air Force Research Laboratory, Metals, Ceramics and NDE Division, RXLN; [3]University of Dayton Research Institute, 300 College Park, Dayton, OH 45469-0120; [4]NDE Computational Consultants, 7697 Aldridge Place, Dublin, OH 43017-8530

9:50 AM **Unconventionally High and Low Frequency Eddy Current Methods for Material Surface Characterization**
---**N. Nakagawa** and C. C. H. Lo, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

10:10 AM ***Break***

10:30 AM **Characterization of an Ultrasonic Surface Wave Technique Designed to Evaluate an Environmentally Degraded Polymeric Surface**
---**S. L. Freed,** Wyle Laboratories, Advanced NDI, Dayton, OH 45440; G. P. Tandon, University of Dayton Reasearch Institute, Nonmetallic Materials Division, Dayton, OH; R. A. Brockman, University of Dayton, Civil & Environmental Engineering & Engineering Mechanics, Dayton, OH; S. Sathish, University of Dayton Reasearch Institute, Structural Integrity Division, Dayton, OH 45469-0127

10:50 AM **Acoustoelasticity of Ultrathin PT Films Deposited on M_gO Studied by Picosecond Ultrasound**
---**N. Nakamura**, Y. Kake, H. Ogi, and M. Hirao, Graduate School of Engineering Science, Osaka University, Japan

11:10 AM **A Model for the Dynamical Behavior of Patterned Thin Film Structures on Silicon**
---**A. G. Every** and A. Maznev, University of the Witwatersrand, School of Physics, Johannesburg, South Africa

11:30 AM **Quantitative Acoustic Model for Adhesion Evaluation of PMMA/Silicon Film Structures**
---**H. S. Ju**, The Pennsylvania State University, Graduate Program in Acoustics, University Park, PA, 16802; B. R. Tittmann, The Pennsylvania State University, Department of Engineering Science and Mechanics, University Park, PA 16802

11:50 AM **Characterization of Zirconium Hydride Orientations in Zircaloy Cladding Tubes with a Laser Ultrasound Technique**
---C.-H. Yeh and **C.-H. Yang**, Institute of Manufacturing Technology, National Taipei University of Technology, Taipei, Taiwan

Vibration Analysis of Ceramic Tiles for NDE

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

---Ceramic tiles are the centerpiece in any high velocity impact resistant protection. These tiles are normally made of Silicon Carbide or Alumina. The quality of the protection depends on the quality of these tiles and after the first impact the usability of the tiles will depend on the induced damage. The most economical and quick way of the non-destructive evaluation of these tiles is using the air-coupled ultrasound. This method is totally non-contact and so clean as no coupling medium is required. The normal range of the frequencies which are used for such analysis is around 112 kHz and 225 kHz. At these low frequencies the tiles vibrates and resonance is set up. These resonance patterns can be used for the evaluation of the tiles. This work is concerned with the theoretical analysis of the tiles at the frequencies of interest. The natural frequencies of the tiles will be presented and then the harmonic response will be evaluated to determine the dominant frequencies. The tiles have then been subjected to forced vibrations and the forced response of the tiles will be presented. Sensitivity of the NDE to tile damage will be discussed.

Aluminum Nitride as a High Temperature Transducer

---**David A. Parks**, Matt M. Kropf, and Bernhard R. Tittmann, Penn State University, Engineering Science and Mechanics, University Park, PA 16802

---We have performed ultrasonic measurements of the attenuation and sound velocity in various materials including SiC and stainless steel up to 1742 degrees Fahrenheit. The tests were performed using 14 MHz longitudinal contact transducers comprised of aluminum nitride. The transducers were immersed in the high temperature environment. The bandwidth and sensitivity of the transducer were monitored and demonstrated aluminum nitrides remarkable robustness as a high temperature transducer material. The work on SiC is similar to that done by Fukuhara and Abe among others and is of substantial importance in turbine design. It was found that the modulus of the SiC sample decreased linearly with temperature by an amount of 5[MPa/deg F].

Thick Film Sol-Gel Deposited Bismuth Titanate Lamb Wave Transducer for Temperatures Over 600°C

---**Cliff T. Searfass**, Bernhard R. Tittmann, and Dinseh Agrawal, Pennsylvania State University, Deparment of Engineering Science and Mechanics, University Park, PA 16802

---A ferroelectric bismuth titanate thick film transducer was deposited onto a thin stainless steel plate. A previously reported modified sol-gel spray on deposition technique where high intensity ultrasound is used to mix the powder-liquid solution and microwave furnaces perform the sintering was used to fabricate the samples. Gold IDEs were sputtered onto the bismuth titanate and an in-plane oil-bath poling technique was required in order to generate Lamb waves. The sensor was capable of operation in atmospheric gas environments at temperatures in excess of 600°C. Received signals varied as temperature increased indicating that the dispersive nature of Lamb waves is quite sensitive to changes in temperature less than 50°C.

