Abstracts

Review of Progress in Quantitative NDE

University of Illinois - Chicago (UIC)
Chicago, Illinois
July 20-25, 2008

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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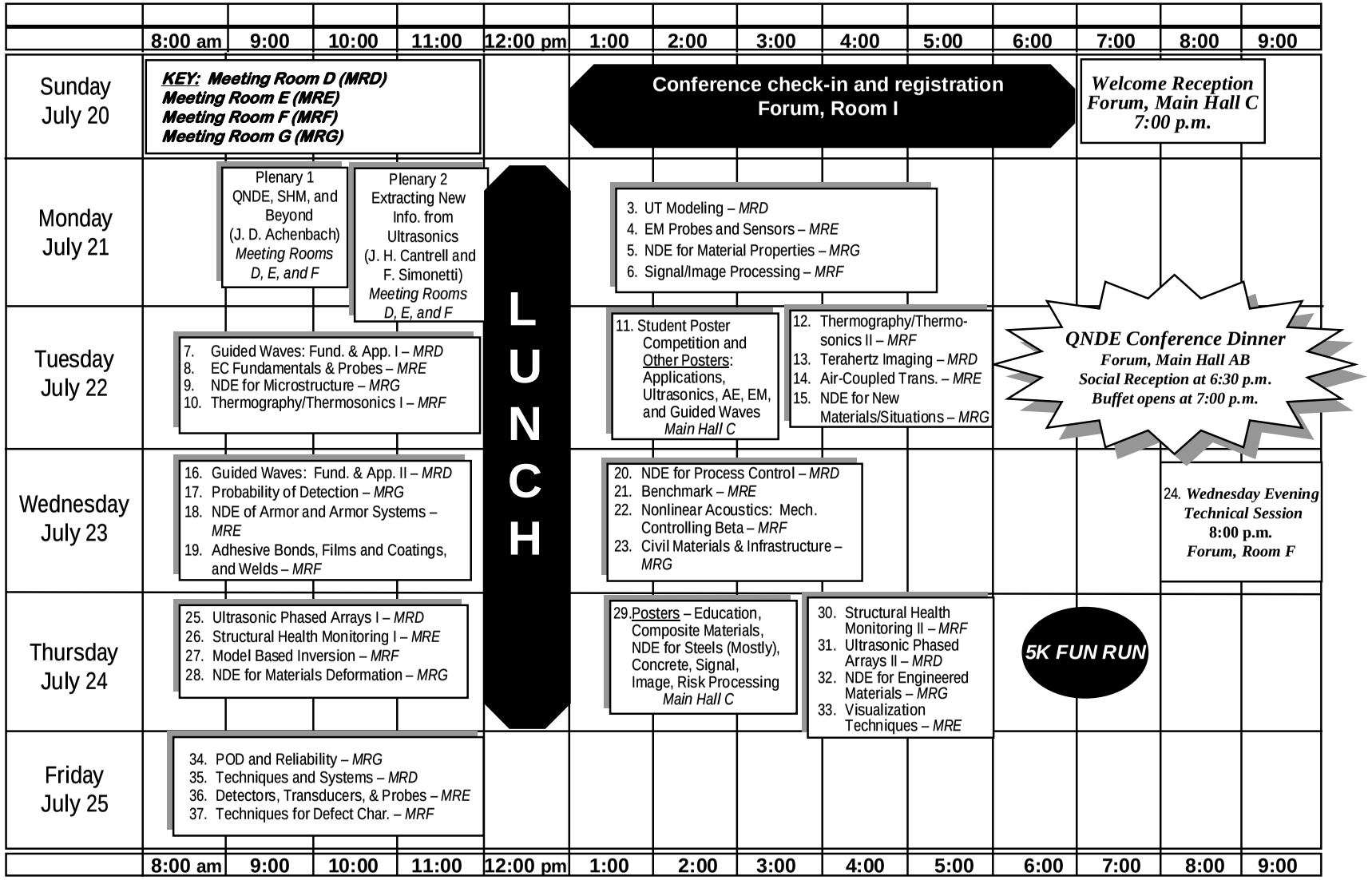
National Science Foundation
Industry/University Cooperative Research Centers

2008 Review of Progress in Quantitative NDE Program Summary



MONDAY

MONDAY AFTERNOON, JULY 21, 2008

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** ***Meeting Room D***	**Session 4** **Electromagnetic Probes & Sensors** ***Meeting Room E***	**Session 5** **NDE for Material Properties** ***Meeting Room G***	**Session 6** **Signal/Image Processing** ***Meeting Room F***
1:30 PM				
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3:10	COFFEE BREAK			
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Plenary Sessions 1 and 2

REVIEW OF PROGRESS IN QUANTITATIVE NDE
University of Illinois at Chicago (UIC)
Chicago, Illinois

July 20 – July 25, 2008

PROGRAM

Monday, July 21, 2008

PLENARY SESSION 1
QNDE, SHM, AND BEYOND
R. B. Thompson, Chairperson
Meeting Rooms D, E, and F

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

9:15 AM **From NDE with a Q to SHM and Beyond**
---**J. D. Achenbach**, McCormick School of Engineering and Applied Science, Northwestern University, Evanston, IL 60208

10:10 AM ***Break***

PLENARY SESSION 2
EXTRACTING NEW INFORMATION FROM ULTRASONICS
D. E. Chimenti, Chairperson
Meeting Rooms D, E, and F

10:30 AM **Nondestructive Evaluation of Metal Fatigue Using Nonlinear Acoustics**
---**J. H. Cantrell**, Mail Stop 231, NASA Langley Research Center, Hampton, VA 23681

11:20 AM **Modern Ultrasound Imaging: An Exciting Window Into the Sub-Surface World**
---**F. Simonetti**, Imperial College, Department of Mechanical Engineering, London SW7 2AZ, United Kingdom

12:10 PM ***Lunch***

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

From NDE with a Q to SHM and Beyond

---**Jan D. Achenbach**, McCormick School of Engineering and Applied Science, Northwestern University, Evanston IL

---In the nineteen-sixties a significant limitation of NDI and NDE became apparent with the advent of fracture mechanics. Fracture mechanics requires quantitative information on defects, which has to be obtained from quantitative non-destructive testing. A DARPA Program directed by Don Thompson provided the point of departure for the journey to put the Q with NDE. The DARPA Program, and subsequent DOD, FAA and industrial programs produced seminal results for diagnostics and prognostics. In diagnostics measurement models entered the picture. Probability of detection considerations and techniques of defect characterization were developed, which were complemented by damage evolution laws, probabilistic failure analysis and damage progression estimates, for methods of prognostication. The new results in QNDE naturally led to structural health monitoring (SHM), whereby sensors are permanently installed on structures. An SHM system can provide on-demand (or continuous) information on the state of a structure, so that an assessment of the structural integrity can be made at any time, and timely remedial actions can be taken. In this paper we review the development from QNDE towards SHM. Data processing, materials engineering and solid mechanics play dominant roles in both the diagnostic and the prognostic components of SHM. A probabilistic approach is essential, as will be shown by examples of pre-crack fatigue damage, crack growth and optimization of an inspection schedule.

Nondestructive Evaluation of Metal Fatigue Using Nonlinear Acoustics
---**John H. Cantrell**, Mail Stop 231, NASA Langley Research Center, Hampton, VA 23681

---Safe-life and damage-tolerant design philosophies of high performance metal structures have driven the development of various methods to evaluate nondestructively the accumulation of damage in such structures resulting from cyclic loading. A method based on nonlinear acoustics is shown to provide a quantitative, unambiguous means to assess the state of fatigue of wavy slip metals from the virgin state to fracture. The salient features of an analytical model are presented that accounts for the microelastic-plastic nonlinearities resulting from the interaction of an acoustic wave with fatigue-generated, state-dependent, dislocation substructures and cracks that evolve during cyclic straining. The interaction is quantified by the material (acoustic) nonlinearity parameter β extracted from acoustic harmonic generation measurements. The model predicts a monotonic increase in β of several hundred percent over the full life of the material that has been verified experimentally and reported in the literature for various metals. Generally, the increase in β during the first 80-95% of fatigue life is dominated by the evolution of organized dislocation structures, while the last 5-20% is dominated by crack growth. Application of the model to aluminum alloy 2024-T4 and 410CB stainless steel specimens fatigued in stress-controlled loading yields excellent agreement between theory and experiment. Current applications and future prospects of nonlinear acoustics for fatigue damage assessment and materials state monitoring are discussed

Modern Ultrasound Imaging: An Exciting Window into the Sub-Surface World
---**Francesco Simonetti**, Imperial College, Department of Mechanical Engineering, London SW7 2AZ, United Kingdom

---Progress in solid state electronics and micromachining has led to the rapid development of ultrasound array technology. It is now possible to measure spatial maps of ultrasonic fields almost instantaneously, with high sensitivity and under various insonification conditions. The technology has become central to imaging in combination with beamforming techniques for applications in medical diagnostics and now in NDE for defect characterization. However, the resolution of current beamforming technology is limited. Indeed, it is not possible to observe the sub-wavelength structure of an object due to diffraction as demonstrated by Lord Rayleigh more than a century ago. Although the resolution can in principle be enhanced by decreasing the wavelength, the penetration depth of the probing wave into the object decreases as the frequency increases due to energy dissipation and/or scattering. This talk introduces the notion that ultrasonic measurements encode more information about the object's structure than beamforming can extract. The key to unlock this information is provided by the knowledge of the scattering mechanism that has caused the encoding in the first instance. This leads to a modern imaging strategy that goes beyond beamforming, can achieve subwavelength resolution and shares some of the underpinning physics with near field microscopy - known to break the Rayleigh criterion. These arguments are supported by experimental images showing unprecedented subwavelength resolution and tomographic reconstructions of a complex 3-D breast phantom that exhibit striking similarities with X-ray CT. The talk will also provide a perspective on future directions and applications in NDE.

Session 3

SESSION 3
UT MODELING
D. Roth, Chairperson
Meeting Room D

1:30 PM **Towards Improved Finite Element Modeling of the Interaction of Elastic Waves With Complex Defect Geometries**
---**P. Rajagopal**, M. Drozdz, and M. J. S. Lowe, Imperial College, Mechanical Engineering, London, SW7 2AZ, United Kingdom

1:50 PM **Prediction of Received Signals in Ultrasonic Testing by Finite Element Method Combined with Geometrical Optics Theory**
---**S. Lin**, H. Yamada, H. Fukutomi, and T. Ogata, Central Research Institute of Electric Power Industry, 2-11-1, Iwado Kita, Komae-shi, Tokyo, 201-8511, Japan

2:10 PM **Prediction of B Scope Images for Ultrasonic Testing by Geometrical Theory of Diffraction**
---**H. Yamada**, H. Fukutomi, S. Lin, and T. Ogata, Central Research Institute of Electric Power Industry, Materials Science Research Laboratory, 2-11-1, Iwado, Kita, Komae-shi, Tokyo, 201-8511, Japan

2:30 PM **2D SH Modeling of Ultrasonic Testing for Cracks Near a Non-Planar Surface**
---**J. Westlund**, Chalmers University of Technology, Department of Applied Mechanics, Division of Dynamics, Göteborg, SE-412 96, Sweden

2:50 PM **Diffraction Coefficients of a Semi-Infinite Planar Crack Embedded in a Transversely-Isotropic Space**
---A. Gautesen, Iowa State University and Ames Laboratory, Department of Mathematic, Ames, IA 50011; **V. Zernov** and L. Fradkin, London South Bank University, Faculty of Engineering, Science, and Built Environment, London, SE1 0AA, United Kingdom

3:10 PM ***Break***

3:30 PM **Modeling of Corner Echo in UT Inspection Combining Bulk and Head Waves Effect**
---**S. Mahaut**, G. Huet, and M. Darmon, CEA-LIST, Centre de Saclay, 91191, Gif-sur-Yvette, France

3:50 PM **Time of Flight Evaluation in a Periodically Inhomogeneous Cladded Plate**
---**M. A. Hawwa**, King Fahd University of Petroleum and Minerals, Department of Mechanical Engineering, Dhahran, 31261, Saudi Arabia

4:10 PM **Influence of Stress Corrosion Crack Morphology on Ultrasonic Examination Performances**
---*O. Dupond****, EDF R&D, Materials and Mechanics of Components Department, Moret-sur-Loing; F. V. Duwig and T. Fouquet, EDF R&D, SINETICS Department, Clamart, France***

4:30 PM **Diffuse Ultrasonic Backscatter from Heterogeneous Solids Through a Liquid-Solid Interface**
---G. Ghoshal and **J. A. Turner**, University of Nebraska Lincoln, Department of Engineering Mechanics, Lincoln, NE 68588-0526

4:50 PM **Effect of Contact Viscosity and Roughness on Interface Stiffness and Wave Propagation**
---**A. Misra** and O. Marangos, The University of Kansas, Civil, Environmental, and Architectural Engineering Department, Lawrence, KS 66045-7609

5:10 PM **NDE Simulations of Welded Components at NASA**
---**D. J. Roth**, MS 6-1, NASA Glenn Research Center, 21000 Brookpark Road, Brookpark, OH 44135

Towards Improved Finite Element Modelling of the Interaction of Elastic Waves With Complex Defect Geometries

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

---Finite element (FE) simulation is increasingly popular for studying ultrasonic wave scattering problems. With improving computational power, researchers now aim to consider more and more complex defect geometries. Conventional wisdom suggests the use of uniform square element meshes, because this avoids scattering by the mesh itself. But these regular meshes do not readily represent the shapes of complex defects, so introducing errors in the scattering calculations. There is thus no perfect option: the modeller must choose between regular meshes with imperfect scattering performance, and irregular meshes with imperfect propagation performance. This paper studies the effects on accuracy resulting from the various modelling decisions, including regular and irregular (automatically generated) meshes, different element types, the degree of refinement of the mesh, and the time step. First the representation of wave scattering is examined with a simple circular hole in a plate as an example defect. Wave propagation performance under different modeling choices is then studied. Recommendations for optimizing the modelling of wave-defect interaction are extracted from the results, with implications for the complex defect problem. The studies are carried out using a commercially available FE package.

Prediction of Received Signals in Ultrasonic Testing by Finite Element Method Combined with Geometrical Optics Theory

---**S. Lin**, H. Yamada, H. Fukutomi, and T. Ogata, Central Research Institute of Electric Power Industry, 2-11-1, Iwado Kita, Komae-shi, Tokyo 201-8511, Japan

---In order to predict received signals in ultrasonic testing with smaller memory and higher speed than conventional FEM, a hybrid numerical method, which combines geometrical optics theory and FEM, is developed. Two main problems have to be solved for this hybrid method, which are absorbing boundary conditions (ABC) and the prediction of received signals. First of all, an efficient ABC called viscous-type perfectly matched layer (VPML) is proposed, which is verified by wave propagation at different directions, frequencies and wave modes. Numerical results show that the VPML is independent of propagating direction, frequency and wave modes. Then, an approach based on reciprocal relation is proposed to calculate received signals. Various received signals are computed by the hybrid method, which are compared with those by experiment. The comparison shows that received signals predicted by the hybrid method are in excellent agreement with those by experiment. Finally, a side view for a specimen with a complicated stress corrosion crack is calculated by the hybrid method, which is in good agreement with that by FEM. The number of nodes and computation time for this calculation by the hybrid method reduce to 1/3 and 1/10, respectively, compared with FEM. The results show that the hybrid method is available to predict received signals as FEM, but with smaller memory and shorter time than FEM.

Prediction of B Scope Images for Ultrasonic Testing by Geometrical Theory of Diffraction
---**Hisao Yamada**, Hiroyuki Fukutomi, Shan Lin, and Takashi Ogata, Central Research Institute of Electric Power Industry, Materials Science Research Laboratory, 2-11-1, Iwado, Kita, Komae-shi, Tokyo, 201-8511, Japan

---The objective of this study is to develop a high speed simulation software to predict B scope images from crack-like defects (slits) in a plate including geometry change regions for ultrasonic testing. The geometrical theory of diffraction (GTD) is used to compute ultrasonic echoes from the reflectors with sharp edges with the aid of reciprocity relation. Two main problems are needed to be solved when GTD used to predict B scope images. One problem is that finite beam paths which are significant to calculate an echo have to be decided firstly, as it is not possible to calculate infinite beam paths probably existing in an ultrasonic testing. Twenty one beam paths are included in the calculation of the echo. Beam paths are followed from the transducer to the reflector. The other problem is near the shadow boundary where the simple diffraction coefficients can not express smooth change from edge diffraction to specular reflection. A novel interpolation formula is proposed to solve this problem. Numerical results show that this formula works well and B scope images are in good agreement with experiment. Moreover, fairy complete B scope images could be obtained by about 10 seconds on a personal computer with clock frequency of 1.5 GHz and RAM memory of 512 MB, respectively.

2D SH Modeling of Ultrasonic Testing for Cracks Near a Non-Planar Surface
---**Jonathan Westlund**, Chalmers University of Technology, Department of Applied Mechanics, Division of Dynamics, Göteborg, SE-412 96 Sweden

---A model of 2D SH ultrasonic nondestructive testing for interior strip-like cracks near a non-planar back surface in a thick-walled component is presented. The model employs a Green's function to reformulate the 2D antiplane wave scattering problem as two coupled boundary integral equations (BIE): a displacement BIE for the displacement on the back surface and a hypersingular traction BIE for the crack opening displacement (COD). The integral equations are solved by performing a boundary element discretization of the back surface and expanding the COD in a series of Chebyshev functions which incorporate the correct behavior at the crack edges. The transmitting ultrasonic probe is modeled by prescribing the traction underneath it, enabling the consequent calculation of the incident field. An electromechanical reciprocity relation is used to model the action of the receiving probe. A few numerical examples which illustrate the influence of the non-planar back surface are given.

Diffraction Coefficients of a Semi-Infinite Planar Crack Embedded in a Transversely-Isotropic Space

---Arthur Gautesen, Iowa State University and Ames Laboratory, Dept. of Mathematics, Ames, IA 50011; **Victor Zernov** and Larissa Fradkin, London South Bank University, Faculty of Engineering, Science and Built Environment, London, SE1 0AA, United Kingdom

---We have considered a semi-infinite crack embedded in a transversely isotropic medium and studied two special cases: In one the axis of symmetry is normal to the crack face and the wave incidence is arbitrary; in another, the axis lies in the crack plane normal to the edge and the incident wave vector is also normal to the edge. The problem is of interest in Non-Destructive Evaluation, because austenitic steels that are found in claddings and other welds in the nuclear reactors are often modeled as transversely isotropic. In both of cases, we have expressed the scattered field in a closed form and computed the corresponding diffraction coefficients.---The work has been partially funded by CEA.

Modeling of Corner Echo in UT Inspection Combining Bulk and Head Waves Effect

---**S. Mahaut**, G. Huet, and M. Darmon, CEA-LIST, Centre de Saclay, 91191 Gif-sur-Yvette, France

---Most UT inspection procedures used for detection of breaking wall notches rely on the corner echo effect, which corresponds to the reflection of an obliquely incident wave on the backwall and on the flaw. The amplitude of this corner echo will vary depending on the angle of the flaw and the backwall, as geometrical effects are mainly responsible of the echo. Mode conversion may also occur which gives rise to additional echoes. In addition to these longitudinal and transverse bulk waves modes, if the incident wave over the flaw or over the backwall is closed to the critical angle, head waves and creeping waves may also be generated and interfere with the flaw. This paper presents some experimental and theoretical studies of these effects taking into account bulk and head waves simulation simultaneously.

Time of Flight Evaluation in a Periodically Inhomogeneous Cladded Plate

---**Muhammad A. Hawwa**, King Fahd University of Petroleum and Minerals, Department of Mechanical Engineering, Dhahran 31261, Saudi Arabia

---A perturbation analysis of the transmission of ultrasonic waves guided by a cladded plate with irregular surfaces is presented. The interface between the host plate and the cladding and the outerface of the cladding are both considered to be periodically undulated. Based on a two-probe scheme of a transmitter and a receiver, an equation is derived for evaluating the wave speed. Results show the time of flight of the ultrasonic signal as an indicator of the conditions of cladded plates. Numerical illustrations are given to check on the influence of various parameters including geometry in terms of surface periodicity and amplitude, plate thickness, and the frequency of ultrasonic propagating waves.

Influence of Stress Corrosion Crack Morphology on Ultrasonic Examination Performances

---**O. Dupond**, EDF R&D, Materials and Mechanics of Components Department, Moret-sur-Loing; France V. Duwig and T. Fouquet, EDF R&D, SINETICS Department, Clamart, France

---Stress Corrosion Cracking represents a potential damage for several components in PWR. For this reason, NDE of stress corrosion cracks corresponds to an important stake for Electricité de France (EDF) both for availability and for safety of plants. This paper is dedicated to the ultrasonic examination of SCC crack defects. The study mixes an experimental approach conducted on artificial flaws - meant to represent the characteristic morphologic features often encountered on SCC cracks - and a 2D finite element modelling with the code ATHENA 2D developed by EDF. Results indicate that ATHENA reproduces correctly the interaction of the beam on the complex defect. Indeed specific ultrasonic responses resulting from the defect morphology have been observed experimentally and reproduced with the modelling.

Diffuse Ultrasonic Backscatter From Heterogeneous Solids Through A Liquid-Solid Interface

---Goutam Ghoshal and **Joseph A. Turner**, University of Nebraska Lincoln, Department of Engineering Mechanics, Lincoln, NE 68588-0526

---Diffuse ultrasonic backscatter techniques are useful for probing heterogeneous materials. They can be used to extract microstructural parameters and to detect flaws which cannot be detected by conventional ultrasonic techniques. Such experiments, usually done using a modified pulse-echo technique, utilize the spatial variance of the signals as a primary measure of microstructure. Quantitative ultrasonic scattering models include components of both transducer beams as well as microstructural scattering information. Of particular interest for interpretation of many experiments is the propagation through a liquid-solid interface at normal and oblique incidence. Here, the Wigner distribution of the beam pattern of an ultrasonic transducer through a liquid-solid interface is used in conjunction with the stochastic wave equation to model this scattering problem within a single scattering formulism. The Wigner distribution represents a distribution in space and time of the spectral energy density as a function of wave vector and frequency. A Gaussian beam is used to model the transducer beam pattern. The scattered response in the time domain is then compared with experimental results for materials of common interest. These results are anticipated to impact ultrasonic nondestructive evaluation and characterization of heterogeneous media.

Effect of Contact Viscosity and Roughness on Interface Stiffness and Wave Propagation

---**Anil Misra** and Orestes Marangos, The University of Kansas, Civil, Environmental and Architectural Engineering Department, Lawrence, KS 66045-7609

---The authors have developed a micromechanical methodology for modeling contact behavior of rough interfaces. This methodology has been applied to determine complex effective normal and shear stiffnesses of interfaces by considering surface roughness, and viscous asperity contact force laws. We find that the surface roughness and asperity properties compete in determining the overall behavior of the interface. For example, the overall relaxation times of the interface depend upon the roughness as well as the contact normal and shear relaxation times. Furthermore, these overall relaxation times are different in the normal and the shear directions. These findings have critical implication on the interpretation of wave propagation through rough interfaces in terms of energy dissipation and phase lag of transmitted and reflected waves. To investigate the wave propagation behavior, we have utilized the imperfectly bonded interface model in which, the displacement discontinuity is accommodated through effective interface stiffnesses. In this work, the micromechanically derived complex effective stiffnesses are used in conjunction with the imperfectly bonded interface model to perform a parametric study by varying surface roughness, contact viscosities, frequency of the incident wave, and wave incidence angles.

NDE Simulations of Welded Components at NASA

---**Don J. Roth**, MS 6-1, NASA Glenn Research Center, 21000 Brookpark Road, Brookpark, OH 44135

---Comprehensive and accurate inspections of welded components have become of increasing importance as NASA develops new hardware such as ARES rocket segments for future exploration missions. Modeling and simulation of nondestructive evaluation (NDE) methods for weld inspection and other applications can play an increasing role in better understanding of the physics of the inspection, determination of feasibility of different inspection methods and setup parameters, fine-tuning of inspection parameters, and probability of flaw detection. As such, these methods can end up resulting in time and cost savings for actual inspections. This presentation describes the results of x-ray and ultrasonic simulations for flaws in welds using x-ray and ultrasonic simulation software programs. Experimental validation of some results is also presented.

Session 4

SESSION 4
ELECTROMAGNETIC PROBES AND SENSORS
Meeting Room E
Y. Y. Kim, Chairperson

1:30 PM **Transient Current Potential Drop Measurements With a Four Point Probe**
---**J. R. Bowler**, Iowa State University, Department of Electrical and Computer Engineering and Center for NDE, Ames, IA 50011

1:50 PM **Edge Effects in Four Point Direct Current Potential Drop Measurement**
---**Y. Lu**, J. R. Bowler, C. Zhang, and N. Bowler, Iowa State University, Department of Electrical and Computer Engineering and Center for NDE, Ames, IA 50011

2:10 PM **Effect of Foil Tilt on Eddy Current Magneto-Resistive (MR) Sensor Signals**
---**B. Naimipour**, X. Liu, Z. Zeng, and L. Udpa, Michigan State University, Electrical and Computer Engineering, East Lansing, MI 48824; B. Koltenbah and R. Bossi, The Boeing Company, Applied Physics, Seattle, WA; G. Steffes, AFRL/MLLP, Dayton, OH 45433

2:30 PM **ECT Simulation of Coil Tilt Effect on 3D Flaw Responses in Planar Geometries**
---**C. Reboud** and G. Pichenot, CEA, LIST, CEA Saclay, F-91191, Gif-sur-Yvette, Cedex, France; T. Theodoulidis, Energy Department, University of West Macedonia, Kozani, Bakola & Sialvera, 50100, Greece

2:50 PM **Flexible Eddy Current Probes for the Inspection of Complex Parts**
---J.-M. Decitre, B. Marchand, O. Casula, and **C. Reboud**, CEA-LIST Saclay, Gif-sur-Yvette, France

3:10 PM ***Break***

3:30 PM **Pulsed Eddy Current Probe Design Based on Transient Magnetic Field Diffusion**
---T. J. Cadeau and **T. W. Krause**, Royal Military College of Canada, Department of Physics, Kingston, Ontario, Canada

3:50 PM **GMR Second Order Electronic Gradiometer as Eddy Current Probe in NDE Applications**
---**M. Valentino**, C. Bonavolonta, G. P. Pepe, and N. Marrocco, CNR-INFM Coherentia, Naples, Italy; M. Valentino, G. P. Pepe, and N. Marrocco, University of Naples “Federico II”, Department of Physical Science, Naples, Italy

4:10 PM **Development of Magnetostrictive Patch-Type Transducers for Guided-Wave Inspection of Plate Structures**
---**Y. Y. Kim**, J. S. Lee, and H. Lee, Seoul National University, School of Mechanical and Aerospace Engineering and National Creative Research Initiatives, Center for Multiscale Design, Seoul, Korea; H. C. Lee, Catholic University of Daegu, School of Mechanical and Automotive Engineering, Daegu, Korea

4:30 PM **Mega Hertz Ultrasonic Elastic Wave Generation by a Magnetostrictive Patch Transducer for Nondestructive Pipe Evaluation**
---**H. W. Kim** 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, Safety Metrology Center, Daejon, Korea

4:50 PM **Rotational Barkhausen Signals Under Rotating Magnetic Field**
---**Y. Tsuchida** and M. Enokizono, Oita University, Faculty of Engineering, Oita, Japan; M. Oka, Oita National College of Technology, Oita, Japan

Transient Current Potential Drop Measurements with a Four Point Probe

---**John R. Bowler**, Iowa State University, Department of Electrical and Computer Engineering and Center for NDE, Ames, IA 50011

---The transient current potential drop (TCPD) between a pair of contact electrodes in a four point probe has been determined for the case where a current pulse is injected into a conductive plate. Four point probes are typically used to measure conductivity or crack dimensions using direct or alternating current injected into the material via sprung-loaded pin electrodes. The advantage of a transient current potential drop measurement is that information on the variations of material properties with depth can be acquired rapidly. As a first step towards analyzing more complex signals, such as those from inhomogeneous conductors, an analytical expression for the transient potential drop of a four point probe on a homogeneous plate has been found. In the presentation we discuss the design criteria for TCPD probes and review potential applications.---This material is based upon work supported by the NSF/IU Program at the Center for NDE, Iowa State University.

Edge Effects in Four Point Direct Current Potential Drop Measurement

---**Yi Lu**, John R. Bowler, Chongxue Zhang, and Nicloa Bowler, Iowa State University, Department of Electrical and Computer Engineering and the Center for Nondestructive Evaluation, Ames, IA 50011

---Four point direct current potential drop (DCPD) is used to measure electrical conductivity and crack depth. It is also used, together with Hall voltage measurements to evaluate carrier concentration and mobility in semiconductors. Here the theory of DCPD is studied for planar structures in which edge effects may have to be taken into account and correction made to ensure accuracy. The current injected at a point on the surface of an infinite plate of finite thickness gives rise to a field that can be express as a summation derived using image theory. Because the images are periodic in the direction perpendicular to the plate surface, the field can also be conveniently expressed in the form of a Fourier series. The two basic formulas; image summation and Fourier series, can be modified for the case where the probe points are near the edge of a plate by further application of images. In fact the electric field in any rectangular parallelepiped can be represented by summing image/Fourier terms in three dimensions. What one must decide is the most efficient way of doing this. For the rectangular parallelepiped, the image terms form an infinite three dimensional array of static monopoles, analogous to the structure found in ionic crystals. Thus the problem of computing the field is equivalent to that of finding the electrical potential in a crystal lattice. This means we can borrow from the extensive literature on the theory of ionic structures to derive the DCPD in a plate of finite length, width and depth.---This material is based upon work supported by the NSF/IU Program at Iowa State University's Center for NDE.

Effect of Foil Tilt on Eddy Current Magneto-Resistive (MR) Sensor Signals

---**Bahare Naimipour**, Xin Liu, Zhiwei Zeng, and Lalita Udpa, Michigan State University, Electrical and Computer Engineering, East Lansing, MI 48824; B. Koltenbah and R. Bossi, The Boeing Company, Applied Physics, Seattle, WA; G. Steffes AFRL/MLLP, Dayton, OH

---Magneto-resistive (MR) sensor is one of the promising advanced electromagnetic sensing methods today. It has been shown in recent years that eddy current foil excitation (ECT) with MR sensors display higher sensitivity to cracks at larger depths. This paper presents the modeling results and analysis of a current foil parallel to a multi-layered structure and then studies the effect of foil tilt on the probability of detecting 1st and 2nd layer cracks. Modeling foil tilt can help understand the effect of tilt parameters on experimental signals. A formulation based on reduced magnetic vector potential will be presented for enhancing the efficiency of the model.

ECT Simulation of Coil Tilt Effect on 3D Flaws Responses in Planar Geometries

---**C. Reboud** and G. Pichenot, CEA, LIST, CEA Saclay, F-91191 Gif-sur-Yvette Cedex, France; T. Theodoulidis, Energy Department, University of West Macedonia, Kozani, Bakola & Sialvera, 50100, Greece

---In eddy current testing the coil tilt may have a strong influence on the flaw's response. This phenomenon has to be taken into account by simulation when considering realistic eddy current testing configurations. In this aim a collaborative work involving the University of West Macedonia, Greece and CEA LIST, France, has led to the development of a modeling tool dedicated to the calculation of the incident electromagnetic field emitted by a tilted coil located above a planar workpiece. This tool has been implemented into the CIVA platform through a coupling with the existing ECT semi-analytical model based on volume integral approach implemented. This paper presents first the theoretical approach used for the calculation of the primary electric field as well as the coil impedance when no defect is present. Then validations of the complete model, carried out by comparing simulation results with experimental data, are detailed and discussed. ECT configurations addressed involve 3D flaws and coils that are tilted with different angles.

Flexible Eddy Current Probes for the Inspection of Complex Parts

---Jean-Marc Decitre, Benoit Marchand, Olivier Casula, and **Christophe Reboud**, CEA-LIST Saclay, Gif-sur-Yvette, France

---In wide range of applications, the surfaces of industrial parts to be inspected are complex. In such cases, flexible eddy-current probes are particularly well adapted. They minimize the effect of the lift-off variations during the scan of the complex surfaces. In this communication, we present recent developments of such probes achieved at CEA-LIST. Various technologies of sensors are used depending of the defects to be detected. All the probes are optimized by using the CIVA simulation and expertise platform for non destructive testing. For the small surface breaking flaws, multi-elements probes with inductive sensors etched on kapton films are developed. One of these probes owns 32 elements and detects few hundreds micrometers long notches with a signal to noise ratio higher than 20 dB at 2 MHz. For the embedded flaws at several millimeters deep, other technologies of sensors are better adapted such as fluxgate, Giant Magneto Resistance or Giant Magneto Impedance because they are more sensitive at low frequency than classical coils. They are mounted on a flexible support which allows the sensor to fit the surfaces. The performances of the probes are shown and discussed on experimental results.

Pulsed Eddy Current Probe Design Based on Transient Magnetic Field Diffusion

---**Trevor J. Cadeau** and Thomas W. Krause, Royal Military College of Canada, Department of Physics, Kingston, Ontario, Canada

---The interpretation of pulsed eddy current as a transient diffusion phenomenon was employed to establish design parameters for driver and pickup coils used in the inspection of multilayer aluminum structures for aerospace inspection applications. Depth of penetration of the magnetic field was taken as a function of the system time constant with larger relaxation times (equivalent to lower frequency components) resulting in greater depth of penetration. The design factors identified for the driving coil included the diameter of the coil and the diameter of the wire used to wind it. The design of the pickup coil was found to be less significant in achieving greater sensitivity at depth. Various ferrite core diameters were utilized to further modify the relaxation time and increase the flux density imparted to the sample. Probes with longer relaxation times were found to generate relatively slow rise times that decayed less in amplitude with depth allowing sensitivity to be maintained at greater depths. The applied driving voltage, corresponding to the amplitude of the driving magnetic field, was found to have a significant effect upon the observed signal-to-noise ratio.

GMR Second Order Electronic Gradiometer as Eddy Current Probe in NDE Applications

---**M. Valentino**, C. Bonavolontà, G. P. Pepe, and N. Marrocco, CNR-INFM Coherentia, Naples, Italy; M. Valentino, G. P. Pepe, and N. Marrocco, University of Naples "Federico II", Department of Physical Science, Naples, Italy

---In the last years the research on new magnetic materials has been largely oriented to the enhancement of the electrical resistance change in response to an applied magnetic field. This phenomenon is known as Giant-Magneto Resistance (GMR), and it can be applied to realise a new generation of solid-state magnetic sensors very useful in the Non Destructive Evaluation. GMR sensors are generally used in magnetic field sensing applications, such as medicine and industry fields, since they represent a good compromise between magnetic field sensitivity, simple handling, and cost. Moreover, they offer advantages such as high thermal stability, low power consumption, wide linear range of operation, and a very high bandwidth (d.c.- 1 MHz) that makes them ideal for detecting eddy currents. This paper reports on GMR electronic second order gradiometer used as an EC probe to detect defects in Al-Ti riveted multi-layers non-magnetic metallic samples used in aircraft structures. An electronic characterization of the GMR gradiometer set-up for investigating the probe performance and its magnetic field sensitivity is presented. The comparison between magnetic images obtained by GMR probes and conventional excitation coils demonstrates the possibility to use successfully GMR technology as sensors for NDT applications.

Development of Magnetostrictive Patch-type Transducers for Guided-Wave Inspection of Plate Structures

---**Yoon Young Kim**, Ju Seung Lee, and Hyunsu Lee, Seoul National University, School of Mechanical and Aerospace Engineering and National Creative Research Initiatives, Center for Multiscale Design, Seoul, Korea; Ho Cheol Lee, Catholic University of Daegu, School of Mechanical and Automotive Engineering, Daegu, Korea

---The recent development of magnetostrictive patch-type transducers for guided-wave inspection of plate structures will be presented. The transducers consist of a circular magnetostrictive patch bonded to a test plate, a set of bias magnets, and coils. They can generate and measure the Lamb waves and/or shear-horizontal waves depending on the relative direction of the time-varying magnetic field by the coil with respect to the bias magnetic field. A main advantage of the developed magnetostrictive transducers over piezoelectric transducers is that the direction of the generated wave by the transducer can be easily varied even without using an array of transducers. If one employs multiple of the transducers located at some distance away to each other, the generated waves can be focused at a target location. Likewise, guided-wave measurement can be focused on a target location by the same technique. Two types of magnetostrictive transducers that are being developed by our group will be discussed: the transducers controlling wave directions mechanically and electronically. Depending on the controlling method, different configurations of magnets and coils are used. A first-order, yet accurate, theory to predict the generated wave pattern by the transducer will be also presented.

Mega Hertz Ultrasonic Elastic Wave Generation by a Magnetostrictive Patch Transducer for Nondestructive Pipe Evaluation

---**Hoe Woong Kim** 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, Safety Metrology Center, Daejon, Korea

---A magnetostrictive transducer is an effective transducer in carrying non-destructive evaluation (NDE) in a pipe or a shaft. However, their operational frequency has been limited under about 500 kHz. Although the non-dispersive torsional wave is the most desirable wave mode for NDE, it is not yet possible to generate and measure mega Hertz torsional waves by conventional transducers. In this investigation, we propose a new magnetostrictive patch transducer configuration for the mega Hertz wave generation. The developed transducer consists of a strip of a magnetostrictive patch wound around a pipe or a shaft, a meander-type coil and bias magnets. The key idea here is to use a meander-type coil for high-frequency wave generation by the magnetostrictive principle. Because a meander-type coil usually has small inductance, it is adequate for the generation of short-wavelength or high-frequency guided waves. Several sets of experiments were conducted to test the effectiveness of the developed magnetostrictive transducer configurations. In fact, the experimental results showed that torsional modes over 500 kHz up to 2 MHz could be generated and measured by the present transducer. No other undesirable mode such as flexural or longitudinal modes was generated. This is an important property of pure torsional wave-generating transducers.

Rotational Barkhausen Signals Under Rotating Magnetic Field

---**Yuji Tsuchida** and Masato Enokizono, Oita University, Faculty of Engineering, Oita, Japan; Mohachiro Oka, Oita National College of Technology, Oita, Japan

---In recent years, non-destructive testing has been playing an important role for safety and maintenance of structures. We have been doing the research on the fatigue evaluation of magnetic materials by magnetic Barkhausen signals. The Barkhausen signal is generated by the movement of the 180-degree magnetic domain inside the magnetic materials. Though the Barkhausen signal of the magnetic materials is usually measured by the magnetic sensor under “the alternating magnetic field”, we revealed that the Barkhausen signal under “the rotating magnetic field” was different from the one under “the alternating magnetic field” and named it as “Rotational Barkhausen Signal”. In this paper, the fundamental features of “Rotational Barkhausen Signal” are presented by comparing them with those of the conventional magnetic Barkhausen signal under the alternating magnetic field.

Session 5

SESSION 5
NDE FOR MATERIAL PROPERTIES
Meeting Room G

1:30 PM **Modeling of Ultrasonic Propagation in a Coarse Grain Structure**
---**F. Jenson** and T. Fortuna, Commissariat à l'Energie Atomique, DRT/LIST, CEA-Saclay, 91191, Gif-sur-Yvette, France; L. Doudet, Electricité de France, EDF R&D, MMC, 77818, Moret-sur-Loing, France

1:50 PM **In-Situ Resistivity Monitoring of Thermally-Induced Microstructure Evolution**
---**E. Madhi** and P. B. Nagy, University of Cincinnati, Department of Aerospace Engineering, Cincinnati, OH 45221-0070

2:10 PM **One-Sided Liquid Coupled Ultrasonic Method for Recovery of Third Order Elastic Constants**
---**D. D. Muir**, T. E. Michaels, and J. E. Michaels, Georgia Institute of Technology, School of Electrical and Computer Engineering, Atlanta, GA 30332-0250

2:30 PM **Ultrasonic Inspection of Bearing Components for Steel Qualification**
---**G. Ghoshal** and J. A. Turner, University of Nebraska Lincoln, Department of Engineering Mechanics, Lincoln, NE 68588-0526; B. M. Wilson, Amsted Rail, Granite City, IL 62040

2:50 PM **Numerical Analysis of the Impulse Excitation of Vibration and Acoustic Resonance Techniques for Rectangular Parallelepipeds**
---**J. I. Etcheverry** and G. A. Sánchez, TenarisSiderca R&D, Applied Physics Department, Campana, Buenos Aires, Argentina

3:10 PM ***Break***

3:30 PM **Ultrasonic Measurement of Dimensional and Material Properties**
---**D. K. Stoyko** and N. Popplewell, University of Manitoba, Department of Mechanical and Manufacturing Engineering, Winnipeg, Manitoba, Canada; A. H. Shah, University of Manitoba, Department of Civil Engineering, Winnipeg, Manitoba, Canada

3:50 PM **Electromagnetic Characterization of the Depth of Surface-Hardening in Steel**
---**C. Zhang**, N. Bowler, and C. Lo, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

4:10 PM **Ductile Iron Grade Characterization Using Magnetic Hysteresis Measurements**
---**M. J. Johnson**, EM Sensors, Inc., 1415 Duff Avenue, Ames, IA 50010; C. Lo, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

4:30 PM **Characterization of Case-Hardened Steels by Model-Assisted Analyses of Magnetic Hysteresis and Barkhausen Effect Signal**
---**C. C. H. Lo** and Y. Shen, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

4:50 PM **Ultrasonic Attenuation Measurements in Thermally Degraded 2205 Duplex Stainless Steel**
---**A. Ruiz**, N. Ortiz, H. Carreón, and A. Sànchez, Universidad Michoacana de San Nicolas de Hidalgo, Instituto de Investigaciones Metalúrgicas, Morelia, Michoacán, Mexico

Modeling of Ultrasonic Propagation in a Coarse Grain Structure

---**F. Jenson** and T. Fortuna, Commissariat à l'Energie Atomique, DRT/LIST, CEA-Saclay, 91191 Gif-sur-Yvette, France; L. Doudet, Electricité de France, EDF R&D, MMC, 77818 Moret-sur-Loing, France

---The metallurgical structure of centrifugally cast stainless steel components makes it difficult to ultrasonically inspect them. The centimeter-size grains forming the macrostructure strongly affect the transmitted field and thus limit inspection capabilities. Such macrostructures can be computed using an algorithm based on the Voronoi diagrams. This mathematical tool provides good qualitative representations of equiaxed and columnar structures. By combining the Voronoi diagrams with existing CIVA functionalities such as the transmitted field computation in a heterogeneous medium using the so-called pencil method, it is shown that some important physical phenomena responsible of inspection difficulties may be reproduced. For instance, the field distortions in phase and amplitude due to the velocity fluctuations that are caused by the large grain structures of these materials are properly described thanks to this approach. These distortions represent deviations from quantities that are usually described by existing theories, such as the mean field attenuation. Comparisons of simulated results with experimental data are also presented and discussed in this paper.

In-Situ Resistivity Monitoring of Thermally-Induced Microstructure Evolution

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

---This study is part of a larger NDE project aimed at state awareness monitoring in high-temperature engine alloys. Microstructural evolution in metals is a rather complex phenomenon that generally depends on both temperature and time. It was found that electric resistivity is probably the material property that is most sensitive to phase transformations, specifically, order-disorder transformation. This method was selected among other available NDE methods mainly because of its ability to selectively assess reversible and irreversible effects of thermal exposure on the material. Of course, the electric resistivity is also a sensitive reversible function of the instantaneous temperature, therefore real-time assessment of microstructural changes also requires accurate monitoring of temperature. We conducted in-situ resistivity monitoring throughout various heating cycles using the Alternating Current Potential Drop (ACPD) technique. Using thermocouple wires as connections, measurement of the dc potential drop without current injection allows parallel monitoring of the local temperature. Resistivity was continuously measured using a Linear Research LR700 ACPD system at 16 Hz, on IN-718 and other nickel-base superalloys specimens repeatedly heated for 10-hour periods at temperatures starting at 400 ºC and successively increased by 50 ºC. Our objective was to capture any anomalous behavior such as strong nonlinearity in temperature dependence, hysteresis, or irreversible change. In this presentation, we will show strong monotonically increasing remnant resistivity change in evidence especially at specific threshold temperatures. In conclusion, because of its simplicity, accuracy, and robustness, ACPD electric resistivity measurements can be readily exploited to record the thermal history experienced by the material and to assess the resulting remnant microstructural changes.