Local and Structural Nondestructive Evaluation of Advanced Silicon Carbide Mirrors

---**R. W. Martin**[3], Shamachary Sathish[3], Mark P. Blodgett[1], John T. Welter[1], Steve Martin[4], and Larry E. Matson[2]; [1]Air Force Research Laboratory, Metals, Ceramics and NDE Division, RXLP, 2230 Tenth Street, Wright Patterson AFB, Dayton, OH 45433-7817; [2]Air Force Research Laboratory, Metals, Ceramics and NDE Division, RXLN; [3]University of Dayton Research Institute, 300 College Park, Dayton, OH 45469-0120; [4]NDE Computational Consultants, 7697 Aldridge Place, Dublin, OH 43017-8530

---Advanced ceramic silicon carbide and siliconized silicon carbide (SiSiC) mirrors have been developed for light-weight and high-temperature aerospace applications. Furthermore, the ceramic materials have low thermal expansion over a wide temperature range which is advantageous for space applications. The slip cast mirror structure consists of a face sheet with supporting rib structure. The top face of the face sheet is polished to produce an extremely flat mirror surface. During processing of the material and fabrication of the mirrors, there is a possibility of inducing defects and residual stresses. In the course of polishing the mirror structure, the residual stress can be redistributed which could lead to dimensional changes and areas of high stress concentration which may enhance the possibility of initiating cracks. To guarantee high quality mirrors, nondestructive evaluation methods are needed. This paper presents a focused acoustic beam method for local measurements and an air coupled acoustic excitation method with scanning laser interferometer detection for evaluation of the mirror substructure. Defects in the mirror can be detected through velocity measurements and through vibrational analysis of the structure. Both local imaging and macroscopic structural evaluations performed on the same mirror are presented. Limitations and advantages of these techniques are discussed.

Unconventionally High and Low Frequency Eddy Current Methods for Material Surface Characterization

---**N. Nakagawa** and C. C. H. Lo, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---Several projects at the Center for NDE, ISU, engage in advanced eddy current (EC) measurement methodology and application developments, aiming not only to the traditional crack-like defect detection and characterization, but also to surface materials characterization. This line of work utilizes various forms of multiple frequency techniques, such as swept frequency EC, pulsed EC, and modulated excitation EC methods. For instance, the recent residual-stress characterization project has led us to the development of a swept high-frequency EC (SHFEC) measurement method and model-based inversion software that provide us with a near-surface conductivity profiling capability on low-conductivity materials, applicable also to other surface characterization problems such as coating characterization, machining anomaly detection, and high-temperature corrosion evolution and its monitoring. Many of these applications require operations at unconventionally high frequencies such as 10-100MHz. This paper mentions a new probe design permiting SHFEC measurements up to 80MHz. In contrast, there are other applications requiring extremely low frequency EC operations such as 1-20 Hz. This paper focuses on a type of such low frequency applications, i.e. case depth determination in steel samples. Specifically, we work with inductively hardened steel rods, in a 30mm diameter and a 100mm length, consisting of case-hardened rods with 1~6 mm nominal case depths and of untreated rods. The key requirement is a one-sided, non-contact access, which we achieved by a nominally uniform-field drive approach with a sensor system containing an excitation coil wound on a U-shaped ferrite core. The resulting nominally uniform magnetic field generates similarly uniform EC in the sample axis direction that is detected by a Hall sensor. The output signals, particularly the phase data, have been shown to correlate with the case depths. We specifically conclude that the case depths of 1-3mm can be separated from the data in the frequency range of 8-16Hz, while 4-6mm case depths from 4-8Hz data. Moreover, this has been achieved without reliance on the conventional encircling coil configuration.---This work was supported by the NSF Industry/University Cooperative Research Program of the Center for Nondestructive Evaluation at Iowa State University.

Characterization of an Ultrasonic Surface Wave Technique Designed to Evaluate an Environmentally Degraded Polymeric Surface

---**Shaun L. Freed,** Wyle Laboratories, Advanced NDI, Dayton, OH 45440; G. P. Tandon, University of Dayton Reasearch Institute, Nonmetallic Materials Division, Dayton, OH; Robert A. Brockman, University of Dayton, Civil & Environmental Engineering & Engineering Mechanics, Dayton, OH; Shamachary Sathish, University of Dayton Reasearch Institute, Structural Integrity Division, Dayton, OH 45469-0127

---An ultrasonic measurement method has been developed for use in characterizing the thin surface layer of property changes that develops for polymeric materials exposed to long term high temperature environments. The method involves creating a Rayleigh surface wave with a wavelength similar in size to the depth of the degraded layer (~200 microns). Since typical wedge transducers are incapable of generating Rayleigh waves in most polymers, a mediator wedge transducer method has been designed to effectively serve as a line source for the ultrasonic wave. High resolution noncontact signal detection is accomplished through the use of a laser vibrometer in order to adequately provide data for automated calculations of velocity and attenuation. The successive events of wave generation, detection, and analog signal processing have been simulated for measurements on an epoxy specimen with an explicit finite element method and representative mathematical post processing algorithms in order to better understand the measurements and their application usefulness. A comparison of the preliminary simulation data and the experimental measurements provides useful insights about the data patterns detected in the experiments.

Acoustoelasticity of Ultrathin PT Films Deposited on MgO Studied by Picosecond Ultrasound

---**Nobutomo Nakamura**, Yosuke Kake, Hirotsugu Ogi, and Masahiko Hirao, Graduate School of Engineering Science, Osaka University, Japan

---Elastic stiffness of thin films still remains a central issue in condensed-matter physics. In this study, we use picosecond ultrasound to evaluate the longitudinal elastic stiffness in the thickness direction of polycrystalline Pt films, thinner than 100 nm, deposited on MgO, and to find the relation between the elastic stiffness and lattice strain. The strain was measured by x-ray diffraction method. Elastic stiffness of the Pt films showed a linear dependence on the strain, and it was qualitatively explained by the higher-order elasticity; compressive strain in the out-of-plane direction increases the longitudinal elastic stiffness in the same direction. However, the third-order elastic constants of bulk Pt failed to explain the magnitude of strain dependence; the changing ratio was significantly larger in the films. Although the detailed mechanism has not been clarified yet, we consider that the following factors are the possible reasons; (i) the reported third-order elastic constants are incorrect and (ii) contribution of fourth-order elastic constants was involved, because the strain in the Pt films were much larger, being 0.3% at most, than that applied to the bulk Pt specimens in the measurement of the third-order elastic constants.