One-Sided Liquid Coupled Ultrasonic Method for Recovery of Third Order Elastic Constants

---**Dave D. Muir**, Thomas E. Michaels, and Jennifer E. Michaels, Georgia Institute of Technology, School of Electrical and Computer Engineering, Atlanta, GA 30332-0250

---Ultrasonic measurements for experimentally determining third order elastic constants typically require multiple experimental setups using both longitudinal and shear wave transducers, and directions of propagation may be both parallel and perpendicular to the direction of applied uni-axial stress. These measurements can be tedious and time-consuming, and may require access to both sides of a specimen. Field applications can thus be problematic, particularly when the direction of propagation is parallel to the loading direction. Shown here is an alternative ultrasonic measurement technique which utilizes an angle beam technique whereby two transducers are mounted on the same side of a parallel faced specimen. The general theory of acoustoelasticity, which relates wave speed changes to applied loads, is used to derive acoustoelastic constants for longitudinal and shear wave propagation at an angle to the principal stress directions for homogeneous and isotropic materials. Specifically considered here is the liquid coupling case where the transducer separation remains constant with load. Third order elastic constants are derived from the acoustoelastic constants utilizing a solution that incorporates one shear vertical and two longitudinal angle beam wave paths. Numerical and experimental results are shown for 7075 aluminum and low carbon steel, and experimentally obtained values for the third order elastic constants are compared to published results. In addition, a sensitivity analysis is performed to understand how small variations in all input parameters affect the accuracy of the third order elastic constants.

Ultrasonic Inspection of Bearing Components for Steel Qualification

---**Goutam Ghoshal** and Joseph A. Turner, University of Nebraska Lincoln, Department of Engineering Mechanics, Lincoln, NE 68588-0526; Brent M. Wilson, Amsted Rail, Granite City, IL 62040

---One of the most important issues for bearing quality steels is the cleanliness. Impurities present in cast steels can manifest themselves as hard/brittle inclusions, which are detrimental to a bearing in service. ASTM standards outline specifications for assessing steel cleanliness based on morphology, which limits inspection to an area small relative to the entire heat or section, assuming the examined area to be a representative of the bulk material. Previous published work by the authors estimated steel cleanliness qualitatively from ultrasonic C-Scan images of an entire inner and outer bearing race and indentified “good” or “bad” locations on bearing samples. The work presented here extends the previous work by investigating the geometric properties of the inclusion in a bearing sample such as the total area of inclusions, total volume of inclusions and the maximum length of inclusions. The steel cleanliness is then defined by comparing the quantitative ultrasonic results and bearing life test results for components manufactured utilizing steels with varying levels of quality. The use of ultrasonic techniques provides a better determination of steel quality for the entire component than the destructive microscopic techniques. These results are anticipated to impact ultrasonic non-destructive evaluation of bearing steel products.

Numerical Analysis of the Impulse Excitation of Vibration and Acoustic Resonance Techniques for Rectangular Parallelepipeds

---**Javier I. Etcheverry** and Gustavo A. Sánchez, TenarisSiderca R&D, Applied Physics Dept., Campana, Buenos Aires, Argentina

---Impulse excitation of vibration and acoustic resonance are techniques to determine the elastic constants of solid materials from the lowest resonance frequencies, excited by means of an impulse or by a periodic stimulus. Rectangular bars are a common choice for the samples, because of the simplicity of excitation of the different resonance modes of interest. A detailed numerical analysis provides results that are more accurate than standard analytical expressions, and allows quantifying the error incurred on from its use.

Ultrasonic Measurement of Dimensional and Material Properties

---**Darryl K. Stoyko** and Neil Popplewell, University of Manitoba, Department of Mechanical and Manufacturing Engineering, Winnipeg, Manitoba, Canada; Arvind H. Shah, University of Manitoba, Department of Civil Engineering, Winnipeg, Manitoba, Canada

---Through-the-thickness measurement of dimensional and material properties by using ultrasonically generated body waves is commonplace. This procedure is inconvenient, however, when both the dimensions and material properties are unknown or intractable if the dimension of interest is too small for a back wall echo to be separated from the initial pulse. On the other hand, guided propagating waves contain information about both the dimensions and material properties of a structure, which can be extracted, in principle, from a limited number of measurements. The theory and computational approximations used to predict the required properties from spatially distributed time histories of waves propagating in a linear isotropic pipe have been presented previously, and the extension to analogous plates is straightforward. A simplified numerical procedure is possible because the approach is based upon merely three individual cut-off frequencies rather than dispersion curves covering a range of frequencies. However, significant difficulties arising in the practical implementation have been experienced; the present objective is to describe their resolution. A prime advantage of using cut-off frequencies is that each one corresponds to a rigid body mode having a frequency value common to all body locations. An individual value, however, has to be determined within about 5 Hz to reasonably predict dimensional and material properties. This is achieved by (1) employing only the body's continuous, damped free vibrations between a transient excitation ending and the reception of any extraneous reflections and (2) finely evaluating the corresponding frequency behavior directly in time. Then three selected cut-off frequencies are used, in addition to a measured density, in an inversion procedure. The resulting dimensions and material properties are shown to be reasonably comparable to laboratory data found conventionally from short cut-offs.

Electromagnetic Characterization of the Depth of Surface-Hardening in Steel

---**Chongxue Zhang**, Nicola Bowler, and Chester Lo, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---Case depth measurements of surface hardened steel parts are important for quality control. Four-point alternating potential drop (ACPD) method has the potential to evaluate different case depths. The potential drop was measured on a series of 1" diameter induction-hardened and carburized steel rod samples using a co-linear probe with pins aligned parallel to the axis of the rod. The initial permeability and differential permeability of the samples were also studied as a function of case hardening. It was shown that four-point ACPD is a promising technique for distinguishing between different depths of case hardening. Especially in the low-frequency range of the real part of the normalized impedance, there is very good distinction between the case depths of the samples. It seems that measurements of initial permeability on surface hardened rods do not give a clear indication of case depth. When H is around 18 Oe, the differential permeability increases more-or-less in the sequence of case depth d in induction hardened samples. Differential permeability measurements give a good indication of case depth in induction hardened rods, but not carburized rods.

Ductile Iron Grade Characterization Using Magnetic Hysteresis Measurements

---**Marcus J. Johnson**, EM Sensors, Inc., 1415 Duff Avenue, Ames, IA 50010; Chester Lo, Center for NDE, Iowa State University, Ames, IA 50011

---Magnetic hysteresis measurement parameters have been used to determine the hardness of various grades of ductile iron. As part of the process, different grades of ductile iron can also be identified. The complex relationship between hardness, microstructure and steel grade is dealt with using a neural network based approach. In theory, the procedure can be adapted for the characterization of steels.

Characterization of Case-Hardened Steels by Model-Assisted Analyses of Magnetic Hysteresis and Barkhausen Effect Signal

---**C. C. H. Lo** and Yuping Shen, Center for NDE, Iowa State University, Ames IA 50011

---This paper reports on the recent advances in the magnetic hysteresis and Barkhausen effect methods for quantitative case depth measurements on surface-hardened steels, with emphasis on model-assisted analyses of measured signals to infer information on the magnetic property depth profiles. In this work, magnetic hysteresis and Barkhausen effect measurements were carried out on a series of induction hardened steel samples with various case depths up to 3.1 mm. Sensitivity of the magnetic hysteresis measurements was improved by implementing a modulation field technique to control the depth of the interrogated surface layer. The experimental hysteresis loops were simulated as a weighed sum of induction signals from the hardened case and the core using an extended hysteresis model. The estimated case depths were found to agree with the values obtained from the hardness profiles, demonstrating the potential of the technique for case depth measurements. Development of the Barkhausen effect technique for case depth measurements has progressed through the derivation of a generalized model to describe the signal power density spectra. The model treats case hardened steels as a layered problem, and describes the generations of Barkhausen effect signal as a random walk process by means of the Langevin equation in which the averaged magnetic properties of the multilayer are expressed in terms of those of each layer. Relationships between the model parameters and the nominal case depth will be presented and interpreted in terms of the differences in domain wall pinning between the hardened case and the core.---This work was supported by the NSF sponsored Industry/University Cooperative Research Program of the Center for Nondestructive Evaluation at Iowa State University.

Ultrasonic Attenuation Measurements in Thermally Degraded 2205 Duplex Stainless Steel

---**Alberto Ruiz**, Noemí Ortiz, Hector Carreón, and Amadeo Sánchez, Universidad Michoacana de San Nicolas de Hidalgo, Instituto de Investigaciones Metalúrgicas, Morelia, Michoacán, México

---Ultrasonic attenuation plays an important role in materials characterization of metal components. This paper present data and discuss ultrasonic attenuation variations in a 2205 duplex stainless steel aged isothermally at 700°C and 900°C for different time intervals. Attenuation measurements as function of frequency where performed using pulse/echo immersion method and broad band planar transducers. Evidence is found of changes in the attenuation coefficient as aging time increases. The corresponding microstructure of aged specimens was observed and impact toughness was measured. Comparison is made with measurements of ferrite content for the two temperatures and different aging times.

Session 6

SESSION 6
SIGNAL/IMAGE PROCESSING
J. Michaels, Chairperson
Meeting Room F

1:30 PM **Diffuse Field Interferometry for Experimental Green's Function Estimation and Damage Detection**
---A. Duroux and K. Sabra, School of Mechanical Engineering, Georgia Institute of Technology, Atlanta, GA 30332 ; J. Ayers and **M. Ruzzene**, School of Aerospace Engineering, Georgia Institute of Technology, Atlanta, GA 30332

1:50 PM **Fractal Analysis of Metal Transfer in MIG Welding**
---A. P. Vieira, H. H. M. Vasconcelas, **L. L. Goncalves**, and H. C. de Miranda, Universidade Federal do Ceara, Departamento de Engenharia Metalúrgica e de Materials, Fortaleza, Ceara, Brazil

2:10 PM **Spectrally Enhanced Eddy Current Inspection Exploiting Fusion Techniques**
---**I. Elshafiey**, A. Algarni, and M. Alkanhal, King Saud University, Department of Electrical Engineering, Riyadh, Saudi Arabia

2:30 PM **Eddy Current Simulations and Measurements of Sodium Effect for Magnetic and Non-Magnetic Steam Generator Tubes of FBR**
---**O. Mihalache**, T. Yamaguchi, M. Ueda, and S. Miyahara, Japan Atomic Energy Agency, Fast Breeder Reactor Research and Development Center, Tsuruga, Fukui, Japan

2:50 PM **Analysis of Giant Magneto-Resistance (GMR) Data Using Detection Angle**
---**Y. Deng**, X. Liu, Z. Zeng, and L. Udpa, NDE Group, Department of Electrical and Computer Engineering, Michigan State University, East Lansing, MI 48824; B. E. Koltenbah and R. H. Bossi, Applied Physics, The Boeing Company, Seattle, WA 98108; G. Steffes, AFRL/MLLP, Dayton, OH 45433

3:10 PM ***Break***

3:30 PM **Application of Special Filtering Techniques in the Analysis of EMAT Data**
---**A. O. Bolshakov**, J. Zhao, E. J. Domangue, V. S. Dubinsky, and D. J. Patterson, Baker Hughes, Houston Technology Center, 2001 Rankin Road, Houston, TX 77073

3:50 PM **Incident Wave Removal Through Frequency-Wavenumber Filtering of Full Wavefield Data**
---**T. E. Michaels** and J. 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

4:10 PM **Assisted Defect Recognition for the Ultrasonic Multizone Inspection of Titanium Forgings**
---**A. Ferro** and P. Howard, GE Aviation, One Neumann Way, MD Q45, Cincinnati, OH 45215-6301

4:30 PM **Reversible Back-Propagation Imaging Algorithm for Post-Processing of Ultrasonic Array Data**
---**A. Velichko** and P. D. Wilcox, RCNDE, Department of Mechanical Engineering, University of Bristol, Bristol, United Kingdom

4:50 PM **Application of Image Processing Tools for Quantification of Defect Features in Radiographs**
---T. Saravanan, K. Arunmuthu, S. Bhagavathiappan, J. Philip, **T. Jayakumar**, and B. Raj, Indira Gandhi Centre for Atomic Research, Nondestructive Evaluation Division, Kalpakkam, Tamil Nadu, India

Diffuse Field Interferometry for Experimental Green's Function Estimation and Damage Detection

---Adelaide Duroux and Karim Sabra, School of Mechanical Engineering, Georgia Institute of Technology, Atlanta GA 30332; James Ayers and **Massimo Ruzzene**, School of Aerospace Engineering, Georgia Institute of Technology, Atlanta, GA 30332

---Structural health monitoring (SHM) systems often rely on propagating elastic waves through complex structures, which can result in the formation of diffuse-fields over a long reverberation time. Recent theoretical and experimental studies have demonstrated that Green's functions between a pair of monitored points can be extracted from cross-correlation of the recorded diffuse fields (e.g. scattered fields or ambient noise). Knowledge of the Green's functions between large numbers of points can be used to successfully identify and localize damage in complex structural components. In this work, Green's functions are first estimated experimentally from full-field measurements obtained with a scanning Laser vibrometer. This provides the wealth of a-priori information necessary to detect and localize "secondary" sources, such as damages, when only a limited number of sensors are actually mounted on the structure. The proposed approach relies on the detailed knowledge of the structural response, which is exclusively obtained through experimental measurements performed on the actual component under consideration.

Fractal Analysis of Metal Transfer in MIG Welding

---Andre P. Vieira, Hilma H. M. Vasconcelos, **Lindberg L. Goncalves**, and Helio C. de Miranda Universidade Federal do Ceara, Departamento de Engenharia Metalúrgica e de Materiais, Fortaleza, Ceara, Brazil

---We apply techniques of fractal analysis in order to classify metal transfer mode in MIG (metal inert gas) welding, the most commonly employed arc fusion process for industrial applications. We work with voltage and current time series obtained during welding, and evaluate statistical fluctuations present in those series by Hurst, detrended-fluctuation, and detrended cross-correlation analyses, for each of three different metal transfer modes: short-circuit, globular and spray. For a given total time span of each series, curves of fluctuation as a function of the time window size are processed by using pattern classification techniques, such as principal-component analysis and Karhunen-Loève expansion. We obtain near 100% success rates for the classification, with time spans as small as 100 milliseconds, with a processing time of the same order. This suggests that our set of tools can be incorporated into an industrial welding apparatus in order to guarantee automatic correction of a process requiring a single metal transfer mode.

Spectrally Enhanced Eddy Current Inspection Exploiting Fusion Techniques
---**Ibrahim Elshafiey**, Ayed Algarni, and Majeed Alkanhal, King Saud University, Department of Electrical Engineering, Riyadh, Saudi Arabia

---Conventional eddy current methods based on single-frequency excitation have limitations in characterizing materials in nondestructive evaluation applications. More rigorous results could be obtained by enriching the spectral information of the eddy current signal. Transient eddy current techniques have been used to obtain broadband excitation. The energy however is practically concentrated at low frequencies, minimizing the information corresponding to high frequency range. An algorithm is developed to enrich the spectral information of eddy current signal, invoking image fusion techniques. C-scan images corresponding to sinusoidal and pulsed eddy current inspection are fused to increase the inspection sensitivity to identify material flaws. The technique uses multiresolution wavelet decomposition with decimated and undecimated algorithms to identify features with different size in the sample. Principal component analysis (PCA) procedure is implemented to synthesize and reorganize information in the original spectral bands into new bands. Results based on the proposed technique, are presented using images generated by computational simulation as well as experimental inspection of samples with different flaw sizes. Image quality metrics are presented to quantitatively assess the quality and information in the resulting fusion images.

Eddy Current Simulations and Measurements of Sodium Effect for Magnetic and Non-Magnetic Steam Generator Tubes of FBR
---**Ovidiu Mihalache**, Toshihiko Yamaguchi, Masashi Ueda, and Shinya Miyahara, Japan Atomic Energy Agency, Fast Breeder Reactor Research and Development Center, Tsuruga, Fukui, Japan

---In fast breeder reactor (FBR), the steam generator (SG) tube wall is the only barrier between water steam and sodium flow. Eddy current signal (ECT) from outer tube defect is modified by both SG support plates (SP) as well as by sodium layer and unknown sodium drops located on the outer SG tube surface. In the present paper, ECT finite element simulations are conducted to evaluate sodium structures ECT noise and to investigate multi-frequency algorithms for sodium signal reduction. The SP plate signal, in the presence of sodium is also minimized in order to increase the defect signal/noise ratio, when a defect is located under SP. Numerical simulations are validated and calibrated with experimental measurements of artificial outer defect for both magnetic and non-magnetic SG tubes in the absence or presence of sodium covering the outer surface of SG tubes. The papers presents also details about measurements of sodium structures (drops, layer) formed on the outer SG tube surface when these are soaked in a test tank filled with sodium at high temperatures (5000C) up to two hours.

Analysis of Giant Magneto-Resistance (GMR) Data Using Detection Angle

---**Yiming Deng**, Xin Liu, Zhiwei Zeng, and Lalita Udpa, NDE Group, Department of Electrical and Computer Engineering, Michigan State University, East Lansing, MI 48824; Benjamin E. Koltenbah and Richard H. Bossi, Applied Physics, The Boeing Company, Seattle, WA 98108; Gary Steffes, AFRL/MLLP, Dayton, OH 45433

---Eddy current testing (ECT) is widely used in aircraft inspection. However ECT is limited by skin depth in detecting defects in multi-layer complex structures. Advanced electromagnetic sensing methods, such as giant magneto-resistive (GMR) sensors offer much higher sensitivity that allow detection of defects located deeper in the test object. Traditional magnitude based GMR signal interpretation methods based on symmetry of images were developed for detecting cracks under titanium fastener heads, however this approach is ineffective when analyzing data from steel fastener heads which results in reduced probability of detection (POD). This paper presents a signal processing algorithm based on mixing the in-phase and quadrature components of the GMR sensor signal via a detection angle (ODA). Features derived from the mixed signal are clustered for automated crack detection using the MR sensor data. Performance of the algorithm is evaluated using signal to noise ratio (SNR) that measures efficacy of different features.

Application of Special Filtering Techniques in the Analysis of EMAT Data

---**Alexei O. Bolshakov**, Jinsong Zhao, Edward J. Domangue, Vladimir S. Dubinsky, and Doug J. Patterson, Baker Hughes, Houston Technology Center, 2001 Rankin Road, Houston, TX 77073

---We are currently investigating the applicability of EMAT for downhole applications in oil and gas industry. This application, when compared to conventional usage of EMAT for pipeline inspection, imposes significant engineering and data processing challenges due to difficult downhole conditions, variability of pipe sizes (both in diameter and thickness) and signal to noise ratio (SNR) limitations. In this study we detail the investigation of different filtering techniques and methods aimed at the analysis of the EMAT data for various downhole scenarios, separation of different modes and improvement of SNR. The investigated cases include different distances between transducers, presence of various materials behind the pipe and variable pipe diameter and thickness. The techniques being investigated are stacking, frequency (FIR) filtering, Gaussian wavelet decomposition, synchronous detection, match filter and their combination. The methods and techniques proposed are confirmed and validated based on the results obtained from the numerical simulations and experiments with physical models.

Incident Wave Removal Through Frequency-Wavenumber Filtering Of Full Wavefield Data
---**Thomas E. Michaels** and Jennifer 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 30332

---Full wavefield measurements of guided waves in a structure provide a wealth of information that can be effectively used for the identification, localization and quantification of damage. Full field measurements can be obtained using an air-coupled transducer mounted on a scanning stage, or via a scanning laser vibrometer. The resulting detailed spatial and time information can be transformed to the frequency-wavenumber domain where waves propagating in different directions appear decoupled. Appropriate filtering strategies can be applied to effectively remove the contribution of incident waves while highlighting reflections associated with structural discontinuities or damage. This paper presents a comparison between two filtering techniques for incident wave removal operating in the frequency-wavenumber domain. The first technique considers spatial polar coordinates and employs a two-dimensional Fourier Transform, while a second technique is based on the application of the three-dimensional Fourier Transform operating in a Cartesian coordinate frame. Advantages and disadvantages of the two methods are investigated when applied to the analysis of full field data recorded on aluminum plates containing a variety of artificial structural defects and areas of impedance mismatch.

Assisted Defect Recognition for the Ultrasonic Multizone Inspection of Titanium Forgings
---**Andy Ferro** and Pat Howard, GE Aviation, One Neumann Way, MD Q45, Cincinnati, OH 45215-6301

---Titanium aircraft engine forgings are inspected at all material depths using the ultrasonic testing (UT) process called multizone inspection. This process creates 2D C-scan slices that image the material's underlying characteristics, which in the case of forged titanium, result in highly variable noise. The intention is to ultimately accept or reject the part by examining for the presence of small anomaly indications in these images in terms of their signal to noise ratio (SNR), where UT inspectors determine that rejection decision by using specialized image software. This manual approach for calculating SNR is susceptible to inspector subjectivity. Enabling assisted defect recognition (ADR) for the forging inspection, an automated SNR calculation has been developed to address these issues. The ADR algorithm's life cycle from design to validation will be discussed, concentrating on its application to the inhomogeneous nature of the forged titanium microstructure. Validation testing results have shown that ADR effectively reduces inspection cycle time, reduces complexity for the operator and provides precise inspection reproducibility.

Reversible Back-Propagation Imaging Algorithm for Post-Processing of Ultrasonic Array Data

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

---The paper describes a method for processing data from an ultrasonic transducer array. Conventional synthetic focusing techniques like the total focusing method (TFM) are based on linear superposition of transmitter-receiver signals in the frequency domain. The algorithm proposed in this paper is formulated in such a way that it is reversible, i.e. the raw data set can be recovered from the image. This is of practical significance because it allows the raw-data to be spatially filtered using the image to extract, for example, only the raw data associated with a particular reflector. The approach is based on plane wave decomposition of the received signals. The mathematical basis of the technique and a numerical implementation are described. The method is tested on experimental data obtained from a commercial 64 element, 5 MHz array on aluminium specimen that contains a number of machined slots and side-drilled holes. Using the reversibility of the imaging algorithm the raw transmitter-receiver data corresponded to each reflector is extracted and the scattering matrices of different reflectors are reconstructed. This allows the signals from 1 mm long slot and a 1 mm diameter hole to be clearly distinguished and the orientation of the slots to be determined to within a few degrees.

Application of Image Processing Tools for Quantification of Defect Features in Radiographs

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

---Various image processing tools are employed for enhancing and extracting defect features from noisy background of radiographs. In this paper, a histogram concavity based thresholding approach has been used for segmenting porosities, voids and inclusions from digitized radiography images. Studies carried out on small defects in cylindrical tubes and flat plates showed that histogram concavity based thresholding approach yields better results compared to conventional automatic thresholding techniques like Maximum Entropy and Otsu methods where heterogeneous background present in the image due to geometry and high X-ray quantum and structural noise may give poor segmentation. The segmentation procedure is optimized by filtering unwanted noise with low-pass median filtering, followed by gray-level global thresholding. The histogram concavity based thresholding approach provided excellent segmentation of voids present in electrochemical hydrogen sensors, micro-pores in tube-to-tube sheet (TTS) welds of steam generators of fast breeder reactor, porosity in cast plates used in refineries, tungsten inclusion in Tungsten Inert Gas (TIG) welds, crater cracks and external undercuts in welds. With appropriate pixel and grey level calibration, an accuracy of 1-2 pixel size (i.e. 65-130 microns) is obtained for estimation of the size of the defects from the gray-level profiling. Using Butterworth band pass filters on the digitized radiographs, the sensitivity and reliability for detection of defects in tube-to-tube sheet weld joints has been considerably enhanced.

TUESDAY

TUESDAY, JULY 22, 2008

	Session 7 **Guided Waves-Fundamentals and App. I** ***Meeting Room D***	**Session 8** **Eddy Current Fundamentals and Probes** ***Meeting Room E***	**Session 9** **NDE for Microstructure** ***Meeting Room G***	**Session 10** **Thermography and Thermosonics I** ***Meeting Room F***
8:30 AM				
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9:50				
10:10	COFFEE BREAK			
10:30				
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11:10				
11:30				
11:50				
12:10 PM	LUNCH			

Session 11 – POSTERS – 1:30 – 3:10 PM – Main Hall C

	Session 12 **Thermography and Thermosonics II** ***Meeting Room F***	**Session 13** **Terahertz Imaging** ***Meeting Room D***	**Session 14** **Air-Coupled Transducers** ***Meeting Room E***	**Session 15** **NDE for New Materials/Situations** ***Meeting Room G***
3:10	COFFEE BREAK			
3:30				
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5:30	ADJOURN			

Session 7

SESSION 7

GUIDED WAVES – FUNDAMENTALS AND APPLICATIONS I

D. E. Chimenti, Chairperson
Meeting Room D

8:30 AM **Higher Order Modes Cluster (HOMC) Guided Waves – A New Technique for NDT Inspection**
---**C. Jayaraman**, C. V. Krishnamurthy, and K. Balasubramaniam, Centre for Nondestructive Evaluation and Department of Mechanical Engineering, Indian Institute of Technology – Madras, Chennai, Tamilnadu, 600036, India

8:50 AM **Experimental Characterization of Guided Waves by Their Surface Displacement Vector Field**
---M. Barth and **B. Köhler**, Fraunhofer IzFP, Branch Lab Dresden, Dresden, Germany

9:10 AM **In-Situ Monitoring of Material Joining Processes by Guided Ultrasonic Waves**
---**S. I. Rokhlin**, The Ohio State University, Edison Joining Technology Center, 1248 Arthur E. Adams Drive, Columbus, OH 43221

9:30 AM **Post-Processing of the Full Matrix of Ultrasonic Transmit-Receive Array Data for Guided Wave Pipe Inspection**
---**A. Velichko** and P. D. Wilcox, RCNDE, Department of Mechanical Engineering, University of Bristol, Bristol, United Kingdom

9:50 AM **Analytical Model of the Scattering of Guided Waves from Fastener Sites with a Stiffness Interface**
---**S. S. Chellapilla**[2], J. C. Aldrin[3], and K. V. Jata[1], [1]Air Force Research Laboratory, Metals, Ceramics & NDE Division, WPAFB, OH 45433; [2]Radiance Technologies, Inc., 350 Wynn Drive, Huntsville, AL 30805; [3]Computational Tools, 4275 Chatham Avenue, Gurnee, IL 60031

10:10 AM ***Break***

10:30 AM **3D Scattering Analysis of Guided Waves in a Plate Using Mode-Exciting Method**
---**S. Hirose**, Tokyo Institute of Technology, Department of Mechanical and Environmental Informatics, Meguro-ku, Tokyo, Japan

10:50 AM **Feasibility of Low-Frequency Time-of-Flight Straight-Ray Guided Wave Tomography**
---**P. Belanger** and P. Cawley, 682 Mechanical Engineering, Imperial College, Exhibition Road, London, SW7 2AZ, United Kingdom

11:10 AM **Simultaneous Ultrasonic Monitoring of Crack Growth and Dynamic Loads During Full Scale Fatigue Tests of Aircraft Wings**
---**T. E. Michaels**, J. E. Michaels, and A. C. Cobb, Georgia Institute of Technology, School of Electrical and Computer Engineering, Atlanta, GA 30332-0250

11:30 AM **SH0 Mode Interaction with the Propagation Directional Crack in a Plate**
---**M. Ratassepp**, Tallinn University of Technology, Department of Mechanics, Tallinn, Estonia; M. J. S. Lowe, Imperial College, Mechanical Engineering Department, London, United Kingdom

11:50 AM **Comparison of Modeling and Experiments of Lamb Waves for Identification of Damage in Structures**
---**N. A. Apetre** and M. Ruzzene, Georgia Institute of Technology, School of Aerospace Engineering, Atlanta, GA 30332-0250; J. E. Michaels, T. E. Michaels, R. Martin, and P. Haldipur, Georgia Institute of Technology, School of Electrical and Computer Engineering, Atlanta, GA 30332

12:10 PM ***Lunch***

Higher Order Modes Cluster (HOMC) Guided Waves – A New Technique for NDT Inspection

---**C. Jayaraman**, C. V. Krishnamurthy, and K. Balasubramaniam, Centre for Nondestructive Evaluation, and Department of Mechanical Engineering, Indian Institute of Technology-Madras, Chennai, Tamilnadu 600036, India

---This paper reports the use of Higher order modes cluster guided waves (HOMC-GW) which are highly non-dispersive over some distance of propagation. The HOMC-GW technique is a recently explored phenomenon which appears to have greater potential for medium range (approximately of the order of few meters) NDT. This HOMC-GW phenomena occurs at very high frequency-thickness product i.e. around 20 mm.MHz. The current effort will be towards understanding the formation, propagation and dispersion characteristics of HOMC-GW. A 2D ABAQUS finite element model will be used to study the behavior of HOMC-GW at different frequency-thickness products. Experiments on an Aluminum plate sample of dimension 2ft x 3ft x 8mm using a commercial 2.25 Mhz, 1 inch diameter transducer mounted on a machined acrylic wedge will be reported. The interaction of this wave modes cluster with defects, that were simulated, is also analyzed. A comparative discussion between the simulated 2D result and the experiments will be presented.

Experimental Characterization of Guided Waves by Their Surface Displacement Vector Field

---Martin Barth and **Bernd Köhler**, Fraunhofer IZFP, Branch Lab Dresden, Dresden, Germany

---The development new nondestructive evaluation (NDE) and structural health monitoring (SHM) methods utilizing guided elastic waves needs a good understanding of wave propagation properties and the interaction of the waves with structures and defects. If the geometrical and stiffness properties of the components are well known, these effects can be studied very efficiently by numerical modelling. But very often there is a lack of precise knowledge of all necessary elastic properties; accurate and non-disturbing measurements are without alternative in these cases. The mapping of wave fields can be done by scanning laser vibrometers as demonstrated in a number of publications. Originally, a laser vibrometer provides only information from one displacement component. To get all three displacement components, the simultaneous measurement with three vibrometers is offered commercially. This is a very expensive approach. The paper describes a method which uses only one vibrometer sequentially for getting all three vector components. The capability of this approach is demonstrated for different applications, including Lamb waves and guided waves on a layered surface.

In-Situ Monitoring of Material Joining Processes by Guided Ultrasonic Waves

---**S. I. Rokhlin**, The Ohio State University, Edison Joining Technology Center, 1248 Arthur E. Adams Drive, Columbus OH, 43221

---This presentation discusses the application of guided waves to in-situ monitoring of several spot welding processes. Two are ultrasonic welding processes where joining occurs in the solid state and the third is electrical resistance welding process where a small liquid nugget is created due to resistance heating followed by rapid solidification. The ultrasonic wire bonding process is widely used in the microelectronic industry and real time quality monitoring of this process is important. The technique involves in-process application of ultrasonic flexural waves excited in the wire by small ultrasonic transducers integrated with the welding apparatus. The flexural waves in the wire interact with the weld and the reflection and transmission coefficients from the weld are measured and related to the bond quality. A second welding process investigated is ultrasonic spot welding of Al, a process currently under development by the automotive industry. For this type of welding Lamb wave monitoring is applied. The Lamb wave signal clearly shows the different stages of the welding process: application of pressure, initiation and termination of weld and after burst action. To relate ultrasonic signatures with weld quality a series of welding experiments have been performed on different aluminum alloys. A similar Lamb wave monitoring concept was also used for in-process quality control of resistance spot welding of coated and uncoated steel.---The work was sponsored by the EWI.

Post-Processing of the Full Matrix of Ultrasonic Transmit–Receive Array Data for Guided Wave Pipe Inspection

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

---The paper describes a method for processing data from a guided wave transducer array on a pipe. The raw data set from such an array contains the full matrix of time-domain signals from each transmitter-receiver combination. The technique is based on circumferential mode decomposition of the full matrix of data and linear superposition of extracted circumferential modes in the frequency domain. It is shown that for certain configurations of an array the total focusing method can be applied which allows the array to be focused at every point on a pipe surface in both transmission and reception. The sensitivity of the proposed method to the random and coherent noise is investigated. The effect of array configuration parameters on this sensitivity is discussed. The imaging algorithm has been tested on modelling data and is shown to be able to detect through-thickness cracks of any orientation over 0.05-wavelength size. Experimental results are presented using electromagnetic acoustic transducers (EMATs) for exciting and detecting the S0 Lamb wave mode in a 12 inch diameter steel pipe at 200 kHz excitation frequency. The results show that using the imaging algorithm a 2 mm diameter (0.08 wavelengths) half-thickness hole can be detected.

Analytical Model of the Scattering of Guided Waves from Fastener Sites With a Stiffness Interface

---**Sandeep S. Chellapilla**[2], John C. Aldrin[3], and Kumar V. Jata[1], [1]Air Force Research Laboratory, Metals, Ceramics & NDE Division, WPAFB, OH 45433; [2]Radiance Technologies, Inc., 350 Wynn Drive, Huntsville, AL 30805; [3]Computational Tools, 4275 Chatham Avenue, Gurnee, IL 60031

---In the structural health monitoring (SHM) domain, ultrasonic guided waves have been proposed for detecting fatigue cracks around fastener sites. However, critical issues remain, such as the time-varying nature of the interface conditions between the fastener shaft and hole. Moreover, changes in the magnitude of scattered ultrasonic signals from fastener sites can result from dynamic structural loading, thermal cycling, and aging of sealant present in some structures. Under certain conditions, the scattered signals from a fastener location can be difficult to distinguish from fatigue crack signals. Prior work from ultrasonic measurements of fastener sites in aging aircraft has highlighted the variation in fastener-hole fit conditions and the challenge of separating crack signals around the fastener site from re-radiated signals from the fastener hole. Analytical models are presented for the interaction of ultrasonic waves from a cylindrical hole with an elastic insert coupled by a stiffness interface. Parametric studies are presented investigating the effect of variations in the fastener contact conditions on the reflection and generation of secondary waves around the fastener hole.

3D Scattering Analysis of Guided Waves in a Plate Using Mode-Exciting Method

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

---This paper presents a method to perform the scattering analysis of guided waves in a 3-D plate by using the mode-exciting method. In the mode-exciting method, guided waves are excited by several patterns of boundary conditions given on boundaries of a target finite domain, and are decomposed into wave modes by a modal analysis to obtain scattering coefficients of scattered guided waves. The mode-exciting method has computational advantage that usual numerical methods like FEM and BEM can be used without coupling with other techniques, and thus numerical procedure becomes simpler than a conventional method. We first explain the theory of guided waves in a 3-D plate and then present the principle of scattering analysis on the base of the mode-exciting method. Some numerical examples are shown and verified by experiments. The analysis and experiment show good agreement.

Feasibility of Low-Frequency Time-of-Flight Straight-Ray Guided Wave Tomography
---**Pierre Belanger** and Peter Cawley, 682 Mechanical Engineering, Imperial College, Exhibition Road, London SW7 2AZ, United Kingdom

---Many aging pipelines and aircraft are suffering from corrosion and the corrosion patches are often inaccessible. Hence the majority of the conventional nondestructive evaluation techniques are compromised. There is therefore a need for a rapid, accurate, long range inspection technique to measure the remaining thickness in corrosion patches. Low-frequency Lamb wave tomography is a potentially attractive technique to rapidly evaluate the thickness of large sections of partially accessible structures. This approach is not new and it has been used in the past to detect the shape of defects in a range of applications. The aim of tomography is to reconstruct the spatial distribution of the material properties of an unknown object with projection data. Time-of-flight straight-ray tomography relies on the dispersive nature of a guided wave mode to reconstruct the depth profile of a corrosion patch. If the frequency is limited to below the cut-off of the higher order modes, only the three fundamental guided wave modes can propagate and thus the interpretation of the signals and the time-of-flight measurement are easier. Below the cut-off of the higher order modes there are two likely points of operation where the modes have an appropriate degree of dispersion: A0 at 0.5 MHz.mm and S0 at 1.75 MHz.mm. In order to reconstruct a thickness map with time-of-flight straight-ray tomography the ray theory needs to be valid. There are two validity criteria: the characteristic size of the defect must be larger than the wavelength and larger than the half-width of the Fresnel zone. For realistic defect sizes the two likely points of operation respect the wavelength condition but not the more stringent Fresnel zone condition. This paper investigates, with finite element simulations and experiments, the severity of the errors due to the breach in the ray theory.

Simultaneous Ultrasonic Monitoring of Crack Growth and Dynamic Loads During Full Scale Fatigue Tests of Aircraft Wings
---**Thomas E. Michaels**, Jennifer E. Michaels, and Adam C. Cobb, Georgia Institute of Technology, School of Electrical and Computer Engineering, Atlanta, GA 30332-0250

---An ultrasonic angle beam method has been developed to detect and size fatigue cracks emanating from fastener holes. The pitch-catch method employs transducers mounted on each side of the hole, and the modulation of the received signal with load is used to detect and size small fatigue cracks. Essential to the success of this method is the ability to use the same ultrasonic signal as is used for crack monitoring to estimate the instantaneous load. The applied load causes a time shift in the ultrasonic echo arrivals resulting from both dimensional changes and the acoustoelastic effect. Waveforms are recorded randomly during fatiguing, and the dynamically applied load associated with each waveform is determined from the measured time shift. Additionally, small cracks near the hole open and close during fatigue loading, causing a modulation of the amplitude of the received signals with load. The amount of energy reduction as a function of load is analyzed to determine the effective area of any cracks near the fastener hole. The focus of this work is the monitoring of a series of critical fastener holes during two full scale fatigue tests of aircraft wings. Each of these tests took place over several months, which has demonstrated the robustness of the method, its ability to both detect cracks and monitor their growth, and the capability of simultaneously determine dynamically applied loads near a fastener hole. The load monitoring capability of the ultrasonic method is also valuable for quantitatively assessing the degree of local loading experienced by a specific fastener hole, which may not be possible with strain gauges.

SH0 Mode Interaction with the Propagation Directional Crack in a Plate

---**Madis Ratassepp**, Tallinn University of Technology, Department of Mechanics, Tallinn, Estonia; Michael J. S. Lowe, Imperial College, Mechanical Engineering Department, London, United Kingdom

---Ultrasonic guided waves are currently of interest for structural health monitoring of large structures such as storage tanks and pipelines. This study focuses on the scattering of the fundamental horizontal shear (SH0) mode at a through-thickness narrow axially aligned crack in a plate. The reflection and diffraction of the wave at a crack are examined using 2D finite element simulations. It is shown that the main reflection is generated by Rayleigh-like surface waves created on the faces of the crack, which radiate energy back into plate. The amplitudes of the reflected and diffracted signals are verified experimentally.

Comparison of Modeling and Experiments of Lamb Waves for Identification of Damage in Structures

---**Nicoleta A. Apetre** and Massimo Ruzzene, Georgia Institue of Technology, School of Aerospace Engineering, Atlanta, GA 30332-0250; Jennifer E. Michaels, Thomas E. Michaels, Ramaldo Martin, and Pranaam Haldipur, Georgia Institute of Technology, School of Electrical and Computer Engineering, Atlanta, GA 30332

---Guided waves, such as Lamb waves, show sensitivity to a variety of damage types and have the ability to travel relatively long distances within the structure under investigation. For this reason, guided ultrasonic waves are particularly suitable for Structural Health Monitoring (SHM) applications, which may employ a built-in sensor/actuator network to interrogate and assess the state of health of the structure. This paper investigates the effectiveness of a Finite Element Method (FEM) to model wave propagation in a plate like structure with and without artificial defects. The capabilities of FEM to model complex phenomena such as sensors and edge reflections will be illustrated. A series of parametric studies for various artificial defects geometries and locations will be also included. Recommendations are made as to how to best use FEM simulations to represent real sensors and structures. In order to study the accuracy of these numerical computations the results are compared with analytical and experimental results.

Session 8

SESSION 8
EDDY CURRENT FUNDAMENTALS AND PROBES
J. Bowler, Chairperson
Meeting Room E

8:30 AM **Model Development for Broadband Spiral-Coil Eddy-Current Probes**
---R. K. Murphy, **H. A. Sabbagh**, and E. H. Sabbagh, Victor Technologies, LLC, Bloomington, IN; M. P. Blodgett and J. Knopp, Air Force Research Laboratory, AFRL/RXLP, Wright Patterson Air Force Base, Dayton, OH 45433; J. C. Aldrin, Computational Tools, Gurnee, IL 60031

8:50 AM **Simulation and Automated Data Classification for Eddy Current Inspection of Fastener Sites Using a GMR Sensor Array with Sheet Current Excitation**
---**J. C. Aldrin**, Computational Tools, Gurnee, IL 60031; G. Steffes and J. S. Knopp, NDE Branch, Materials and Manufacturing Directorate, U. S. Air Force Research Laboratory, Wright Patterson Air Force Base, Dayton, OH 45433

9:10 AM **Eddy Current System for Detection of Cracking Beneath Braiding in Corrugated Metal Hose**
---**B. Wincheski** and P. Williams, NASA Langley Research Center, Hampton, VA 23681; J. Simpson, Lockheed Martin, Hampton, VA; G. Hall, George Washington University

9:30 AM **Study of the Effects of EDM Notch Width on Eddy Current Signal Response**
---**N. Nakagawa**, B. F. Larson, M. Yang, and E. M. Madison, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011; D. Raulerson, Pratt and Whitney, Jupiter, FL 33458

9:50 AM **Multifrequency Eddy Current Evaluation of Heat Exchangers Structures**
---**T. Chady** and J. Kowalczyk, Szczecin University of Technology, Department of Electrical Engineering, Szczecin, Poland

10:10 AM ***Break***

10:30 AM **Finite Element Modeling of Pulsed Eddy Current Signals From Conducting Cylinders and Plates**
---**V. K. Babbar**, P. Van Kooten, T. J. Cadeau, and T. W. Krause, Department of Physics, Royal Military College of Canada, Kingston, Ontario, K7K 7B4, Canada

10:50 AM **Comparison of Computational Modeling Techniques of Pulsed Eddy Current Inspection**
---**I. Elshafiey**, King Saud University, Department of Electrical Engineering, Riyadh, Saudi Arabia

11:10 AM **Effects of Dynamic and Static Loading on Eddy Current NDE of Fatigue Cracks**
---**C. C. H. Lo** and N. Nakagawa, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

11:30 AM **Eddy Current Probe Impedance Changes Due to Edge Cracks Using New Generation Kernels**
---**J. R. Bowler**[1] and T. Theodoulidis[2], [1]Department of Electrical and Computer Engineering and the Center for NDE, Iowa State University, Ames IA 50011. [2] Department of Engineering and Management of Energy Resources, West Macedonia University, Kozani, Greece

12:10 PM ***Lunch***

Model Development for Broadband Spiral-Coil Eddy-Current Probes

---R. Kim Murphy, **Harold A. Sabbagh**, and Elias H. Sabbagh, Victor Technologies, LLC, Bloomington, IN; Mark P. Blodgett, and Jeremy Knopp, Air Force Research Laboratory, AFRL/RXLP, Wright-Patterson Air Force Base, Dayton, OH; John C. Aldrin, Computational Tools, Gurnee, IL

---A key problem with planar spiral-coil eddy-current probes is that they do not perform well above 30MHz due to stray capacitive effects, which begin to dominate as the resonant frequency of the probe is approached. The objective of current research is to develop models to account for these problematic parasitic effects, and allow for probe optimization in the design stage, rather than through the tedious and inefficient trial-and-error approach. In this presentation we demonstrate how the volume-integral algorithm of VIC-3D(c) has been applied to develop a computer code to design spiral-coil eddy-current probes for optimal broadband performance. The code is then applied to various model problems extending over a frequency range of 10MHz to 1THz.