A Model for the Dynamical Behavior of Patterned Thin Film Structures on Silicon

---**Arthur G. Every** and Alex Maznev, University of the Witwatersrand, School of Physics, Johannesburg, South Africa

---Metrology of metal-dielectric thin film structures fabricated on silicon wafers has emerged as a major application of laser ultrasonics. The measurements are oftentimes performed on structures comprised of periodic line arrays, which as regards their dynamical behavior, form a distinct class of phononic crystals. Recently reported measurements of laser-generated surface acoustic modes in Cu-SiO2 line arrays on silicon have uncovered a number of interesting phenomena. The goal of this paper is to provide a simple theoretical model capturing the salient features of the experiment and leading to a better understanding of the physical nature of the observed phenomena. The structure is simulated by a uniform layer on a substrate with periodic mass loading applied to its surface, and is treated by the plane wave expansion method. We establish that the large bandgap observed inside the Brillouin zone originates from the hybridization of the Rayleigh and Sezawa modes of the film-substrate structure. The displacement pattern in the Rayleigh and Sezawa waves explains their strong interaction, leading to a larger bandgap than the ones formed at the zone boundary. Unexpectedly low radiation loss of the hybridized Rayleigh-Sezawa mode in the “supersonic” domain, is also reproduced by the model.

Quantitative Acoustic Model for Adhesion Evaluation of PMMA/Silicon Film Structures

---**Hyeong Sick Ju**, The Pennsylvania State University, Graduate Program in Acoustics, University Park, PA, 16802; Bernhard R. Tittmann, The Pennsylvania State University, Department of Engineering Science and Mechanics, University Park, PA 16802

---A Poly-methyl-methacrylate (PMMA) film on a silicon substrate is a main structure for the photolithography of the semiconductor process. This film is essentially a layered structure on an anisotropic substrate fabricated by spin casting. Adhesion failure of the PMMA/Si interface is a commonly encountered issue during the fabrication and post-fabrication processes. This paper presents a potential for the nondestructive evaluation of the PMMA/Si adhesion by means of scanning acoustic microscopy (SAM). Providing wave propagation characteristics of dispersion and angular dependence, the SAW propagation theory based on a matrix method are reviewed for the anisotropic layered media. Physical models employing partial discontinuity in displacement and stress are developed for the rigorously quantitative evaluation of the interfacial weakness. The models are implanted to the matrix method for the SAW propagation. In result, variations in the SAW velocity, reflectance functions and wave structures are predicted to show their sensitivity to the adhesion condition. Practical aspects of these parameters are also considered for experiments using SAM.

Characterization of Zirconium Hydride Orientations in Zircaloy Cladding Tubes with a Laser Ultrasound Technique

---Cheng-Hung Yeh and **Che-Hua Yang**, Institute of Manufacturing Technology, National Taipei University of Technology, Taipei, Taiwan

---The degradation of mechanical properties in Zircaloy cladding is directly related to the precipitated hydrides which also cause the hydrogen embrittlement phenomenon. The relation between concentration of the precipitated hydride and hydrogen embrittlement is well known. Recently it is further found out that direction of the precipitated hydride is another key factor influencing the degradation mechanism; hydrides orientated in the radial direction can reduce the fracture toughness much more than hydrides orientated in the circumferential direction. This research is focused on characterizing Zircaloy cladding tubes with different concentration ratios between hydrides orientated in the circumferential (C) and radial (R) directions. A procedure corporate with an experimental technique and an inversion algorism is used to investigate the effects of R/C ratio on the dispersion spectra of GW. A laser ultrasound technique (LUT) is used to measure the dispersions of circumferential guided waves (CGW) propagating along the circumferential direction of the cladding tubes. An inversion algorism based on simplex method is used to extract interested properties from the measured GW dispersion spectra. It is shown that the procedure introduced in the current research is able to relate the phase velocities with hydrogen concentration. In the meanwhile, this procedure is able to distinguish the R/C ratio in a quantitative way as well. It is also found out that the bulk elastic modulus increases as the R/C ratio increases. This method is potentially useful to probe the hydrogen concentration and the associated R/C value in a remote and nondestructive way which is desired in nuclear power industry.

Session 35

SESSION 35

NEW TECHNIQUES, INSTRUMENTS, AND SYSTEMS

B. Drinkwater, Chairperson
Chafee 273

8:30 AM **Inspection of Austenitic Welds with EMAT**
---**H. Gao**, S. Ali, and B. Lopez, Innerspect Technologies, 4004 Murray Place, Lynchburg, VA 24501

8:50 AM **Progress Towards the Development of an Environment Controlled Automated Ultrasonic Non-Linear Measurement System**
---**K. B. Boudreau**, D. A. Parks, B. T. Reinhardt, M. M. Kropf, and B. R. Tittmann, The Pennsylvania State University, Engineering Science and Mechanics Department, University Park, PA 16802

9:10 AM **Bond Inspection by Tap Test**
---**Y. Yang**, D. Xiang, and Y. Qin, Intelligent Automation Inc, Rockville, MD 20855; R. V. Coulter, USAF Warner Robins Air Logistics Center, Robins AFB, GA 31098