Simulation and Automated Data Classification for Eddy Current Inspection of Fastener Sites Using a GMR Sensor Array with Sheet Current Excitation

---**John C. Aldrin**, Computational Tools, Gurnee, IL 60031; Gary Steffes and Jeremy S. Knopp, NDE Branch, Materials and Manufacturing Directorate, U.S. Air Force Research Laboratory, Wright-Patterson Air Force Base, Dayton, OH 45433

---The use of GMR linear arrays with sheet current excitation has the potential to enhance the speed and sensitivity of eddy current inspections of fastener sites for fatigue cracks. However, challenges remain for practical application due to strong irregular responses at some steel fastener sites, the complex asymmetric response generated by a sheet current source at a fastener site, and the sensitivity to adjacent geometry (holes, edges). This paper explores the potential for improving crack detection capability for GMR measurements through simulation and development of automated data classification algorithms. Simulated studies were performed that highlight the differences in the response with respect to the fastener site material properties and indicated potential locations for greater sensitivity to cracks. Simulations also investigated variations in permeability in the fastener. Automated algorithms were developed to register the fastener sites in a scan and extract the crack features in the data. Features were found for crack detection away from the fastener site center with sensitivity to smaller cracks and in thick specimens. However, the preliminary crack detection approach was found to produce false calls for fasteners found at the edge of the scan. To address this important challenge, a model-based approach is introduced.

Eddy Current System for Detection of Cracking Beneath Braiding in Corrugated Metal Hose

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

---Corrugated metal hose is a common component used for the delivery of liquids and gases in applications involving offsets, vibration, and/or temperature variations. For high pressure applications a metal braid is used to encompass the hose, greatly increasing its pressure rating. The operating environment of such flex hoses typically involves cyclic pressurization along with vibration and bending strains, providing the opportunity for crack growth and fatigue failure. Inspection of flex hoses is complicated by the convoluted surface profile of the thin-walled metal hose, the metallic braid overwrap, and the necessary capability of in-situ inspection of the hoses at operating pressure. Such constraints have limited typical nondestructive evaluations to a visual inspection or leak check. In this work the development of an eddy current (EC) system for the detection of partially-through-the-thickness cracks in flex hose components is presented. The EC probe and scanning system are designed for in-situ inspection of the hose through the metal braid, with the ability to conform to various hose curvatures. A tangential EC probe design has been used in both absolute and differential configurations. Numerical modeling and experimental data will be used to highlight the capabilities of the system. Also, a case study for detection of cracking damage in space shuttle radiator retract flex hoses using the developed EC system will be presented.

Study of the Effects of EDM Notch Width on Eddy Current Signal Response

---**Norio Nakagawa**, Brian F. Larson, Ming Yang, and Erin M. Madison, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011; David Raulerson, Pratt and Whitney, Jupiter, FL

---A sometimes stated rule-of-thumb is that the strength of an eddy current signal from a fatigue crack can be 40% less than that produced by a similarly sized, rectangular EDM notch. A study was conducted to explore the effect that the width of a discontinuity has on signal strength when inspecting low conductivity materials for small cracks with eddy current surface probes. EDM notches of different sizes and shapes were planted in Ti-6-2-4-6 and IN-100 specimens. Each of the two materials received six 0.020 inch long by 0.010 inch deep notches and six 0.030 inch and 0.015 inch deep notches. Three of the notches of each size were rectangular shaped and three were semicircular shaped. One of the notches in each material size group was 0.005 inch wide, one was 0.003 inch wide and one was 0.001 inch wide. Each of the notches was scanned using absolute and differential pencil probes driven at several different frequencies. The experimental results were compared with numerically generated results, which allowed for a zero width notch to be considered. The results indicated that the signal reduction factor from a 0.005 inch wide, rectangular notch to a theoretical zero-width notch of the same size ranged from 25 to 42%.---This material is based upon work supported by the Air Force Research Laboratory under contract #FA8650-04-C-5228 at Iowa State University Center for NDE.

Multifrequency Eddy Current Evaluation of Heat Exchangers Structures

---**Tomasz Chady** and Jacek Kowalczyk, Szczecin University of Technology, Department of Electrical Engineering, Szczecin, Poland

---In this paper a method of the outer flaws detection in heat exchangers is presented. The aim of this work was to propose the eddy current testing algorithm, which will be effective in case of complex structures evaluation. The applied transducer consists of differentially connected excitation coils and a single pick-up coil. Proper selection of the excitation frequency allows us to minimize influence of radiator and to receive signal containing mostly flaws information. Amplitude, phase as well as multi-frequency signals were utilized in detection process. Parallel construction of ribs and dedicated signal processing algorithms enable additional reduction of radiator influence. The final target is to propose the modified version of the transducer for tube heat exchangers. The irregular construction of heat exchangers makes evaluation process more difficult than evaluation of the plates with parallel ribs. For tubes with irregular construction of exchanging surface, different configurations of transducer excitation was used to reduce influence of radiator elements. All results of experiments are presented and the most suitable configuration was selected.

Finite Element Modelling of Pulsed Eddy Current Signals From Conducting Cylinders and Plates

---**Vijay K. Babbar**, Patrick Van Kooten, Trevor J. Cadeau, and Thomas W. Krause, Department of Physics, Royal Military College of Canada, Kingston, Ontario, K7K 7B4, Canada

---Pulsed eddy current is a technique being developed for the detection of flaws located at depth within conducting plates. The present work investigates the pulsed eddy current response from cylindrical and flat-plate conductors by using 2D finite element modelling employing COMSOL Multiphysics commercial package. The benchmark case of a driver/pick-up coil configuration that encircled a solid conducting cylindrical geometry was used to model the transient electromagnetic response of cylinders of different conductivities, diameters and lengths. The geometry and electrical parameters modeled those of the experimental configuration used in the laboratory. The modelling of pick-up coil response to variation in cylinder length, diameter and conductivity were in good agreement with the experimental results. The variation of pick-up voltage with cylinder diameter revealed the existence of a lift-off intersection point. The work was extended to model a planar coil response to flat-plate aluminum structures. The variation of pick-up voltage peak was investigated as a function of plate thickness and lift-off. The peak amplitude decreased with increase in plate thickness, while the peak position first moves to longer times and then swings back with progressive increase in plate thickness. The lift-off intersection point was also observed in this case.

Comparison of Computational Modeling Techniques of Pulsed Eddy Current Inspection

---**Ibrahim Elshafiey**, King Saud University, Department of Electrical Engineering, Riyadh, Saudi Arabia

---Pulsed eddy current PEC methods have gained wide interest in NDE applications. Various computational modeling techniques have been proposed for the transient analysis of this modality. This paper provides a comparison of two widely used modeling approaches. The first is based upon Fourier domain solutions using finite element FE modeling, while the second depends on finite different time domain FDTD techniques. Finite element analysis is performed under ANSYS environment to model the diffusion fields. The displacement current is thus neglected in the formulation which is done in terms of the vector magnetic potential and the electrical potential functions. On the other hand, the FDTD is performed under SEMCAD-X environment, formulating the problem in terms of the electric and magnetic field intensities, and implementing Maxwell's equations including displacement current term. Reduction of the number of time iterations determined by Courant-Friedrich-Levy (CFL) criterion is achieved by a translation in frequency-conductivity or permittivity values. Comparison is presented of results obtained using each translation method. Results are presented based on the two approaches to simulate fields corresponding to various pulse waveforms and obtain c-scan imaging of materials with different flaw sizes. Discussions are provided of the encountered limitations, needed resources and performance of each of the considered approaches.

Effects of Dynamic and Static Loading on Eddy Current NDE of Fatigue Cracks

---**C. C. H. Lo** and N. Nakagawa, Iowa State University, Center for NDE, Ames, IA 50011

---This paper reports on the effects of dynamic and static loading on eddy current (EC) crack signals in aerospace materials, obtained as part of the ongoing investigation on the influence of defect morphology on NDE signals. In situ EC measurements were carried out on a series of fatigue crack samples (0.055" to 0.350" long) grown in Al 6061 bars when the cracked surfaces were subjected to dynamic tension and compression. The EC signals detected at a fixed location on the fatigue cracks were found to vary periodically with cyclic loading. Under dynamic tension, the amplitude of the vertical signal component, which is perpendicular to the liftoff direction, increases in positive correlation with the load amplitude where the effect is stronger for longer cracks. Such changes in EC signals are attributable to crack morphology changes (i.e. crack opening) under tension, indicating increase of the resistance across the crack face. In contrast, the signal amplitude remains relatively unchanged under compression, presumably due to the insulation effect of an oxide layer on the crack face. The loading effects on crack signals were confirmed by obtaining c-scan images of the fatigue cracks under static loads. Similar c-scans conducted on a series of Ti-6Al-4V fatigue crack samples (0.056" to 0.246" long) under static loads revealed significantly stronger stress effects on crack signal than in the Al samples. Interpretation of the results will be presented in terms of load-induced crack morphology changes, taking into account of likely differences between the Al and Ti alloy samples.---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.

Eddy Current Probe Impedance Changes Due to Edge Cracks Using New Generation Kernels

---**John R. Bowler**[1] and T. Theodoulidis[2], [1]Department of Electrical and Computer Engineering and the Center for Nondestructive Evaluation, Iowa State University, Ames IA 50011. [2] Department of Engineering and Management of Energy Resources, West Macedonia University, Kozani, Greece

---An efficient method for calculating eddy current probe signals is to use an integral method in which the integral kernel satisfies the interface conditions at the surface of the part. This approach can be used, for example, with a crack in an infinite plate and an infinite tube because the require kernels are available for these elementary structures. In such cases, where a dedicated kernel is available, a numerical estimate of the field due to a flaw can be found by making only the flaw region discrete. This usually means that very few boundary or volume elements are needed, the accuracy is easy to control and the results are calculated rapidly. The problem with this approach is that dedicated kernels are only available for a few simple canonical shapes for the host conductor. On the other hand, to deal with a crack at the edge of a plate using boundary elements, it is typically necessary to populate both the plate surfaces with elements as well as the crack surfaces. Thus the number of elements increases and these must accurately represent the edge singularities in the field. However, a new class of integral kernels is now available that can extend the class of problems that can be efficiently solved using very few elements. The approach that we have adopted for finding new dedicated kernels is based on the truncated region eigen-function expansion method. This method has been used to determine the field due to a coil in the presence of a right angled conductive wedge and the field at the edge of a conductive plate. By using the same method, we show how the Green's kernels for such structures can be determined, and hence how these can be used for efficient calculations of the flaw response using boundary and volume element schemes.---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 9

SESSION 9
NDE FOR MICROSTRUCTURE
A. Lasseigne and D. Olson, Co-Chairpersons
Meeting Room G

8:30 AM **Assessing Creep Degradation of Ferromagnetic Steels Via Magnetic Measurements**
---**J. E. Indacochea** and A. Polar, University of Illinois at Chicago, Civil & Materials Engineering Department, Chicago, IL 60607

8:50 AM **Assessment of Magnetocorrosion by Magnetic and Impedance Measurements**
---**J. E. Jackson**, J. A. Roubidoux, B. Mishra, and D. L. Olson, Colorado School of Mines, Department of Metallurgical and Materials Engineering, Golden, CO 80401; A. N. Lasseigne, National Institute of Standards and Technology, Materials Reliability Division, Boulder, CO 80301

9:10 AM **Applying TEP Measurement to Assess the Mechanical Properties Response to Long Term Aging of Hastelloy**
---**S. Ifergane**, A. Bussiba, I. Dahan, and A. Landau, NRCN, Materials Science Department, Beer-Sheva, P. O. Box 9001, 84190, Israel; Y. Gelbstein, Ben-Gurion University, Department of Materials Engineering, Beer-Sheva, 84105, Israel

9:30 AM **Relation Between Ultrasonic Backscattering and Microstructure for Polycrystalline Materials**
---**N. Feuilly**, O. Dupond, and B. Chassignole, EDF R&D, Materials and Mechanics of Components Branch, 77818 Moret sur Loing, France; J. Moysan and G. Corneloup, Université de la Mèditerranée, LCND, 13625 Aix-en-Provence, Cedex, France

9:50 AM **Characterization of Precipitation Behavior in Nimonic 263 by Ultrasonic Velocity Measurements**
---**G. V. S. Murthy**, G. Sridhar, and R. N. Ghosh, MST Division, National Metallurgical Laboratory, Jamshedpur-831 007, India; K. Anish and T. Jayakumar, NDE Division, Indira Gandhi Centre for Atomic Research, Kalpakkam, 603 102, India

10:10 AM ***Break***

10:30 AM **Material Property Measurement Using NDE Methods at GE Global Research**
---**S. Nath**, E. Nieters, N. Tralshawala, W. Faidi, Y. Plotnikov, and H. Sun, GE Global Research Center, Nondestructive Technologies Lab, Niskayuna, NY 12309; S. Ramaswamy, GE John F. Welch Technology Center, Bangalore, India

10:50 AM **Real-Time Low Frequency Impedance Measurements for Determination of Hydrogen Content in Pipeline Steel**
---**A. N. Lasseigne**, National Institute of Standards and Technology, Materials Reliability Division, Boulder, CO 80305; K. Koenig, D. L. Olson, J. E. Jackson, and B. Mishra, Colorado School of Mines, Department of Metallurgical and Materials Engineering, Golden, CO 80401

11:10 AM **Correlation Between NDT Measurements and Sigma Phase Contents in Duplex Stainless Steels**
---**E. I. Todorov**, M. G. Lozev, and N. D. Ames, Edison Welding Institute (EWI), 1250 Arthur E. Adams Drive, Columbus, OH 43221-3585; L.-O. Skogh, Sandvik Materials Technology, SE-81181, Sandviken, Sweden

11:30 AM **Assessing Residual Stress on Machined Uranium Using Nondestructive Induced Impedance and Thermoelectric Power Measurements**
---**C. A. VanHorn**, D. L. Olson, and B. Mishra, Colorado School of Mines, Metallurgy and Materials Engineering, Golden, CO; K. Evans, BW Y-12, Oakridge, TN 37830

12:10 PM ***Lunch***

Assessing Creep Degradation of Ferromagnetic Steels Via Magnetic Measurements

---**J. Ernesto Indacochea** and Alberto Polar, University of Illinois at Chicago, Civil & Materials Engineering Department, Chicago, IL 60607

---Creep damage is a concern in structural materials operating at elevated temperatures under stresses. In power plants boilers and turbines are exposed to stresses at high temperatures. Even though new steels are designed for better creep resistance, there is always interest to monitor and assess the remaining life of structures and components. Conventional metallographic replicas provide good creep measurement, however it requires a plant shutdown and the inspection is localized and superficial. Creep evolution was followed by magnetic measurements of test samples with different creep strains. 410 stainless steel specimens were submitted to creep at 625 °C at an applied stress of 124 MPa for different creep times. A magnetic hysteresis curve was generated for every sample. The shape of the hysteresis curves varied with creep time. Creep was assessed by measuring magnetic saturation, coercivity, and remanence. The changes in microstructure due to creep are related to variations in magnetic properties which are explained in terms of possible magnetic domain pinning. A correlation was found in terms of the microstructural changes due to creep and the coercivity of the material. In summary, it is possible to use a magnetoelastic sensor to detect the partial level of creep in a ferromagnetic material by non destructive examination.

Assessment of Magnetocorrosion by Magnetic and Impedance Measurements

---**Joshua E. Jackson**, John A. Roubidoux, Brajendra Mishra, and David L. Olson, Colorado School of Mines, Department of Metallurgical and Materials Engineering, Golden, CO 80401; Angelique N. Lasseigne, National Institute of Standards and Technology, Materials Reliability Division, Boulder, CO

---Magnetocorrosion is enhanced corrosion experienced in the presence of a magnetic field. In pipeline steels, magnetocorrosion significantly alters the hydrogen content, pitting, and cracking susceptibility in a detrimental manner. Magnetic property measurements and electrochemical impedance spectroscopy were utilized to assess the corrosion behavior of pipeline steels in the presence of various applied magnetic field levels. Correlations between microstructure, mechanical properties, magnetic properties, and applied electrical and magnetic field levels are made to corrosion behavior as observed through electrochemical impedance measurements and pitting and cracking characterization. Thermodynamic and kinetic interpretations are discussed to give further insight into the magnetocorrosion phenomena.

Applying TEP Measurement to Assess the Mechanical Properties Response to Long Term Aging of Hastelloy

---**Sigalit Ifergane**, Arie Bussiba, Isaac Dahan, and Alex Landau, NRCN, Materials Science Department, Beer–Sheva, P.O.Box 9001, 84190, Israel; Yaniv Gelbstein, Ben–Gurion University, Department of Materials Engineering, Beer-Sheva–84105, Israel

---Hastelloy C-276 is an advanced wrought nickel based super alloy, characterized by high corrosion resistance in various environments. This alloy is commonly used in the chemical process industry for high temperature applications. However, its service temperature is restricted due to precipitation of grain boundary carbides and intermetallic particles at the temperature range of 650-10900C. Time-temperature curves indicate that a very high precipitation rate is obtained at about 870°C. Thermoelectric power (TEP) measurements were proved as an effective method for evaluating thermal aging of various precipitation hardening alloys. The current research focuses on monitoring the precipitation kinetics at the critical temperature and its effect on TEP mechanical properties and the microstructure of Hastelloy C-276. Impact energy measurements as well as hardness testing, Scanning electron and optical microscopy were used to characterize alloy microstructures and fracture modes for the different aging time. X-ray diffraction (XRD) was utilized in order to identify the various phases and to estimate their quantity. A dramatic gradual decrease in the specific impact energy was noted after 24 hours of aging at 870°C and was accompanied by a transition in fracture mode from highly dimple ductile fracture to intergranular brittle fracture. A good correlation was found between the TEP measurements and the decrease in the specific impact energy as well as the microstructural modifications during the heat treatment.

Relation Between Ultrasonic Backscattering and Microstructure for Polycrystalline Materials

---**Nicolas Feuilly**, Olivier Dupond, and Bertrand Chassignole, EDF R&D, Materials and Mechanics of Components Branch, 77818 Moret sur Loing, France; Joseph Moysan and Gilles Corneloup, Université de la Méditerranée, LCND, 13625 Aix-en-Provence Cedex, France

---Within the framework of the maintenance of its nuclear power stations, EDF uses ultrasonic inspections to make sure of the lack of defects. But in some cases, the structure of polycrystalline materials can produce the scattering of the ultrasound wave which results in an important attenuation of the signal and in the apparition of a structural noise. Industrial inspections on various components demonstrated the importance of these physical phenomena which can lead to decrease the performances of the ultrasonic inspections. We suggest a study which aims at linking microstructural characteristics to diffusion phenomena. In a first approach, the polycrystalline material studied has an isotropic and homogeneous microstructure with various grain sizes. Experiments are conducted on Inconel material. The finite element software ATHENA developed by EDF simulates the propagation of an ultrasound beam in a 2D-structure. The shape of the grains is assumed to be polygonal. A modelling of the material at a microstructural scale, using Voronoï diagrams, gives results which are coherent with experimental attenuation values and microstructural noise is correctly predicted.

Characterization of Precipitation Behavior in Nimonic 263 by Ultrasonic Velocity Measurements

---**G. V. S. Murthy**, G. Sridhar, and R. N. Ghosh, MST Division, National Metallurgical Laboratory, Jamshedpur-831 007 India; K. Anish and T. Jayakumar, NDE Division, Indira Gandhi Centre for Atomic Research, Kalpakkam-603 102, India

---Ultrasonic velocity measurements have been carried out in Nimonic 263 specimens thermally aged at 923 and 1073 K for durations up to 75 h and correlated with the hardness measurements and electron microscopy studies. The ultrasonic velocities and hardness results obtained in the specimens thermally aged at both the temperatures clearly indicated that ultrasonic velocity is more sensitive to the initiation of the precipitation, whereas, the influence of precipitation on hardness can be felt only after the precipitates attain a minimum size to influence the movement of dislocations. Further, ultrasonic velocity measurements could also reveal faster kinetics and lesser amount of precipitation at 1073 K as compared to 923 K due to higher solubility of precipitate forming elements.

Material Property Measurement Using NDE Methods at GE Global Research

---**Shridhar Nath**, Edward Nieters, Nilesh Tralshawala, Waseem Faidi, Yuri Plotnikov, and Haiyan Sun, GE Global Research Center, Nondestructive Technologies Lab, Niskayuna, NY 12309; Sivaramnivas Ramaswamy, GE John F. Welch Technology Center, Bangalore, India

---General Electric (GE) has a rich history and track record for solving problems with NDE. GE researchers develop NDE methodologies in a wide rage of businesses. As NDE transforms itself from detection to more diagnostic and prediction mode, material characterization and property measurements will be key. Fundamental microstructural characteristics such as grain size, porosity, texture and residual stresses to failure mechanism such as fatigue and creep are of increasing interest to the NDE community. Additionally, with more usage of composites (ceramic and polymer based), insight into failure mechanisms such as delamination, wrinkle, voids and porosity is also gaining a lot of momentum. This presentation will discuss several examples being pursued at GE Global Research, including non-linear ultrasound for characterizing low cycle fatigue and eddy current measurements for hardness and residual stresses.

Real-Time Low Frequency Impedance Measurements for Determination of Hydrogen Content in Pipeline Steel

---**Angelique N. Lasseigne**, National Institute of Standards and Technology, Materials Reliability Division, Boulder, CO 80305; Kamalu Koenig, D. L. Olson, J. E. Jackson, and B. Mishra, Colorado School of Mines, Department of Metallurgical and Materials Engineering, Golden, CO

---The assessment of hydrogen content in pipeline steel is an essential requirement to monitor loss of pipe integrity with time and to prevent failures. With use of pipeline steels of increasing strength, the threshold hydrogen concentration for hydrogen cracking in steel is significantly being reduced. Cathodic protection and corrosion processes both contribute to accumulation of hydrogen as a function of time, which will eventually meet the cracking criteria. New and unique methodologies based on electronic property measurements offer the pipeline industry advanced non-destructive tools to provide in-situ, real-time quantified hydrogen content measurements. The use of low frequency impedance measurements as a non-contact sensor has been demonstrated for real-time determination of hydrogen content in coated pipeline steel specimens in the laboratory. Scale-up to field measurements is in progress, and the development and use of a field sensor are discussed.

Correlation Between NDT Measurements and Sigma Phase Contents in Duplex Stainless Steels

---**Evgueni I. Todorov**, Margarit G. Lozev, and Nathan D. Ames, Edison Welding Institute (EWI), 1250 Arthur E. Adams Dr., Columbus, OH 43221-3585; Lars-Ove Skogh, Sandvik Materials Technology, SE-811 81, Sandviken, Sweden

---Sigma phase can be formed in duplex and super duplex stainless steels due to unfavorable heat treatment cycles. The presence of sigma phase can be detrimental to the material properties. Only electron microscopy and X-Ray diffraction methods provide direct measurements of sigma phase content. However, these techniques are impractical. Several NDT methods (eddy current, induced positron analysis and X-Ray diffraction) were investigated as alternative quantitative techniques for measuring sigma phase. Two eddy current techniques were performed – conventional sorting procedure and algorithm for assessment of electrical conductivity and magnetic permeability of test specimens. Volumetric (IPA-V) and surface (IPA-S) induced positron analysis were also conducted. NDT measurements were compared to metallographic tests performed on twin specimens. Conventional and advanced eddy current techniques proved to be very sensitive to phase transformations in duplex stainless steels. Although X-Ray diffraction measurements had high scatter, some of them correlated with eddy current measurements and with some of IPA-V measurements. This paper details the findings of the study and highlights the recommendations for future work and improvements to testing process.

Assessing Residual Stress on Machined Uranium Using Nondestructive Induced Impedance and Thermoelectric Power Measurements

---**Craig A. VanHorn**, David L. Olson, and Brajendra Mishra, Colorado School of Mines, Metallurgy and Materials Engineering, Golden, CO; Ken Evans, BW Y-12, Oakridge, TN

---This study correlates thermoelectric power and induced impedance measurements to residual stress on machined uranium surfaces. Thermoelectric power is a nondestructive, contact probe that measures defects at the near surface. Thermoelectric power measured with a high impedance nanovoltmeter is very sensitive to variation in the effective mass of the electron, which is a measure of perturbation of the periodic lattice, i.e. strain. Induced impedance analysis is a non-contact, nondestructive coiled probe that can measure various depths into a material depending on the frequency induced. Induced impedance measures the change in electron scatter from a material that is subject to lattice defects and strained periodic lattice. Uranium specimens were four point bend tested to achieve known surface stresses, which were measured by thermoelectric power and induced impedance to achieve a uranium stress calibration curve. Following calibration, the nondestructive probes can be used to analyze parts for quantitative residual stress damage due to machining.

Session 10

Tuesday, July 22, 2008

SESSION 10

THERMOGRAPHY AND THERMOSONICS I

X. Han, Chairperson

Meeting Room F

8:30 AM **Thermographic Imaging of Subsurface Flaws in Structures with Complex Surface Geometries**
---**W. P. Winfree** and P. A. Howell, NASA Langley Research Center, MS 231, Hampton, VA 23681-2199; J. N. Zalameda, U.S. Army Research Laboratory Vehicle Technology Directorate, NASA Langley Research Center, MS 231, Hampton, VA 23681-2199; T. M. Ely and J. L. Grainger, Lockheed Martin Mission Services, NASA Langley Research Center, MS 231, Hampton, VA 23681-2199

8:50 AM **Thermal Imaging Analysis of Thermal Barrier Coatings**
---**J. Sun**, Argonne National Lab., Nuclear Eng. Division, 9700 S. Cass Avenue, Argonne, IL 60439

9:10 AM **Induction and Conduction Thermography: Optimizing the Electromagnetic Excitation Towards Application**
---**J. Vrana** and K. Bailey, Siemens PG Inc., MC Q3-031, 4400 Alafaya Trail, Orlando, FL 32828; M. Goldammer and M. Rothenfusser, Siemens AG Corporate Technology, Otto-Hahn-Ring 6, D-81730 Munich, Germany; W. Arnold, Fraunhofer Institut for Nondestructive Testing (IzFP), Campus E 3.1, University, D-66123 Saarbrücken, Germany (present address: Department of Materials, Saarland University, Campus D 2.2, D-66123, Saarbrücken)

9:30 AM **What Role a Coupling Material Could Play in Sonic IR Imaging**
---**X. Han** and Y. Song, Dept. of Electrical and Computer Engineering, Wayne State University, Detroit, MI 48202; G. Godfrey, Dept. of Physics, Wayne State University, Detroit, MI 48202

9:50 AM **Modeling to Predict Sonic IR Detectability of Defects in Metals**
---**X. Han**, Dept. of Elec. and Computer Engineering, Wayne State University, Detroit, MI 48202; A. S. Ajanahalli and Z. Ahmed, Dept. of Mechanical Engineering, Wayne State University, Detroit, MI 48202; G. Newaz and L. D. Favro, Inst. for Mfg. Res., Wayne State University, Detroit, MI 48202; R. L. Thomas, Dept. of Physics and Astronomy, Wayne State University, Detroit, MI 48202

10:10 AM ***Break***

10:30 AM **The Effect of Crack Closure on Heat Generation in Vibrothermography**
---**J. Renshaw**[1], S. D. Holland[2], R. B. Thompson[1,2], and C. Uhl[2], Iowa State University, Center for NDE, [1]Dept. of Matls. Science and Engineering, [2]Dept. of Aerospace Engineering, Iowa State University, Ames, IA 50011

10:50 AM **Relating Crack Heating to Vibration and Crack Size for Vibrothermography**
---**C. Uhl**, S. D. Holland, and J. Renshaw, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

11:10 AM **FE Modeling of the Temperature Rise Due to the Propagation of Ultrasonic Waves in Viscoelastic Materials and Experimental Validation**
---**B. Hosten**, C. Bacon, and C. Biateau, Laboratoire de Mécanique Physique, Université Bordeaux 1, UMR CNRS, 5469, 351 Cours de la Libération, 33405, Talance, Cedex, France

11:30 AM **Image Processing Techniques for Thermosonics**
---**U. Polimeno**, D. P. Almond, B. Weekes, and S. Pickering, UK Research Center for NDE, Dept. of Mech. Eng., University of Bath, Bath, United Kingdom

11:50 AM **Objective Comparison of Pulse and Lock-In Thermography NDE Techniques Using Matched Excitation Energies**
---**S. G. Pickering** and D. P. Almond, University of Bath, Dept. of Mech. Eng., Bath, Banes, BA2 7AY, United Kingdom

12:10 PM ***Lunch***

Thermographic Imaging of Subsurface Flaws in Structures with Complex Surface Geometries

---**William P. Winfree** and Patricia A. Howell, NASA Langley Research Center, MS 231, Hampton, VA 23681-2199; Joseph N. Zalameda, U.S. Army Research Laboratory Vehicle Technology Directorate, NASA Langley Research Center, MS 231, Hampton, VA 23681-2199; Thomas M. Ely and John L. Grainger, Lockheed Martin Mission Services, NASA Langley Research Center, MS 231, Hampton, VA 23681-2199

---A significant advantage of thermographic inspection is that it is a non-contacting technique, which allows for the inspection of irregular surfaces. This simplifies the inspection of either curved surfaces or surfaces with abrupt changes in shape. The surface geometry does, however, result in variations in the surface temperature following irradiative flash heating. This presentation examines the variations in temperature that occur on curved surfaces when irradiated with the flash lamps of a thermographic system which has a hood that concentrates the lamp energy at the hood opening. A relationship is derived for heat flux per unit area to a surface, as a function of the distance from the hood opening and the angle between the surface normal of the sample and that of the hood opening. This relationship is used to provide guidance on the reduction in flaw detectability for particular radii of curvature and surface geometries. Methods for reducing the effects of the uneven heating and correctly sizing flaws are presented.

Thermal Imaging Analysis of Thermal Barrier Coatings

---**Jiangang Sun**, Argonne National Laboratory, Nuclear Engineering Division, 9700 South Cass Avenue, Argonne, IL 60439

---Pulsed thermal imaging has been widely used for nondestructive characterization of thermal barrier coatings (TBCs). However, most of the current analysis methods are qualitative or semi-empirical and therefore are not suited for quantitative TBC analysis. Recent development of a multilayer thermal modeling method at Argonne National Laboratory has showed that accurate prediction of TBC thickness and thermal properties, which provides information for TBC quality and health conditions, is possible. This method is based on a numerical solution of a TBC-system model, which is fitted with experimental data to determine correct TBC parameters. The process is automated to generate full-field distributions of these TBC parameters. In this paper, the significance of various TBC parameters that dictate the thermal imaging data is investigated. It is identified that one TBC parameter cannot be uniquely determined from typical thermal imaging data. Experimental results are presented and discussed to demonstrate the potential application of this method for TBC health monitoring and lifetime prediction.

Induction and Conduction Thermography: Optimizing the Electromagnetic Excitation Towards Application

---**Johannes Vrana** and Kevin Bailey, Siemens PG Inc., MC Q3-031, 4400 Alafaya Trail, Orlando, FL 32828; Matthias Goldammer and Max Rothenfusser, Siemens AG, Corporate Technology, Otto-Hahn-Ring 6, D-81730 Munich, Germany; Walter Arnold, Fraunhofer Institut for Non-Destructive Testing (IZFP), Campus E 3.1, University, D-66123 Saarbrücken, Germany (present address: Department of Materials, Saarland University, Campus D 2.2, D-66123 Saarbrücken)

---Active thermography using electric current is specifically able to detect defects like cracks which distort the flow of current in the tested part. Like other thermography techniques it works reliably and fast by imaging with an infrared camera. Electric current can be used in two ways for thermography: In induction thermography a current is contactlessly coupled into the component to be tested by a coil while in conduction thermography the part is contacted galvanicly by direct contact. In this paper the specific advantages of both coupling methods are discussed including the efficiency part of the coupling and optimization strategies for testing. Taking these considerations into account a number of different systems for use in laboratory or on the shop floor were developed at Siemens and are presented also covering necessary algorithms to analyze the data and possible approaches for achieving the best results testing a component.

What Role a Coupling Material Could Play in Sonic IR Imaging

---**Xiaoyan Han** and Yuyang Song, Department of Electrical and Computer Engineering, Wayne State University, Detroit, MI 48202; Garrett Godfrey, Department of Physics, Wayne State University, Detroit, MI 48202

---Our goal of developing Sonic IR Imaging is to make it a reliable NDE technique for different applications. We have learned from both our analytical and FEA models that the engagement between the ultrasonic transducer and target can affect the vibration behavior infused in the target from the single frequency ultrasound excitation source. We have also experimentally investigated the effect of coupling materials between the transducer and the sample. We'll present some results of our study at this conference on how the coupling materials affect the vibration and heating in defects.---This work was sponsored by NSF Career Award Number CMS-0238622, and by the Institute for Manufacturing Research, Wayne State University.

Modeling to Predict Sonic IR Detectability of Defects in Metals

---**Xiaoyan Han**, Department of Electrical and Computer Engineering, Wayne State University, Detroit, MI 48202; Abhijith S. Ajanahalli and Zeeshan Ahmed, Department of Mechanical Engineering, Wayne State University, Detroit, MI 48202; G. Newaz and L. D. Favro, Institute for Manufacturing Research, Wayne State University, Detroit, MI 48202; R. L. Thomas, Department of Physics and Astronomy, Wayne State University, Detroit, MI 48202

---At last year QNDE, we have presented our finite-element study of the vibration and heating in aluminum and titanium to investigate the effects of their different material properties. In the models, we allow both friction and plastic deformation as sources of heating. We have continued our investigation on the correlation of vibration behavior and heat generation in cracks to gain comprehensive understanding in crack heating mechanism in Sonic IR Imaging. With the experimental vibration measurements and infrared signals as references, we have been developing FEA models for surface cracks, subsurface cracks and edge cracks with different geometries. This research provides us a mean for model-based study on predicting Sonic IR detectability of defects in materials.---
This work was sponsored in part by the Air Force through Contract Number #FA8650-04-C-5228 to ISU, Subcontract #421-25-95, and in part by the Institute for Manufacturing Research, Wayne State University.

The Effect of Crack Closure on Heat Generation in Vibrothermography

---**Jeremy Renshaw**[1], Stephen D. Holland[2], R. Bruce Thompson[1,2], and Christopher Uhl[2], Iowa State University, Center for NDE, [1]Department of Materials Science and Engineering, [2]Department of Aerospace Engineering, Iowa State University, Ames, IA 50011

---Vibrothermography is an NDE technique that uses vibration-induced heat generation to detect surface and near surface cracks. A lack of understanding of the heat generation process has hindered its application as a widespread inspection technique. We present a method that isolates and identifies contacting crack face asperities as the primary sources of heat generation in a vibrating crack. We present a model for crack closure and how closure stresses of a crack affect the vibrothermographic heating response. We also demonstrate how observed heating as a function of an applied static bending stress can be used to measure surface closure stresses of a crack. These results help to explain the physics of the crack heating process in Vibrothermography.

Relating Crack Heating to Vibration and Crack Size for Vibrothermography

---**Christopher Uhl**, Stephen D. Holland, and Jeremy Renshaw, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---Vibrothermography is an inspection technique that detects cracks by observing vibration induced crack heating. Frictional crack heating in a vibrating specimen is directly linked to the resonant vibrational stress on the crack. In simple geometries we can measure the vibrational mode structure and intuit the dynamic vibrational stress field on the crack. This is used to establish a relationship between crack heating and vibration. Such a relationship will be critical for vibrothermography to be accepted as a viable inspection technology. We correlate stress to heating by exciting specimens in a well understood and repeatable resonant vibration mode. Through knowledge of the mode shape, a single point surface velocity measurement is sufficient to calculate the deformed shape of the entire specimen. The loads and stresses within the specimen are calculated from the deformed shape and used to identify the relationship between crack heating and vibration. The observed relationship between normal stress, crack size, and crack heating is presented.---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.

FE Modeling of the Temperature Rise Due to the Propagation of Ultrasonic Waves in Viscoelastic Materials and Experimental Validation

---**Bernard Hosten**, Christophe Bacon and Christine Biateau Laboratoire de Mécanique Physique, Université Bordeaux 1, UMR CNRS. 5469 351 Cours de la Libération, 33405 Talence Cedex, France

---The ultrasound stimulated thermography method is usually used to detect the temperature rise at a defect position. The temperature rise can be due to the friction between the edges of the defect and/or the plastic deformation around the defect. This paper presents another aspect of the method when the ultrasounds are propagating in a viscoelastic anisotropic material, such as polymers or fibers reinforced polymers. The attenuation of the waves produces a distributed temperature field. Therefore, even a defect that does not produce some heat, can be detected, since the ultrasonic field is modified. A FE model is used for computing the temperature field and for predicting the possibility for an infrared camera of detecting the temperature rise and its modification due to a defect. The model computes the stress and displacement fields associated to the propagation and the loss of energy. Then the heat equation is solved with this loss as a source of heating. An experiment is done with a sonotrode that excites a PVC plate. The ultrasonic displacement at the top of the plate is measured with a laser velocimeter and introduced in the model. Finally, the model result is compared to the image produced by the camera.

Image Processing Techniques for Thermosonics

---**Umberto Polimeno**, Darryl P. Almond, Ben Weekes, and Simon Pickering, UK Research Center for NDE, Department of Mechanical Engineering, University of Bath, Bath, United Kingdom

---The main aims of this work are to improve the sensitivity of the thermosonic NDE technique to enable it to be operated using reduced ultrasonic excitation energy and to automate defect image presentation. The paper is focused on image processing techniques that increase the sensitivity and reliability of thermosonic defect detection. The image processing techniques involve image background subtraction, filtering, frame integration and automatic defect identification. Results obtained from fatigue cracks in metals and impact damage in composites will be presented. The composite damage images are compared with those obtained using pulse transient thermography and ultrasonic C-scan. Thermosonics is found to be more reliable than pulse transient thermography but may underestimate the defect size, indicated by ultrasonic C-scan.

Objective Comparison of Pulse and Lock-In Thermography NDE Techniques Using Matched Excitation Energies

---**Simon G. Pickering** and Darryl P. Almond, University of Bath, Department of Mechanical Engineering, Bath, BANES, BA2 7AY, United Kingdom

---The defect detection capabilities of pulse transient thermography and lock-in thermography have been compared using equal excitation energies. A signal-to-noise ratio analysis has been performed on defect images obtained by the two techniques using a CFRP sample with flat-bottomed hole artificial defects of 4mm, 6mm and 12mm diameters at depths ranging from 0.25mm to 3.5mm. Similar limits of defect detection have been found for the two techniques. Lock-in thermography phase images have been found to exhibit anomalous switches between positive and negative phase values for different modulation frequencies and for different combinations of defect diameter and depth. This effect resulted in values of defect phase response that differed substantially from the one-dimensional thermal wave interpretation of lock-in thermography imaging. The consequences of this anomalous effect and its physical origins are discussed.

Session 11

SESSION 11
STUDENT POSTER COMPETITION
Main Hall C

NOTE: Student posters are to be mounted Monday, July 21st 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 22nd from 1:30-3:10 p.m. For more details on the student poster competition, please see the "Conference Guide" document (page 9) on the QNDE web site at: www.cnde.iastate.edu/QNDE/2008/

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- Evaluation of MASW Data Testing Configuration for Analysis of Asphalt Pavements
- Developments in Magnetic Sensing for Corrosion Monitoring of Metals
- Air-Coupled Ultrasonic Tomographic Imaging for Solids
- Ultrasonic Liquid Steel Inclusion Monitor: Measurement Principles and Probe Design
- Robotic Pipe Crawling Inspection System for Nondestructive Evaluation (NDE)
- Characterization of Nonlinearity Parameters in an Elastic Material with Quadratic Nonlinearity with a Complex Wave Field
- In-Situ Measurement of Interface Permeability
- Utilizing Electron Backscatter Diffraction to Validate EMAT Measurements for Aluminum and Steel Sheet
- Nonlinear Impact Resonant Acoustic Spectroscopy for the Characterization of Alkali-Reactivity of Aggregates
- Evaluation of Delamination at Composite Tubing by Dual Pitch-Catch Method
- An Examination of Trailing Echoes in Tapered Rods
- Simulation and Implementation of Ultrasonic Remote Sensing Agents for Reconfigurable NDE Scanning
- Wideband Ultrasonic Time of Flight Diffraction Combining B-Scans and Cross-Sectional Imaging
- Detection of Micro-Cracks on Metal Surfaces Using Near-Field Microwave Resonators
- Investigation of the Radiation Pattern of the Lamb Waves Generated by a Circular Magnetostrictive Patch Transducer
- Preliminary Tests to Design an EMAT with Pulsed Electromagnet for High Temperature
- Defect Detection in Multi-Layered Structures Using Guided Ultrasonic Waves
- Multi-Channel Dispersion Estimation
- Fatigue Crack Detection Using Digital Image Correlation
- Characterization of Cement-Based Multiphase Materials Using Ultrasonic Wave Attenuation
- Millimeter Wave Depth Characterization of Surface Damage in Fuselage Skins

3:10 PM ***Break***

Evaluation of MASW Data Testing Configuration for Analysis of Asphalt Pavements

---The development of multi-channel surface waves (MASW) analysis in recent years is promising for accurate non-destructive characterization of asphalt (HMA) pavements. However, it is known that result accuracy depends on data acquisition parameters, optimum number of signal traces, and the range of Poisson's ratio evaluated. Although MASW analyses normally assume elastic material behavior, HMA pavements exhibit noted temperature dependency and visco-elastic response. This paper investigates the application of MASW to pavements in order to characterize the effects of testing configuration, material temperature and pavement structure on the results. Experimental results from full-scale composite section and a full-depth HMA pavements are reported for a wide range of material temperatures. The results show that these parameters affect MASW response behavior, and this data interpretation and accuracy.

Developments in Magnetic Sensing for Corrosion Monitoring of Metals

---Reinforcement corrosion is a serious problem for the civil infrastructure, thus creating a need for efficient sensing techniques to determine corrosion extent and rate in situ. Recent efforts to apply giant magneto-resistive response (GMR) magnetometers and eddy current sensors for corrosion sensing are described. These methods overcome some difficulties faced by traditional NDE and sensing techniques for corrosion, especially since no physical or electrical contact with the corroding metal is required. An active testing configuration that monitors corrosion activity remotely in aluminum samples is explored. These results serve as the basis for further developments for non-contact corrosion magnetic sensing, and future developments for this technology are finally proposed.

Air-Coupled Ultrasonic Tomographic Imaging for Solids

---Ultrasonic tomography is a powerful tool for identifying defects within an object or structure. This method can be applied on structures where x-ray tomography is impractical due to size, low contrast, or safety concerns. By taking many ultrasonic pulse velocity (UPV) readings through the object, an image of the internal velocity variations can be constructed. One of the largest drawbacks in ultrasonic tomography is the time consuming requirement of transducer coupling at many locations. Variability in coupling pressure can also result in variation in data collection. Air-coupled UPV can eliminate these problems and allow for more automated and rapid collection of larger amounts of data. With continued development air-coupled ultrasonic tomography could provide for fast and accurate evaluation of unseen defects in massive structures, such as reinforced concrete bridge piers. This research aims to integrate recent developments in air-coupled ultrasonic measurements with the current tomography technology. Using measurements from capacitive ultrasonic transducers and advanced signal processing methods, high and low velocity inclusions in a solid object are imaged. Issues related to the application to massive concrete structures are discussed.

Ultrasonic Liquid Steel Inclusion Monitor: Measurement Principles and Probe Design

---The goal of the project is to develop a disposable ultrasonic probe measurement system that will give particle size distributions for non-metallic inclusions in liquid steel after a one minute measurement. This will allow the opportunity to analyze several hundred kilograms of liquid steel. Two novel concepts for the ultrasonic evaluation of liquid steel that will produce information on particle size distribution for inclusions are suggested. Both these methods use a measured value such as attenuation and a theoretical description of acoustic wave theory to produce the size characterization of inclusions. One of these methods depends upon the representative estimation of inclusion size parameters for assumed particle distributions. The other technique relies on the detection of individual particles, via the scattered ultrasonic energy in the Rayleigh regime. Some similar work has taken place in the aluminum industry but it has been heavily based on experimentally obtained empirical data. Implementation difficulties are much greater in liquid steel. This paper will describe some of the theories developed and focus on their implementation via a novel design and testing of a disposable probe system. Liquid steel trials have taken place, and the results have been used to aid the design of subsequent prototypes.

Robotic Pipe Crawling Inspection System for Nondestructive Evaluation (NDE)

---The demand for remote inspection of pipework in the processing cells of nuclear plant provides significant challenges of access, navigation, inspection technique and data communication. Such processing cells typically contain several kilometers of densely packed pipework whose actual physical layout may be poorly documented. Access to these pipes is typically afforded through the radiation shield via a small removable concrete plug which may be several meters from the actual inspection site, thus considerably complicating practical inspection. Our current research focuses on the robotic deployment of multiple NDE payloads for weld inspection along non-ferritic steel pipework (thus precluding use of magnetic traction options). A fully wireless robotic inspection platform has been developed that is capable of travelling along the outside of a pipe at any orientation, while avoiding obstacles such as pipe hangers and delivering a variety of NDE payloads. An eddy current array system provides rapid imaging capabilities for surface breaking defects while an on-board camera, in addition to assisting with navigation tasks, also allows real time image processing to identify potential defects. All sensor data can be processed by the embedded microcontroller or transmitted wirelessly back to the point of access for post-processing analysis.