9:30 AM **Experimental and Theoretical Characterization of Kissing Bonds in Adhesive Joint**
---**D. Yan**, B. W. Drinkwater, and S. A. Neild, Department of Mechanical Engineering, University of Bristol, University Walk, Bristol, United Kingdom

9:50 AM **Linear Scanning Method Based on the SAFT-Coarray**
---**C. J. Martín**, O. Martínez, D. Romero, and L. G. Ullate, C.S.I.C, Instituto Automática Industrial, Madrid, Spain; R. T. Higuti, Department of Electrical Engineering, Universidade Estadual Paulista – Campus Ilha Solteira, Sao Paulo, Brazil

10:10 AM ***Break***

10:30 AM **Automated Ultrasonic Disbond Inspection of Metal Matrix Composite Tank Track Shoes**
---**D. Xiang** and G. Zhao, Intelligent Automation Inc., 15400 Calhoun Drive, Rockville, MD 20850; B. B. Raju, US Army RDECOM/TARDEC, Detroit, Michigan 48202

10:50 AM **Microwave Interferometer for Non-Destructive Testing**
---**J. Choi** and T. Itoh, UCLA, Electrical Engineering, Los Angeles, CA 90095; S. Breugnot, Bossa Nova Technologies, 606 Venice Blvd. – Suite B, Venice, CA 90291

11:10 AM **A Probabilistic Approach to Robotic NDE Inspection**
---**R. Summan**, G. Dobie, G. Pierce, and G. Hayward, University of Strathclyde, Centre for Ultrasonic Engineering (CUE), Glasgow, United Kingdom; J. Hensman and K. Worden, University of Sheffield, Department of Mechanical Engineering, Sheffield, United Kingdom

11:30 AM **A Secure Method for Enterprise Wide Digital Inspection and Maintenance Records in Aviation Industry**
---**P. Pisupati** and S. K. Dewangan, Infosys Technologies Limited, Software Engineering and Technology, Labs (SETLabs), #44, Electronics City, Bangalore, Karnataka, 560100 INDIA;
A. Saxena, Infosys Technologies Limited, Software Engineering and Technology, Labs (SETLabs), Manikonda, Hyderabad, Andhra Pradesh, 500019 INDIA

Inspection of Austenitic Welds with EMAT

---**Huidong Gao**, Syed Ali, and Borja Lopez, Innerspect Technologies, 4004 Murray Place, Lynchburg, VA 24501

---Nondestructive testing of austenitic welds is very important for nuclear, petrochemical, and many other industries. Due to the strong material anisotropy and coarse grain size in the dendritic weld zone, shear vertical waves suffer significant skew and attenuation. The only solution available now is using longitudinal waves, which can only inspect the bottom portion of the weld zone. It is well known in the industry that shear horizontal waves generated from electromagnetic acoustic transducer (EMAT) can be a good solution for the inspection of austenitic welds. However, due to its high resistivity, sound generation in stainless steel using EMAT is typically very difficult. Therefore, although some previous efforts were reported, no system has been successful enough for field applications. At Innerspec Technologies, we have made significant progress in the inspection of austenitic welds using SH wave EMATs. This paper introduces our new development of flexible EMAT coils, and powerful EMAT pulsors. A new signal processing technique is developed to significantly improve signal to noise ratio. With these improvements in the system, two samples from Electric Power Research Institute (EPRI) are successfully inspected. One is a similar weld with stainless steel on both sides, and the other is a dissimilar weld. Notch defects from both sides of the weld are all successfully detected with beam steering achieved using frequency sweeping technique in a one channel system. Using the EMAT SH wave, both half skip and full skip inspection can be performed. A prototype of an eight channel phased array system has also been validated and now in the process of development for commercialization.

Progress Towards the Development of an Environment Controlled Automated Ultrasonic Non-linear Measurement System

---**Kate B. Boudreau**, David A. Parks, Brian T. Reinhardt, Matthew M. Kropf, and Bernhard R. Tittmann, The Pennsylvania State University, Engineering Science and Mechanics Department, University Park, PA 16802

---Ultrasonic non-destructive evaluation utilizing non-linear acoustic measurements has been of increasing prevalence in modern research. Non-linear measurements based on harmonic amplitude ratios, in the form of the β term, can be used to detect variations in higher order material properties. This study presents the efforts in establishing an automated setup and procedure to measure the non-linear β parameter for a variety of materials with environmental controls such as temperature. The setup utilizes through transmission, tone burst signals, and digital signal analysis while carefully compensating for the transducers' frequency response. Finally, results will be presented for the case of non-linear wave propagation in fluids pertinent to chemical and biofuel processing applications.

Bond Inspection by Tap Test

---**Yubing Yang**, Dan Xiang, and Yexian Qin, Intelligent Automation Inc, Rockville, MD 20855; Rodney V. Coulter, USAF Warner Robins Air Logistics Center, Robins AFB, GA 31098

---Kissing bond detection has been a challenging issue for NDE of bonded structures in aeronautical industry. A novel tap test technique for bond inspection has been developed, which shows great potential for kissing bond detection. The tap test employs a solenoid to produce impact forces in a bonded structure, and the induced acoustic wave in the structure was picked up by an EMAT sensor, which located side by side with the solenoid. Both solenoid and EMAT sensor was integrated into a tap header that is mounted onto an automatic 2-D scanner to realize an automatic 2-D scanning. Multiple samples with artificial defects including kissing bonds and disbonds were used to test the tap test technique. The results show that those bond defects in the samples can be detected by the developed tap test technique. For comparison purpose, those samples were also tested with traditional ultrasonic C-scan.