Characterization of Nonlinearity Parameters in an Elastic Material With Quadratic Nonlinearity With a Complex Wave Field

---The objective of this research is to determine the relationship between the third-order elastic constants in an elastic material with quadratic nonlinearity, and a complex wave field that consists of superposed bulk and surface waves propagating in this material. In this case, higher-order harmonic effects occur and can be used to measure the nonlinearity of a material. The quantitative characterization of this material nonlinearity will be essential for estimating the damage-state of a component. This research considers wave propagation in an elastic half-space with quadratic nonlinearity due to a line load (Lamb's Problem). The resulting nonlinear wave field is computed numerically with a finite-difference scheme based upon the package CentPack, which solves a hyperbolic system of conservation laws. As predicted by theory, regions with different wave patterns will arise; these individual regions are used to investigate the dependence of a specific wave type on the measured material nonlinearity parameters for pure longitudinal, pure shear or Rayleigh surface waves. Quantitative knowledge of this relationship between third-order elastic constants and material nonlinearity measured with a complex wave field provides the theoretical foundation for state awareness in a complex engineering component and can be used to predict remaining structural life.

In-Situ Measurement of Interface Permeability

---In-situ permeability of a porous interface is important for many chemical processes range from bio-pharmaceuticals to petroleum processes. Biot's theory described that porous materials are able to support the propagation of two longitudinal waves: fast and slow wave. By measuring the propagation threshold of the slow longitudinal wave when the wave number is higher than the critical wave number kcr, we can obtain the intrinsic permeability of a porous interface. The ability to sense permeability change due to differences in pore size and fluid viscosity is demonstrated. The measured is compared to an exact solution for kcr . The application to a separation cell used in chemical processes is also shown.

Utilizing Electron Backscatter Diffraction to Validate EMAT Measurements for Aluminum and Steel Sheet

---Electron Backscatter Diffraction (EBSD) is a destructive surface-specific technique that measures accurately crystallographic orientations within an SEM. It can realistically scan an area of order ~ mm². Careful surface preparation is also required for optimum results. From the Bunge-Euler angle data we have developed ways to infer elastic properties of the samples' scanned, can potentially calculate magnitudes of stress, and can accurately measure microstructural properties such as grain size and aspect ratios. EBSD also gives a good qualitative description of a microstructure. Electromagnetic Acoustic Transducers (EMAT) can be use in NDE on conducting material, such as rolled Aluminium and Steel sheet. EMATs are non-contact, relatively cheap and quick with the ability to scan over a large area. These listed advantages are of benefit to industry when NDE applications are required on such sheet metal. This paper illustrates some of the work and successful results obtained when using the SEM-based EBSD method as a way of validating EMAT measurements on rolled sheet, to determine such things as microstructural properties like grain size using polarized shear wave through-thickness attenuation experiments, or macroscopic properties like texture.

Nonlinear Impact Resonant Acoustic Spectroscopy for the Characterization of Alkali-Reactivity of Aggregates

---Cementitious materials such as mortar and concrete are inherently nonlinear in their constitutive behavior and this nonlinearity becomes more pronounced with increasing deterioration due to various factors including alkali-silica reaction (ASR). In this research, a new acoustic technique – nonlinear impact resonant acoustic spectroscopy (NIRAS) was developed and used to characterize damage due to the alkali-reactivity of aggregates. The nonlinear constitutive relationship of materials results in an important acoustic phenomenon when the vibration modes of samples are excited – shifting of resonant frequencies with excitation level. The shift of resonant frequency also depends on the nonlinearity parameters which can be directly correlated with the damage condition in the samples. The developed NIRAS method was used to examine the progressive deterioration of mortar samples due to alkali-silica reactivity of aggregates using these two parameters. The results from NIRAS were also compared with the results from a previously developed acoustic technique (Nonlinear Wave Modulation Spectroscopy) and expansion data obtained using standard ASR expansion tests. The agreement among the results indicates that the proposed NIRAS is a promising diagnostic test for detection of ASR damage in cementitious materials. Experimental results are also compared with some preliminary results from the nonlinear vibration analysis.

Evaluation of Delamination at Composite Tubing by Dual Pitch-Catch Method

---A common structural element for engineering application is the hollow cylinder or tube. Tubes are used in a wide variety of fabricated applications including hoses, piping system, drive shafts and structural members. Recently, the application of composite materials is increased significantly in amount of tubing production because they offer various advantages. However, defect such as delamination, porosity may cause the safety to decrease. It is necessary to detect such kind of defects in composite tubing during manufacturing. The new dual pitch-catch technique based on ultrasonic scattering reflection concept was developed in this research and it could provide an excellent image with higher resolution of delamination in composite tubing. It is concluded that the dual pitch-catch technique can be applied for defect detection in composite tubing.

An Examination of Trailing Echoes in Tapered Rods

---Physical access to locations of interest is frequently a challenge when implementing ultrasonic inspection methods on complex structures. Although waveguides present a potential method of providing access, trailing echoes resulting from mode conversions along the waveguide boundaries often interfere with echoes of interest. Tapered rods have been demonstrated to reduce the impact of trailing echoes, but no clear relation with the taper angle has been established. As a simplification to the intended pulse-echo usage, this research studies the effect of the taper angle on trailing echoes in a one-way through-transmission configuration to develop a relationship between the taper angle and attenuation of the trailing echoes. The relationship makes it possible to choose an optimal angle for each application that results in minimal interference from trailing echoes. Experimental results are included to confirm the relation between taper angle and trailing echoes as well as a comparison with the theoretically predicted optimal angles.

Simulation and Implementation of Ultrasonic Remote Sensing Agents for Reconfigurable NDE Scanning

---Remote Sensing Agents (RSAs), in the form of miniature robotic platforms, offer remarkable possibilities for structural inspection. Autonomous groups of RSAs can quickly cover large areas, access hazardous and inaccessible environments and work together intelligently to detect, localise and identify defects. This paper describes such a concept, using wireless RSAs that incorporate air-coupled Lamb wave ultrasonic sensors combined with magnetic traction. Alternative sensor technologies can include eddy current, magnetic flux leakage and miniature cameras. The work focuses on reconfigurable array scanning in plates, where transmission and reception are facilitated by different RSAs and guided waves are used for imaging. The ability to reconfigure the scanner intelligently requires an understanding of the ultrasonic wave generation, its propagation and the mechanics, positioning and control of RSAs. Ultrasonic generation has been modelled by the Linear Systems 1D Model; the resulting wave propagation was modelled in 3D using the Local Interaction Simulation Approach and a dynamic simulation of the RSA was used to model the transducer positions. The complete model is used to evaluate and optimise inspection strategies. The authors present extensive model validations, demonstrate a reconfigurable scan in both simulation and hardware and discuss the potential for future reconfigurable array scanning systems.

Wideband Ultrasonic Time of Flight Diffraction Combining B-Scans and Cross-Sectional Imaging

---Time of Flight Diffraction and Imaging (ToFDI) is a new technique, combining B-Scans and cross-sectional imaging. It utilizes a sparse array of transducers in conjunction with signal processing to improve B-Scan output and create a cross-sectional image of the sample. The use of a sparse array rather than the increasingly popular dense arrays, as used in piezoelectric array probes, is driven by a desire to be able to scan non-flat sample surfaces and also to take advantage of transducer technologies other than piezoelectric probes. In particular, laser-EMAT systems, which are ill-suited to dense array configurations, can be used in situations where non-contact is a requirement due to the necessity of rapid scanning over hot or rough surfaces. Using EMAT transducers leads to readily detectable multiple wave modes and exploiting these modes is vital in forming a good image when only a few receive elements are active. Presented here is the preliminary work demonstrating the concept, including; FEM modelling, the simplified processing chain, likely applications in industry. The eventual aim is for fast and automated detection, identification, positioning and sizing for all defects in a sample for which the basic characteristics such as bulk and shear moduli are known.

Detection of Micro-Cracks on Metal Surfaces Using Near-Field Microwave Resonators

---This paper is aimed at demonstrating that small depth (below 5 mm) micro-cracks at the surface of metals can be detected and imaged by near-field microwave resonators from the crack-induced variations of the resonance frequency and of the resonant circuit quality factor. It deals with two microstrip resonant probes: a quarter-wavelength-long-resonator ended by an electric dipole and an original Dual Behavior Resonator (DBR) band-pass filter. Simulation data and measurement results carried out on a stainless steel mock-up with several 200-µm-wide EDM rectangular notches show that the DBR sensor is more sensitive than the electric dipole probe and highlight the link between the spatial resolution and the width of the high-frequency stub of the DBR filter. Moreover, we demonstrate the possibility to detect the notch whatever the orientation of the defect in relation to the DBR sensor and to differentiate notches differing by their depth.

Investigation of the Radiation Pattern of the Lamb Waves Generated by a Circular Magnetostrictive Patch Transducer

---A circular magnetostrictive patch transducer consisting of a circular nickel patch, a set of permanent magnets and a figure-of-eight coil has been recently developed to generate and measure effectively guided waves in a non-ferromagnetic plate. When a circular magnetostricitve patch bonded to a plate using an adhesive is subjected to static biasing magnetic field by magnets and dynamic actuating magnetic field by the coil, the patch deformation generates guided waves in the plate. To fully understand the characteristics of the circular patch-based transducer, the radiation pattern of the Lamb waves for arbitrary relative orientations of the two magnetic fields was experimentally investigated. The test frequency range between 200 kHz and 400 kHz was selected. The experimental results showed that the largest Lamb wave propagated in a 2 mm aluminum plate was generated when the direction of the two magnetic fields make an oblique angle around 70°, not at 0°. To explain the experimental findings, a first-order theory developed earlier by the authors was extended and the experimental results were shown to be consistent with the theoretical prediction.

Preliminary Tests to Design an EMAT with Pulsed Electromagnet for High Temperature

---Electromagnetic Acoustic Transducers (EMATs) typically make use of permanent magnets since they can exert high magnetic fields with compact structures and without any additional driver circuitry. The relatively low Curie points of permanent magnets, which is approximately 100-150C in NdFeB, is their main disadvantage. In order to avoid these problems an alterative approach is to employ an electromagnet, as was typical in the earlier generations of EMATs and is still used in various designs today. Electromagnets can be used at elevated temperatures without cooling, beyond the maximum operation temperature of permanent magnets such as NdFeB or SmCo. With DC current electromagnets capable of producing magnetic flux densities comparable to NdFeB magnets, large power supplies are required and there are significant heating effects in the coil. If one uses a pulsed current, synchronous to the excitation current to the EMAT coil, the high field can be obtained with a relatively low duty cycle and insignificant heating of the coil. We present the preliminary results in the design of an EMAT intended for high temperature operation using a pulsed electromagnet. A significant enhancement in the generated amplitude of approximately a factor of four is observed for operation on steel at room temperature.

Defect Detection in Multi-Layered Structures Using Guided Ultrasonic Waves

---Aircraft structures are subject to various types of loading conditions, mainly during take-off, landing, and maneuvering. This can give rise to high stress concentrations at fastener holes connecting multi-layered components, thus leading to the development of fatigue cracks at these locations. The detection of fatigue damage in the 2nd layer of multi-layered structures using conventional techniques can sometimes be problematic. This contribution presents a preliminary study to investigate the possibility of defect detection in multi-layered structures using low frequency guided ultrasonic waves. The model multi-layered structure investigated consists of two aluminium plate-strips adhesively bonded using a structural paste adhesive (Hysol 9394 EA). Piezoelectric transducers were glued to the multi-layered structures for the excitation of the guided waves. The propagation characteristics of the resulting guided wave modes in these structures were investigated experimentally and theoretically. Experiments and Finite Element (FE) simulations were conducted in order to investigate the sensitivity for the detection of defects at fastener holes. Experimentally the displacement of the scattered wave field at the surface of the structure was monitored using a laser vibrometer. Results from experiments and FE simulations were compared and the influence of typical defects on the scattered field around fastener holes was evaluated. Further investigation of this initial study might open the path for the development of an inspection technique using guided ultrasonic waves for fatigue damage detection in multi-layered structures.

Multi-Channel Dispersion Estimation

---Sparse arrays of permanently attached ultrasonic transducers are capable of quickly interrogating large areas, thereby reducing or eliminating the need for extensive bulk wave testing in plate-like structures capable of supporting guided waves. Current imaging methods typically ignore dispersion, analyzing received signals by approximating wave propagation with a nominal group velocity. Dispersion compensation can significantly improve the resolution and accuracy of such methods by more accurately modeling the propagation environment and thereby leveraging a larger percentage of the energy and information contained in broadband signals. By adaptively estimating dispersion curves at the time of test, a system will operate with the most accurate dispersion curves possible and will thus be robust to homogeneous environmental changes. This paper will review features and limitations of current dispersion estimation algorithms and describe a new multi-channel approach that incorporates a priori assumptions on the nature of the dispersion curves. Performance of this algorithm will be evaluated using signals obtained from known dispersion curves, finite element modeling, and experiments with aluminum plates.

Fatigue Crack Detection Using Digital Image Correlation

---We have investigated using digital image correlation to detect fatigue cracks propagating from fastener holes. High resolution photographs taken of the hole before and during typical loading are correlated to determine the displacement field. Cracks can be seen as discontinuities in the displacement field, as long as they open by approximately 0.2 pixels or more. This value determines the minimum crack length that can be detected for a given load and pixel size. A set of aluminum plates were drilled with holes and EDM notches of various lengths were cut at the holes to simulate fatigue cracks. The plates were tested in a tensile testing machine at various loads and the results of the digital image correlation were compared to the finite element results. Because the crack opening is very small it was necessary to photograph a single hole in order to obtain a sufficiently small pixel size. We found that surface-breaking cracks of length 2 mm and greater could be reliably detected at moderate far-field strains (~200 microstrain) and 1 mm cracks could be detected at higher far-field strains (~350 microstrain).

Characterization of Cement-Based Multiphase Materials Using Ultrasonic Wave Attenuation

---Ultrasonic wave attenuation measurements have been used to successfully characterize the microstructure and material properties of multiphase materials; these ultrasonic techniques have the potential to provide for the in situ characterization of heterogeneous, cement-based materials. Recent research has applied existing acoustic scattering models to predict wave attenuation in relatively simplified cement-based materials with good results. The goal of the current research is to extend this past work and to consider a more realistic microstructure: a cement paste matrix material that contains both rigid inclusions and air voids. The rigid inclusions simulate coarse aggregate, while the air voids provide an additional microstructure complication that is present in concrete components. This research considers an independent scattering model combined with different types of effective media theory approaches. Next, the ultrasonic wave attenuation is measured (using spectral ratio techniques) in cement paste specimens that contain both hard inclusions and entrained air voids. The measured ultrasonic wave attenuation is then compared to the model predictions and the possibility of inversion techniques for material characterization is investigated.

Millimeter Wave Depth Characterization of Surface Damage in Fuselage Skins

---Aircraft fuselage skins are susceptible to damage from a number of sources. Impact damage, corrosion and incidental damage caused by maintenance operations can affect the long-term structural integrity of fuselage skins. Even minor damage such as scratches and pits can negatively impact corrosion resistance and/or fatigue life. This is especially true if the damage has extended below the cladding layer. Nondestructive evaluation (NDE) methods to rapidly detect these conditions and characterize the depth of damage, are necessary to help make more informed repair decisions, which in turn, helps keep maintenance costs manageable. Millimeter wave NDE methods have shown great potential for detecting such damages (even when under paint). More importantly, significant effort has been expended for characterizing the dimensions of a pit or scratch, in particular depth characterization. At millimeter wave frequencies (30-300 GHz), with relatively short wavelengths, this type of damage is still considered to be small in overall dimensions. Fortuitously, in millimeter wave region, a dielectric-filled scratch, crack or pit “looks” deeper than when empty rendering shallow damages, that are usually more difficult to size, more easily characterized. This paper presents the foundation of the technique, results of comprehensive electromagnetic simulations, and some corresponding experimental results.

SESSION 11 – POSTERS
APPLICATIONS, ULTRASONICS, ACOUSTIC EMISSION, ELECTROMAGNETICS, AND GUIDED WAVES
Main Hall C

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Applications

Update of FPI Engineering Studies with a Focus on Developer Application Methods
---**L. Brasche**, R. Lopez, and D. J. Eisenmann, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

FPI Cleaning Study Update
---**D. J. Eisenmann** and L. Brasche, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

Generating Tap Test Images with a Free-Hand Motorized Tapper
---**D. J. Barnard** and D. K. Hsu, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

Ultrasonics

Investigation of Ultrasonic Beam Focusing Effects for Inhomogeneous Media Using the Time Reversal Method
---**H. Jeong**, Wonkwang University, Mechanical and Automotive Engineering, Iksan, Jeonbuk, South Korea

Analysis of Scattering in Ultrasonic Burning Rate Measurements of Solid Propellants
---**H.-T. Oh**, H.-J. Kim, S.-J. Song, and S.-F. Ko, School of Mechanical Engineering, Sungkyunkwan University, Suwon, Korea; I.-C. Kim, J.-C. Yoo, J. Yong, and J. Core; Technology Development, Agency for Defense Development, Daejeon, Korea

Ultrasonic Flaw Detection Using the 1-Bit DORT Method
---**S. Robert** and C. Prada, Laboratoire Ondes et Acoustique, Université Denis Diderot, UMR CNRS 7587, 10 rue Vauquelin, 75231, Paris, Cedex, 05, France

Heat Generation Assumption at Fatigue Crack by Ultrasound Infrared Thermography
---**S. S. Lee**, M. Y. Choi, J. H. Park, and K. S. Kang, Korea Research Institute of Standards and Science, Safety Metrology Group, Daejeon, South Korea; W. T. Kim, Kongiu National University, Department of Bio-Mechanical Engineering, Yesan, Chungnam, South Korea; K. S. Kim, Chosun University, Department of Mechanical Design Engineering, Gwangju, South Korea

Ultrasonic Detection of Anomalous Machining Damage
---**D. Enyart**, F. J. Margetan, and R. B. Thompson, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

Acoustic Emission

Acoustic Emission Measurements for Tool Wear Evaluation in Drilling
---M. P. Gomez, Facultad Regional Buenos Aires, Universidad Tecnológica Nacional, Buenos Aires, Argentina; J. Migliori, Comisión Nacional de Energia Atómica, San Martín, Buenos Aires, Argentina; C. E. D`Attellis, Universidad Favaloro, Buenos Aires, Argentina; J. E. Ruzzante, Facultad Regional Delta, Universidad Tecnológica Nacional, Campana, Buenos Aires, Argentina (*Poster will be presented by **P. Katchadjian***)

Application of Acoustic Emission Technique for Internal Leak Detection of LNG Carrier's Membrane Tank
---**Y.-H. Kim**, J.-H. Lee, J.-H. Kim, and B.-M. Song, Graduate School of Mechanical Engineering, Pusan National University, Jangjeon-dong, Gumjeong-gu, Busan, 609-735, Korea

Electromagnetics

Frequency-Modulated Continuous-Wave (FM-CW) Radar for Evaluation of Refractory Structures Used in Glass Manufacturing Furnaces
---B. Carroll, **S. Kharkovsky**, and R. Zoughi, Missouri University of Science and Technology, Electrical and Computer Engineering Department, Rolla, MO 65409; R. A. Limmer, Johns Manville Corporation, Littleton, CO 80202

Solution of Boundary Integral Equations for Eddy Current Flaw Detection in Three Dimensions
---**M. Yang** and N. Nakagawa, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011; J. Song, Department of Electrical and Computer Engineering, Iowa State University, Ames, IA 50011

Computer Controlled Eddy Current Tomography System
---**T. Chady** and I. Spychalski, Szczecin University of Technology, Department of Electrical Engineering, Szczecin, Poland

Guided Waves

A Feasibility Study on Model-Based Tomography of Guided Wave
---Lianji Jin[1], **Younho Cho**[2], Bong-Young Ahn[3], and J. L. Rose[4], [1,2]School of Mechanical Engineering, Pusan National University, South Korea; [3]NDE Division, Korea Research Inst. of Standardization Science, South Korea; [4]Engineering. Science and Mechanics Department, Pennsylvania State University

3:10 PM ***Break***

Update of FPI Engineering Studies with a Focus on Developer Application Methods
---**Lisa Brasche**, Rick Lopez, and David Eisenmann, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---Fluorescent penetrant inspection plays a key role in the safe operation of aircraft and engines. Recognizing the importance of FPI, the FAA has funded a program to generate engineering data in support of improved understanding of FPI performance and the factors which impact FPI response. Iowa State University is teamed with OEMs and airlines in performance of the program. A series of twelve engineering studies have been defined and are underway. Efforts have included developer application methods, emulsification parameters, light level studies, cleaning studies among others. Recent results will be presented with a focus on developer application methods.---This material is based upon work supported by the Federal Aviation Administration under Contract #DTFA03-98-D-00008, Delivery Order #0016 and performed at Iowa State University's Center for NDE as part of the Center for Aviation Systems Reliability program.

FPI Cleaning Study Update
---**David J. Eisenmann** and Lisa J. H. Brasche, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---Fluorescent penetrant inspection (FPI) is widely used in the aviation industry and other industries for surface-breaking crack detection. As with all inspection methods, adherence to the process parameters is critical to the successful detection of defects. Effective fluorescent penetrant inspection begins with a clean, dry part. A variety of cleaning methods are available and used by the aviation industry in preparation for FPI and other inspection and repair processes. In a recent study of cleaning practices, it was found that some cleaning methods were detrimental to the brightness of FPI indications, particularly for Titanium alloys.---This material is based upon work supported by the Federal Aviation Administration under Contract #DTFA03-98-D-00008, Delivery Order #0016 and performed at Iowa State University's Center for NDE as part of the Center for Aviation Systems Reliability program.