Experimental and Theoretical Characterization of Kissing Bonds in Adhesive Joint

---**Dawei Yan**, Bruce W. Drinkwater, and Simon A. Neild, Department of Mechanical Engineering, University of Bristol, University Walk, Bristol, UK

---This paper describes an experimental apparatus and procedure for the detection and characterization of kissing bond defects in adhesive joints using non-linear ultrasonic technique. It also presents a study of comparison between experimental and modeling results. Kissing bonds are adhesive bonding defects which broadly can be split into two categories: fracture surface and contamination layer defects. They are detrimental to adhesive joints in terms of reducing joint strength and shortening service life and are difficult to be detected by using conventional ultrasonic technique. However with high amplitude ultrasonic incident wave propagating through the kissing bond region, the system will behave non-linearly and hence the measurement of generated non-linearity makes the detection of kissing bonds possible. The approach adopted here is to measure non-linear parameters for perfectly and imperfectly bonded specimens for both fracture surface and contamination layer kissing bond specimens. Moreover, a non-linear interface stiffness model which describes non-linear interaction between elastic wave and contact interface is presented.

Linear Scanning Method Based on the SAFT-Coarray

---**Carlos J. Martín**, Oscar Martínez, David Romero, and Luis G. Ullate, C.S.I.C, Instituto Automática Industrial, Madrid, Spain; Ricardo T. Higuti, Dep. Electrical Engineering, Universidade Estadual Paulista – Campus Ilha Solteira, Sao Paulo, Brazil

---Linear array scanning is a common tool in ultrasonic NDE. A phased array system uses electronic scanning to activate a subaperture that is swept along the length of the probe to create a cross-sectional profile without moving the transducer. Successive subapertures produce successive A-scans, that are "stacked", creating a B-scan image. This work presents a method to obtain B-scan images based on linear array scanning and 2R SAFT. The 2R SAFT method uses one channel in emission and two in reception, in order to complete the pulse-echo coarray. By this way, it avoids grating lobes formation, typical of conventional SAFT. What we propose here, is that each line of the B-scan image is obtained by choosing active subapertures in the coarray, instead of using the original array. Using the coarray structure some advantages are obtained: the ultrasonic system is very simple, with only one channel in emission and two channels in reception; emission-reception dynamic focussing can be used; the subaperture size (and thus the resolution) can be adapted to every particular NDE case. The proposed method has been tested experimentally in the pulse-echo inspection of thin pieces of CFRP with good results.

Automated Ultrasonic Disbond Inspection of Metal Matrix Composite Tank Track Shoes

---**Dan Xiang** and George Zhao, Intelligent Automation Inc., 15400 Calhoun Drive, Rockville, MD 20850; Basavaraju B. Raju, US Army RDECOM/TARDEC, Detroit, MI

---Tank track shoes made of Metal Matrix Composites (MMC) are light in weight, and can resist high temperature and wear. Defects such as disbond, porosity, and cracks can be introduced during manufacturing process and in service. In this work, we focused on investigation of the test procedures in order to establish valid processes and criteria for the automated detection of disbond in track shoes. A standard block has been designed and fabricated for the calibration of transducers in the system. This standard block has also been used to study the factors, such as the repeatability, reproducibility, coupling effects, and contact condition effects, etc., that affect the system performance. Statistical data analysis was used to quantify the effects of those factors. Based on the analysis results, an automated test procedure and criteria for detection and classification of MMC disbond has been established. As we applied the established automated inspection procedure and criteria to a set of track shoes, more reproducible and reliable results than previous tests have been obtained. Good agreement between the automated inspection and the ultrasonic C-scan images for the same splines of track shoes has been achieved.

Microwave Interferometer for Non-Destructive Testing

---**Jun Choi** and Tatsuo Itoh, UCLA, Electrical Engineering, Los Angeles, CA 90095; Sebastien Breugnot, Bossa Nova Technologies, 606 Venice Blvd. – Suite B, Venice, CA 90291

---A K-band (20 GHz) microwave interferometer for non-destructive sensing of high frequency low amplitude (nm) vibration is demonstrated. This sensor uses direct-conversion receiver architecture with a phase shifter to adjust its sensitivity while varying the target distance. A simple model to describe the set-up is proposed. Experimental results are compared to the theoretical model. Evaluation of the sensitivity of the interferometer is presented. The advantage of using microwave frequency is its ability to penetrate through dielectric walls. Detection of nanoscale vibration through and without the dielectric wall are measured and then compared to the numerical and simulated results. Future improvements using synchronized phase shifters with fixed relative phase offset is also proposed to reduce the undesired DC offset. We will also present experimental detection of laser-generated ultrasound.

A Probabilistic Approach to Robotic NDE Inspection

---**Rahul Summan**, Gordon Dobie, Gareth Pierce, and Gordon Hayward, University of Strathclyde, Centre for Ultrasonic Engineering (CUE), Glasgow, United Kingdom; James Hensman and Keith Worden, University of Sheffield, Department of Mechanical Engineering, Sheffield, United Kingdom

---The application of wireless robotic inspection vehicles equipped with different NDE payloads has been introduced previously, with emphasis placed on inspection applications in hazardous and inaccessible environments. A particular challenge to the practical application of such robotic inspection lies in the accurate location and positioning of the devices; this is essential for both route planning and execution, and for the accurate mapping of defects. The authors here consider a fully probabilistic approach to both the positioning and defect problems by using the location of the robot and the NDE measurements (acquired from the onboard transducers) to make inference about defect existence and position. A machine learning technique is implemented that builds an observation model from scanned plate samples and utilizes training data to relate transducer position to the probability of defect detection. Using a particle filter approach running locally on the robots, the vehicle location is tracked by fusing noisy redundant data sets supplying positional information. The performance of the algorithm is evaluated through both experimental measurements and numerical simulations implemented using a Local Interaction Simulation.

A Secure Method for Enterprise Wide Digital Inspection and Maintenance Records in Aviation Industry

---Preeti Pisupati and **Sandeep Kumar Dewangan**, Infosys Technologies Limited, Software Engineering and Technology, Labs (SETLabs), #44, Electronics City, Bangalore, Karnataka, 560100 India; Ashutosh Saxena, Infosys Technologies Limited, Software Engineering and Technology, Labs (SETLabs), Manikonda, Hyderabad, Andhra Pradesh, 500019 India

---Structural health related inspection and maintenance records, of the cost and safety critical engineering components in aviation industry, are securely preserved and monitored. Various Non-Destructive Testing (NDT) methods which include, ultrasound, radiography, computed tomography, eddy current testing, visual inspection, infra-red imaging etc. are used to generate the inspection data. These are generated in the form of 1-dimensional signals or 2 and/ or 3-dimensional images in conjunction with annotations, interpretations and conclusions made by the inspector. Regulatory requirements mandate that the records must be tamper proof in order to safe guard their integrity and authenticity. Digital signature is one of the mechanisms for demonstrating data integrity and performing source authentication. Timestamps are useful for confirming data existence at a particular point in time. The value of timestamp pertaining to digital signatures is limited due to lack of tools and techniques that address the problems which accrue over the period of time, like expiration, revocation, cryptanalytic and computational advances. We present a secure schema for enterprise wide digital information, related to inspection and maintenance of engineering parts and components, throughout manufacturing and service usage life-cycle. The proposed method covers the source authentication, integrity of information during transactions and secured archiving of data for long periods.

Session 36

SESSION 36
NEW APPLICATIONS AND TECHNIQUES II
T. Jayakumar, Chairperson
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8:30 AM **Fiber Optic Thermographic Detection of Flaws in Composites**
---**M.-C. Wu** and W. P. Winfree, NASA Langley Research Center, MS 231, Hampton, VA 23681-2199

8:50 AM **Remote Defect Visualization with Thermal Phase Angle Shearography**
---**P. Menner**, H. Gerhard, and G. Busse, University of Stuttgart, Institute of Polymer-Technology, Department, Non-Destructive Testing, Stuttgart, Germany

9:10 AM **Scanning Acoustic Microscopy — Velocity Imaging Using Defocused Image Sets**
---D. P. T. Jalluri, S. Sosamma, A. Kumar, C. B. Rao, **T. Jayakumar**, and B. Rai, Indira Gandhi Centre for Atomic Research, Non Destructive Evaluation Division, Kalpakkam, Tamil Nadu, 603102 India

9:30 AM **Guided Waves Propagating in a Piezoelectric Solid/Fluid Bi-Layer System**
---C.-H. Wu and **C.-H. Yang**, Institute of Manufacturing Technology, National Taipei University of Technology, Taipei, Taiwan

9:50 AM **Experimental Results of Guided Wave Travel Time Tomography**
---**A. Volker**, A. Mast, and J. Bloom, TNO Science and Industry, Stieltjesweg 1, P. O. Box 155, 2600 AD Delft, Netherland

10:10 AM ***Break***

10:30 AM **Ultrasonic Nonlinearity Measurements on Rolled Polycrystalline Copper**
---**A. Zinck** and S. Krishnaswamy, Center for Quality Engienering & Failure Prevention, Northwestern University, Evanston, IL 60208-3020

10:50 AM **An Automatic Crack Detection Using Frequency Response of Thick Walled Cylinders**
---**M. A. Hussain** and M. A. Johnson, Benet Laboratories, 1 Buffington Street, Watervliet, NY 12189-4000

11:10 AM **Defect Characterization Using Ultrasonic Guided Waves in Advanced Hybrid Structural Elements**
---F. Yan and J. L. Rose, FBS, Inc., 143 Hawbaker Industrial Drive, State College, PA 16803;
K. "Xue" Qi and J. L. Rose, Department of Engineering Science and Mechanics, Pennsylvania State University, University Park, PA 16802; H. Weiland, Alcoa Technical Center, Alcoa Center, PA 15069

11:30 AM **Autonomous Classification of Passive Thermal Objects in Outdoor Scenes for Mobile Robots**
---**M. K. Hinders**, Department of Applied Science, College of William and Mary, Williamsburg,
VA 23187-8795; W. L. Fehlman II, Dept. of Mathematical Sciences, United States Military Academy, West Point, NY 10996

11:50 AM **Influence of Human Factor on Sensibility of Resistance Spot Weld Analyzer Used in Massive Projection**
---A. Ambroziak and **M. Korzeniowski**, Wroclaw University of Technology, Mechanical Department, Wroclaw, Poland

12:10 AM ***Adjourn***

Fiber Optic Thermographic Detection of Flaws in Composites

---**Meng-Chou Wu** and William P. Winfree, NASA Langley Research Center, MS 231, Hampton, VA 23681-2199

---A new technique is presented for thermographic detection of flaws in materials and structures by performing temperature measurements with fiber Bragg gratings. Individual optical fibers with multiple Bragg gratings employed as surface temperature sensors were bonded to the surfaces of structures with subsurface defects or thickness variations. Both during and following the application of a thermal heat flux to the surface, the individual Bragg grating sensors measured the temporal and spatial temperature variations. The investigated structures included a 10-ply composite specimen with subsurface delaminations of various sizes and depths. The data obtained from grating sensors were further analyzed with thermal modeling to reveal particular characteristics of the interested areas. These results were found to be consistent with the simulation results. Limitations of the technique were investigated using both experimental and numerical simulation techniques. Methods for performing in-situ structural health monitoring are discussed.

Remote Defect Visualization with Thermal Phase Angle Shearography

---**Philipp Menner**, Henry Gerhard, and Gerd Busse, University of Stuttgart, Institute of Polymer-Technology, Department, Non-Destructive Testing, Stuttgart, Germany

---Shearography is an optical method for remote non-destructive testing by monitoring the deformation field of the inspected object under load. The overall deformation of the object may exceed the deformation effects of small defects. Even if lots of fringe images are recorded during the (usually static) thermal loading, only one image is used for further evaluation, so most of the information is lost. We extract the information by modulating the excitation and a temporal analysis of the induced object deformation. So we record a sequence of fringe images and extract the periodical component of the deformation by Fourier transformation at each pixel, providing an amplitude- and a phase angle image. Since all images are used for evaluation, the signal-to-noise ratio is substantially better than in conventional Shearography techniques. Intact areas give a constant phase signal, which makes the method defect selective. Depth range is adjustable via the modulation frequency. Our examples show how well this Lockin-Shearography performs in the inspection of modern materials.

Scanning Acoustic Microscopy – Velocity Imaging Using Defocused Image Sets

---Durga P. T. Jalluri, Samvel Sosamma, Anish Kumar, Chelamchala B. Rao, **Tammana Jayakumar**, and Baldev Rai, Indira Gandhi Centre for Atomic Research, Non Destructive Evaluation Division, Kalpakkam, Tamil Nadu, 603102 India

---Scanning acoustic microscopy (SAM) is a non destructive imaging method for quality and process control in industry as well as research applications. The scanning acoustic microscope was developed as a tool for studying the internal microstructure of nontransparent solids. In acoustic microscopy, a sample is imaged by ultrasound waves, and the contrast in reflection provides a map of the spatial distribution of the acoustic properties with nearly optical resolution. It is also possible to image the sub-surface of the material by de-focusing the lens. Further, the transducer output voltage v(z) is periodic with axial motion of the lens, as the lens moves down from focal plane towards the specimen plane along the z-direction. The period of this variation is the characteristic of the specimen's elastic properties at the point of observation. Acquiring the v(z) curves at each point of the material is a tedious process, To overcome this, a global methodology is developed. A set of image slices are obtained at different depths by de-focusing the lens. Using these sliced images, v(z) curve at each point (pixel) is constructed by plotting a graph between gray intensity and z-value. Based on this, a set of maximal image, minimal image and velocity image are generated. The Maximal image gives the information about the topography of the surface of the specimen. The Minimal image conveys the information about the region which is having same ultrasonic velocity. The velocity image provides the quantitative ultrasonic velocity information at each pixel. This paper presents the methodology employed along with a few typical results obtained.

Guided Waves Propagating in a Piezoelectric Solid/Fluid Bi-Layer System

---Chia-Han Wu and **Che-Hua Yang**, Institute of Manufacturing Technology, National Taipei University of Technology, Taipei, Taiwan

---While Lamb waves are applied for the purpose of liquid sensor, very often there exists a condition that the plate substrate is loaded by a fluid layer with similar thickness. This study is focused on the theoretical modeling and experimental measurements for the dispersion relations of guided waves propagating in LiNbO3 plates loaded by a fluid layer. The LiNbO3 plates have a thickness of 0.5 mm or 1.0 mm, while thickness of the fluid layer varies from 1 to 3 mm. The theoretical model based on a recursive asymptotic stiffness matrix method (RASM) is used to model the dispersion spectra. A laser ultrasound technique (LUT) is used to measure the dispersion relations. The fluid layer is modeled as equivalent elastic body with mass density and wave velocities same as the fluid. Based on the RASM model, a large variety of parameters influencing the dispersion spectra are studied. The studied parameters include crystal-cut direction, azimuthal angle, plate/fluid thickness and density ratios, dielectric permittivity constant and conductivity. The experiments are concentrated on the effects of thickness ratio and different crystal-cuts. For all the investigated cases, the theoretical dispersion spectra agree well with the measurements. Coupling effects for the guided modes propagating in the fluid-layer-loaded plate are characterized while the thickness varies.

Experimental Results of Guided Wave Travel Time Tomography

---**Arno Volker**, Arjan Mast, and Joost Bloom, TNO Science and Industry, Stieltjesweg 1, P. O. Box 155, 2600 AD Delft

---Corrosion is one of the industries major issues regarding the integrity of assets. Currently inspections are conducted at regular intervals to ensure a sufficient integrity level of these assets. Both economical and social requirements are pushing the industry to even higher levels of availability, reliability and safety of installations. The concept of predictive maintenance using permanent sensors that monitor the integrity of an installation is an interesting addition to the current method of periodic inspections reducing uncertainty and extending inspection intervals. Guided wave travel time tomography is a promising method to monitor the wall thickness quantitatively over large areas. Obviously the robustness and reliability of such a monitoring system is of paramount importance. Laboratory experiments have been carried out on a 10" pipe with an nominal wall thickness of 8 mm. Multiple, inline defects have been created with a realistic morphology. The depth of the defects was increased stepwise from 0.5 mm to 2 mm. Additionally the influences of the presence of liquid inside the pipe and surface roughness have been evaluated as well. Experimental results show that this method is capable of providing quantitative wall thickness information over a distance of 4 meter, with a sufficient accuracy such that results can be used for trending. The method has no problems imaging multiple defects.

Ultrasonic Nonlinearity Measurements on Rolled Polycrystalline Copper

---**Aurora Zinck** and Sridhar Krishnaswamy, Center for Quality Engienering & Failure Prevention, Northwestern University, Evanston, IL 60208-3020

-- Ultrasonic nonlinearity is known to be sensitive to microstructural changes that may not be readily detectable using conventional ultrasonic techniques currently used for nondestructive testing. Changes in the ultrasonic nonlinearity parameter, β, have been attributed to changes in dislocation density caused by damage mechanisms induced by fatigue or loading into the inelastic region. In this work, we explore the connection between ultrasonic nonlinearity measurements and inelastic deformation using copper as the material system. Polycrystalline copper samples have been cold rolled to generate well-defined dislocation microstructures. The samples have their β value measured by longitudinal waves traversing orthogonally to the rolling direction. Methods for obtaining β are presented, with specific focus on those procedures that minimize variations in measurements, thus ensuring repeatability. Finally, the observable relationship between β and dislocation structures is compared to nonlinear ultrasonic theory.

An Automatic Crack Detection Using Frequency Response of Thick Walled Cylinders

---**Moayyed A. Hussain** and Mark A. Johnson, Benet Laboratories, 1 Buffington Street, Watervliet, NY 12189-4000

---A method for detecting cracked cylindrical geometries using statistical pattern recognition is described. A set of accelerometer mounted on the outside of cylinder provide vibration data due to an impulse load. Response to the load is then filtered and spectrum of the data used as a feature to be used in automated statistical detection processor to monitor the degree of damage due to crack or cracks. The crack causes shift of natural frequencies, increase of the decay or equivalently increases the Q factor and causes splitting of its natural frequencies. These effects are larger for greater damage and allow comparison to un-cracked system using maximum likelihood method of statistical pattern recognition. The vibration data can alternatively obtained using laser vibro-meters. Primary application would be a monitoring of large caliber gun mounted on various defense systems. Theoretical analysis predicts various breathing modes of vibration that is validated with the experiments. The experimental data were obtained on three swage section of 150 mm tube two of which had cracks and one was without cracks. The method was applied to more than one hundred data set for reach section and the performance of the classifier was evaluated.

Defect Characterization Using Ultrasonic Guided Waves in Advanced Hybrid Structural Elements

---Fei Yan and Joseph L. Rose, FBS, Inc., 143 Hawbaker Industrial Drive, State College, PA 16803; **Kevin Qi** and Joseph L. Rose, Department of Engineering Science and Mechanics, Pennsylvania State University, University Park, PA 16802; Hasso Weiland, Alcoa Technical Center, Alcoa Center, PA 15069

---Nondestructive testing for multilayered structures is challenging because of increased numbers of layers and plate thickness. In this paper, ultrasonic guided waves are applied to detect delamination defects inside a 23-layer Alcoa Advanced Hybrid Structural plate. A semi-analytical finite element (SAFE) method generates dispersion curves and wave structures in order to select appropriate wave structures to detect certain defects. One guided wave mode and frequency is chosen to achieve high stress level at regions of interest. A finite element model simulates the interaction of the selected mode with defects. Theoretically driven experiments are conducted and compared with bulk wave measurements. It is shown that guided waves can detect deeply embedded damages inside thick multilayer fiber-metal laminates with suitable mode and frequency selection.

Autonomous Classification of Passive Thermal Objects in Outdoor Scenes for Mobile Robots

---**Mark K. Hinders**, Department of Applied Science, College of William and Mary, Williamsburg, VA 23187-8795; William L. Fehlman II, Dept. of Mathematical Sciences, United States Military Academy, West Point, NY 10996

---The usefulness of passive thermal infrared imaging as a mobile robot sensing modality is explored. A set of methods and algorithms that use an infrared camera to automatically characterize non-heat generating objects in outdoor environments is described. Objects that extend laterally beyond the thermal camera's field of view, such as brick walls, hedges, picket fences, and wood walls as well as compact objects that are laterally within the thermal camera's field of view, such as metal poles and trees trunks, are considered. We discuss the acquisition and preprocessing of thermal images, as well as the generation and selection of thermal-physical features from these objects within thermal images, as well as the results of a physics-based model to automatically classify these objects.

Influence of Human Factor on Sensibility of Resistance Spot Weld Analyzer Used in Massive Projection

---Andrzej Ambroziak and **Marcin Korzeniowski**, Wroclaw University of Technology, Mechanical Department, Wroclaw, Poland

---Ultrasonic non destructive testing are one of the methods which are used for evaluation of spot welds in automotive industry. There are few ultrasonic application widely used in practice. The biggest problem in ultrasonic technique especially in massive production is repeatability of measurements. Due to methodology of measurements performed by single probe with water delay line, interpretation of ultrasonic signal is very difficult and irreparable. Obtained results strongly depend of operators, their experience, force used to put the probe into the sheet and diameter of transducer.RSWA device has been coupled with the new type of ultrasonic head: matrix 2D-array heads consisting of a couple dozens of small transducers performing the delayed scan function. This way the A-scan presentation, unclear for some operators has been replaced by C-scan image. Due to flat surface of plastic delay line action of operator has been cut down. Comprehensive presentation RSWA and results obtained in one of the big plant in Poland. The tests have been performed by novice and experienced operators. The results show that capabilities of described system make it insensitive for human factor.
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