Generating Tap Test Images with a Free-Hand Motorized Tapper

---**D. J. Barnard** and D. K. Hsu, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

---Previously we have described the Computer Aided Tap Tester (CATT), a simple instrumented probe and software that facilitates the generation of tap test C-scans in field environments. Early in the CATT development it was noted that inspectors prefer hand tapping at random locations over the part, eventually covering the part to the satisfaction of the inspector. To speed inspections, a regimented method of tapping was incorporated into the CATT via a grid laid over the part. Although the CATT system is quite simple to use, the method of taping at each grid location in a pre-determined raster pattern continues to encountered resistance from the inspectors. The preferred free scanning of the inspection area dovetails nicely with the GenScan system, where the operator scans over the inspection area freely, starting with larger pixels, and refines the geometry of flaw indications with finer pixels. As part of an Air Force project, we are merging the CATT instrumented tap data with position encoding and pixel change on-the-fly features of the GenScan. A description and demonstration of its operation will be presented. This material is based on work supported by the Air Force Research Laboratory under Contract # FA8650-04-C-5228 at Iowa State University's Center for NDE.

Investigation of Ultrasonic Beam Focusing Effects for Inhomogeneous Media Using the Time Reversal Method

---**Hyunjo Jeong**, Wonkwang University, Mechanical and Automotive Engineering, Iksan, Jeonbuk, South Korea

---Time reversal (TR) of body waves in fluids and isotropic solids has been used in many applications including ultrasonic NDE. However, the study of the TR method for inhomogeneous media including anisotropic materials is not well established. In this work, the full reconstruction of the input signal is investigated for anisotropic media using an analytical formulation, called a modular Gaussian beam (MGB) model. The time reversal operation of this model in the frequency domain is performed by taking the complex conjugate of the Gaussian amplitude and phase received at the TR mirror position. A narrowband reference signal having a particular frequency and number of cycles is then multiplied and the whole signal is inverse Fourier transformed to obtain the time domain signal. The original input signal is seen to be fully restored by the TR process of MGB model. This model is then more generalized to simulate the spatial and temporal focusing effects due to TR process in inhomogeneous media including anisotropic solids. Simulation results on the beam focusing effects of standard flaws due to the time reversal of flaw-reflected signals received by an array type transducer are presented.

Analysis of Scattering in Ultrasonic Burning Rate Measurements of Solid Propellants

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

---For measuring burning rates of solid propellants, ultrasonic method is widely adopted, since ultrasonic method can be measured burning rates as a function of pressure in a single test. But, it is necessary to verify accuracy and reliability of ultrasonic method to replace the strand burner method. So, in previous study, we have investigated the performance of the ultrasonic method for burning rate measurements by comparison to the strand burner results. From the previous study, we found that there is scattering in measured burning rates using ultrasonic method. Thus, in this study, we will investigate main cause of those scattering by analysis variation in attenuation and central frequency of received ultrasonic waveform during burning test. Because, most of solid propellants are high attenuated material and shape of ultrasonic waveform could be changed during burning test. In this presentation, analysis results of correlation between solid propellants attenuation as a function of pressure and its burning rates will be presented. Furthermore, we will also present comparison result of ultrasonic waveform with different pressure to those of experiments.

Ultrasonic Flaw Detection Using The 1-Bit DORT Method

---**Sébastien Robert** and Claire Prada, Laboratoire Ondes et Acoustique, Université Denis Diderot, UMR CNRS 7587, 10 rue Vauquelin, 75231 Paris Cedex 05, France

---The efficiency of the DORT method in ultrasonic non-destructive testing has already been demonstrated. The method uses a transducer array working in transmission and reception mode and consists in the singular value decomposition (SVD) of the array response matrix. Each element of this matrix corresponds to the backscattering response at one frequency between a pair of transducers. The aim of this work is to show that the DORT method remains valid when only the phases of the received signals are considered (the amplitudes of the received signals are set to ±1 before computing the array response matrix and its SVD). The amplitude information is lost but it is not necessary to successfully detect and localize flaws. Moreover, in some applications, as the detection of flaws near the bottom surface of a test piece, we obtain better results. Experiments performed on an aluminium block with flat bottom holes of different sizes show that the 1-bit DORT method allows to detect flaws localized a half-wavelength away from the bottom surface. The classical (8-bit) DORT method or a focusing technique in transmit and receive mode do not achieve such a resolution.

Heat Generation Assumption at Fatigue Crack by Ultrasound Infrared Thermography
---**Seung Seok Lee**, Man Yong Choi, Jung Hak Park, and Ki Soo Kang, Korea Research Institute of Standard and Science, Safety Metrology Group, Daejeon, South Korea; Won Tae Kim, Kongju, National University, Department of Bio-Mechanical Engineering, Yesan, Chungnam, South Korea; Koung Suk Kim, Chosun University, Department of Mechanical Design Engineering, Gwangju, South Korea

---This paper describes the application of ultrasound excited infrared thermography. In this technique, an ultrasound wave passing through a material with mechanical discontinuity such as a crack or disband causes temperature raise of that due to internal friction or thermo-mechanical effect and the localized heating area is visualized with infrared camera. Although several papers have been investigated about this, the heat generation mechanism is still not well understood, yet. This paper shows results of our assumption regarding the heat generation mechanism at fatigue crack. Fatigue cracks of aluminum alloy are inspected to verify our investigation. Our experiment shows most of heat generation is contributed by friction between crack interface and thermo-mechanical effect is a negligible quantity.

Ultrasonic Detection of Anomalous Machining Damage
---**Darrel Enyart**, Frank J. Margetan, and R. Bruce Thompson, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---During manufacture, rotating jet-engine components are shaped into their final configurations by machining operations which may include turning, drilling and broaching. Anomalous machining conditions, such as a loss of coolant or a damaged cutting tool, can result in an altered near-surface microstructure, possibly shortening the useful life of the component. In this paper we report on preliminary attempts to detect anomalous machining damage using ultrasonic pulse/echo inspections. Results are compared for two types of titanium-alloy turned specimens: those manufactured using accepted best practices; and those purposely damaged by out-of-spec machining conditions.---This material is based upon work supported by the Federal Aviation Administration under Contract #DTFA03-98-D-00008, Delivery Order #0036 and performed at Iowa State University's Center for NDE as part of the Engine Titanium Consortium Phase III Anomalous Machining Detection program.

Acoustic Emission Measurements for Tool Wear Evaluation in Drilling

---M. P. Gomez, Facultad Regional Buenos Aires, Universidad Tecnológica Nacional, Buenos Aires, Argentina; J. Migliori, Comisión Nacional de Energia Atómica, San Martín, Buenos Aires, Argentina; C. E. D`Attellis, Universidad Favaloro, Buenos Aires, Argentina; J. E. Ruzzante, Facultad Regional Delta, Universidad Tecnológica Nacional, Campana, Buenos Aires, Argentina (*Poster will be presented by **P. Katchadjian***)

---Drilling is one of the most commonly used machining processes in the manufacturing industry. In this context, tool wear condition monitoring is very important in order to control the quality of the product, minimize costs and help to the automation process. In this work, tool wear in a drilling process was studied by means of acoustic emission. The acoustic emission signal was measured during the drilling process of SAE 1040 steel samples, making holes with 5 mm diameter twist drills, in continuous feed. The studied drills were modified with artificial and real failures such as: different degrees of wear in the cutting edge, the chisel and the outer corner. The measurements were made with a 2 channel high resolution PAC PCI-2 acoustic emission system and PAC broadband sensors, for a complete analysis in frequency. For each studied case, the correlation between the acoustic emission parameters and the drill wear condition was found, especially for the energy and the mean power of the acoustic emission signals.

Application of Acoustic Emission Technique for Internal Leak Detection of LNG Carrier's Membrane Tank

---**Young-Hoon Kim**, Joon-Hyun Lee, Jin-Hyun Kim, and Bong-Min Song, Graduate School of Mechanical Engineering, Pusan National University, Jangjeon-dong, Gumjeong-gu, Busan, 609-735, Korea

---The membrane tank of LNG (Liquefied Natural Gas) carrier needs high level of safety requirement because the leakage in membrane tank can be connected to a catastrophic disaster for human and nature. The purpose of this study is to verify the feasibility of the acoustic emission method for internal leak detection of membrane tank of LNG carrier. Internal leak generates both elastic wave and acoustic sound wave though medium in the insulation panel. The mock-ups which has artificial leaks was fabricated to simulate the AE leak signal in real condition of LNG carrier. AE sensor and microphone were installed on the external wall and the leak was made at the internal one. In this study, characteristics of AE parameters are analyzed from the various size of leak under different pressure conditions. As a result, the existence of leakage generated in the membrane which consists of multi-layered media was recognized efficiently by using AE technique.

Frequency-Modulated Continuous-Wave (FM-CW) Radar for Evaluation of Refractory Structures Used in Glass Manufacturing Furnaces

---Brian Carroll, **Sergey Kharkovsky**, and Reza Zoughi, Missouri University of Science and Technology (MST), Electrical and Computer Engineering Department, Rolla, MO, Randy A. Limmer, Johns Manville Corporation, Littleton, CO

---Furnaces are the most crucial components in the glass industry, which require periodic maintenance and repair. Today, furnaces are being operated at higher temperatures and for longer periods of time thus increasing the rate of wear on the furnace refractory lining. Consequently, there is a need to know the state of a refractory structure to prevent premature or unnecessary maintenance shutdowns. The non-uniform rate of regression of a refractory lining depends on the type of the refractory lining, the materials being melted, seepage, mechanical stresses, and temperature. For many years the observation skills of an experienced operator has been the only source of evaluating the wear associated with a refractory structure. Refractory bricks are low loss dielectric materials rendering microwave inspection techniques suitable for their evaluation. Consequently, a frequency-modulated continuous-wave (FM-CW) handheld radar operating in the frequency range of 8-18 GHz, resulting in a relatively fine range resolution, was designed and constructed for on-site inspection of refractory structure thickness. This paper presents the design of the radar and the results of measurements conducted on typical wall and floor sections of a refractory furnace assembled in the laboratory. In addition, the potential and wider application of this tool will be discussed.

Solution of Boundary Integral Equations for Eddy Current Flaw Detection in Three Dimensions

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

---Eddy current nondestructive evaluation (NDE) of airframe structures involves the detection of electromagnetic field irregularities due to non-conducting inhomogeneities in an electrically conducting material, which often treats with complicated geometrical features such as cracks, fasteners, sharp corners/edges, multi-layered structures, etc. The eddy-current problem can be formulated by the boundary integral equations (BIE) and discretized into matrix equations by the method of moments (MoM) or the boundary element method (BEM). This paper introduces the implementation of Stratton-Chu formulation for the conductive medium, in which the induced electric and magnetic surface currents are expanded in terms of Rao-Wilton-Glisson (RWG) vector basis function and the normal component of magnetic field is expanded in terms of pulse basis function. Also, low frequency approximation is applied in the external medium, that is, free space in our case. Computational tests are presented to demonstrate the accuracy and capability of the three-dimensional BIE method with a complex wave number for arbitrarily shaped objects described by a number of triangular patches. Furthermore, the BIE method can be embedded with the Fast Multipole Method (FMM), which is a well-established and effective method for accelerating numerical solutions of the matrix equations. Accelerated by the FMM, the BIE method will have the capability of solving large-scale electromagnetic wave propagation and eddy-current problems.---This material is based upon work supported partially by the Federal Aviation Administration under Contract #DTFA03-98-D-00008, Delivery Order #0039 and performed at Iowa State University's Center for NDE as part of the Center for Aviation Systems Reliability program.

Computer Controlled Eddy Current Tomography System

---Tomasz Chady and Ireneusz Spychalski, Szczecin University of Technology, Department of Electrical Engineering, Szczecin, Poland

---In many kinds of NDT systems an eddy current method is used to detect and evaluate defects in high conductivity materials (metals). The proposed eddy current system can be also used to analyze low conductivity materials, like biological structures. In constructed measuring system a magnetic flux generated by an excitation coil is inducing eddy currents in a tested material and a reference sample. The sensing coils detect response of both structures. Pick-up sensors and relevant reference sensors are connected differentially. The differential signals obtained from the sensing coils of the probe are converted into digital form by the data acquisition subsystem. The whole system is controlled by the PC class computer connected to data acquisition devices. The system is driven by a specialized program written in LabView. Construction of the transducer enables us to achieve high sensitivity and elimination of a background signal. On the other hand, this kind of transducer has many restrictions. It is prone to noises and external influences. Because of weak signals even the operating person may induce noises. Therefore, very important problem to resolve is optimization of transducer construction in order to achieve high sensitivity of sensor while preserving the required resolution. The results of numerical simulation and measurements carried out for different configurations of transducer are given in this paper.

A Feasibility Study on Model-Based Tomography of Guided Wave

---Lianji Jin[1], **Younho Cho**[2], Bong-Young Ahn[3], and Joseph L. Rose[4], [1]School of Mechanical Engineering, Pusan National University, South Korea; [2]School of Mechanical Engineering, Pusan National University, South Korea; [3]NDE Division, Korea Research Institute of Standardization Science, South Korea; [4]Engineering Science and Mechanics Department, Pennsylvania State University

---Presented in this paper is a feasibility study on defect image reconstruction based on the combination of modeling and tomography technologies of ultrasonic guided waves. The guided wave mode conversion phenomenon under through transmission scheme is simulated by the hybrid BEM and employed as a useful feature for defect location. The influence of mode selection and mode conversion on the guided wave tomography is also investigated to enhance the physical base of the emerging technology for quantitative NDE. This can also help subsequent field applications via the comparison with experimental data providing a room for the absolute scale measurement over the conventional relative scale one in which the consistent data acquisition at each different time is essential for data comparison. In addition, defect sizing potential in tomography analysis is also discussed with the mode conversion BEM models.

Session 12

SESSION 12
THERMOGRAPHY AND THERMOSONICS II
X. Han, Chairperson
Meeting Room F

3:30 PM **Logarithmic Derivative Analysis of Thermographic NDE Data**
---**S. M. Shepard**, Y. Hou, and J. R. Lhota, Thermal Wave Imaging, Inc., 845 Livernois, Ferndale, MI 48220

3:50 PM **Phase Angle Thermography for Depth Resolved Defect Characterization**
---**A. Gleiter**, C. Spiessberger, and G. Busse, Institute of Polymer-Technology, Nondestructive Testing, University of Stuttgart, Pfaffenwaldring 32, 70569, Stuttgart, Germany

4:10 PM **Towards Quantitative Resonance Inspection: Resonance Mode Identification and Modeling**
---**C. J. Dasch**, L. Ouimet, and D. Simon, General Motors Corporation, Warren, MI 48090; X. Sun and C. Lai, Pacific Northwest National Labs, Richmond, WA; G. Harmon and C. Grupke, Chrysler LLC, Auburn Hills, MI; M. Jones, Ford Motor Company, Livonia, MI; J. Saxton, Magnaflux-Quasar, Albuquerque, NM; G. Stultz, The Modal Shop, Cincinnati, OH: G. Palombo, Polytec, Ann Arbor, MI 48104

4:30 PM **The Reliable Implementation of Thermosonics NDT**
---M. Morbidini and **P. Cawley**, Imperial College, Mechanical Engineering, London, United Kingdom

4:50 PM **Dependence of the Sonic IR Signal on Crack Length and Crack Closure**
---**J. C. Chen** and C.-H. (Leo) Wong, Rowan University, Department of Mechanical Engineering, Glassboro, NJ 08028; W. Riddell, Rowan University, Department of Civil and Environmental Engineering, Glassboro, NJ 08028

5:10 PM **Modeling of NCATS Interrogation of Fatigue Damage in Ti6Al-4V**
---S. A. Martin[2], **S. Sathish**[3], K. V. Jata, J. T. Welter[1], [1]Air Force Research Laboratory, Metals, Ceramics and NDE Division, 2230 Tenth St., Wright Patterson AFB, Dayton, OH 45433-7817, [2]NDe Computational Consultants, Dublin, OH 43017-8530; [3]University od Dayton Research Institute, 300 College Park, Dayton, OH 45469-0127

Logarithmic Derivative Analysis of Thermographic NDE Data

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

---Since the introduction of the Thermographic Signal Reconstruction (TSR) method in 2000, the use of logarithmic derivative analysis has become increasingly popular for both visualization and quantification of flash thermography data. Compared to the original data, the TSR derivatives are free of temporal noise reflection artifacts, and significantly more sensitive to subtle features that do not appear in the raw data sequence. Recent results have shown the derivatives to be highly effective for interrogation of multilayer structures, as each interface may be analyzed separately. In such cases, the objective of NDE is not only to identify defects that may be present, but to establish that the layer structure meets dimensional, compositional and strength specifications. The derivative approach allows quantitative, non-visual characterization of interfaces, based on the derivative characteristics. Although no a priori knowledge of sample thermophysical properties is required, if minimal input of first layer properties is provided, the inverse problem for the entire structure may be solved. Experimental results for composite laminates adhesively bonded to metals will be discussed in detail.

Phase Angle Thermography for Depth Resolved Defect Characterization

---**Andreas Gleiter**, Christian Spiessberger, and Gerd Busse, Institute of Polymer-Technology, Nondestructive Testing, University of Stuttgart, Pfaffenwaldring 32, 70569 Stuttgart, Germany

---Optically excited Lockin-Thermography is a non-contact NDE-method which found its place in a broad range of applications. However, the depth information about thermal boundaries (i.e. defects) which is included in the resulting phase angle images has not been extracted rigorously till now. A simple approach is presented in this paper. 1) Lockin-Thermography. Due to periodic surface heating a thermal wave is injected into the sample. At subsurface-defects (i.e. cracks, delaminations) the thermal wave is reflected and finally superposed with the incident wave at the surface. With an infrared camera, several excitation periods are recorded. The Fourier transform (performed at the modulation frequency) results for each pixel in a phase and a magnitude value. The depth range of this method depends on the excitation frequency. Lower frequencies allow deep-lying defects to be discovered. 2) Depth profiling and visualization. On the base of phase angle values obtained at several excitation frequencies, thermal boundaries can be displayed in a 3d plot, similar to tomograms. The imaging parameter is the frequency value for a local extremum in the phase angle spectrum. This behavior of thermal wave superposition allows a 3d reconstruction of subsurface boundaries.

Towards Quantitative Resonance Inspection: Resonance Mode Identification and Modeling

---**Cameron J. Dasch**, Larry Ouimet, and Daniel Simon, General Motors Corp., Warren, MI 48090; Xin Sun and Canhai Lai, Pacific Northwest National Labs, Richmond, WA; George Harmon and Cliff Grupke, Chrysler LLC, Auburn Hills, MI; Martin Jones, Ford Motor Company, Livonia, MI; Jay Saxton, Magnaflux-Quasar, Albuquerque, NM; Gail Stultz, The Modal Shop, Cincinnati, OH; and Gregg Palombo, Polytec, Ann Arbor, MI

---Resonance inspection uses the natural acoustic resonances of a part to identify anomalous parts. Modern instrumentation can measure the many resonant frequencies rapidly and accurately. Sophisticated sorting algorithms trained on sets of good and anomalous parts can rapidly and reliably inspect and sort parts. This inspection method is becoming widely used in the manufacture of castings but has two major limitations. The reliance on training sets often means that relatively small engineering changes may require an entirely new training exercise and the sensitivity to specific defects or defect locations is unknown. This paper describes several new approaches that put resonance inspection on a more quantitative basis. 1) The resonance frequencies measured with three methods agree within the frequency range of each method. 2) Scanning laser vibrometry is used to determine the mode shape corresponding to each resonance. 3) The material properties including anisotropy are measured to high accuracy using resonance spectroscopy on cuboids cut from the material. 4) The part shape is verified with computed tomography. 5) The resonance frequencies and shapes are modeled with conventional finite element methods using the verified part shape. 6) Comparing the laser vibrometry and modeled mode shapes allows a full FEM mode shape for each experimental resonance to be determined. 7) These FEM modes provide a means to computationally test the sensitivity of the frequencies to various possible defects such as porosity or oxide inclusions especially in the high stress regions that the part will experience in service.

The Reliable Implementation of Thermosonics NDT

---Marco Morbidini and **Peter Cawley**, Imperial College, Mechanical Engineering, London, United Kingdom

---Thermosonics (also known as Sonic-IR) has potential for detecting small fatigue cracks in metals and delaminations in composites. A high power acoustic horn excites a strain pulse in the testpiece which causes relative motion of the defect surfaces, so generating heat by friction; the resulting local increase in temperature can be detected by an IR camera. Unfortunately the vibration generated by the horn is inherently non-reproducible as it is a function of the precise contact conditions between the horn and the testpiece. This means that it is difficult to determine whether the test has been carried out successfully. This paper introduces the Heating Index which is a measure of the excitation and is a function of the induced vibration amplitude and frequency. The heating index can be calculated from measurement of the vibration of the testpiece made with any convenient transducer, for example a laser vibrometer or a simple, high frequency microphone. The correlation between the Heating Index and the measured temperature rise at the defect is shown on a variety of components including turbine blades with in-service defects, as well as laboratory cracked beam specimens. It is shown that measurement of the Heating Index provides a means of ensuring that the test has been carried out satisfactorily, and so makes it possible to use thermosonics for the practical inspection of safety critical components. Proposed calibration and test procedures are presented.

Dependence of the Sonic IR Signal on Crack Length and Crack Closure

---**John C. Chen** and Chang-Hwa (Leo) Wong, Rowan University, Department of Mechanical Egnineering, Glassboro, NJ, 08028; William Riddell, Rowan University, Department of Civil and Environmental Engineering, Glassboro, NJ 08028

---Previous sonic IR studies have tried to elucidate the dependence of the sonic IR signal produced under various test conditions. This is of obvious importance in the development of this technique and its acceptance by industry. In this study, two specific parameters are examined in detail: Crack length and crack closure. This presentation will detail a modified test rig for studying sonic IR, and present results from several sets of specimens which contain carefully controlled cracks of varying lengths and closures (tightness). Comparisons of these results with previous studies by other researchers will also be presented.

Modeling of NCATS Interrogation of Fatigue Damage in Ti-6Al-4V

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

---Non-Contact Acousto-Thermal Signatures (NCATS) is a new method of Nondestructive Evaluation of materials involving the thermal response to high intensity insonification. The method differs from traditional thermography in that a portion of the induced heat loading occurs from conversion of acoustic to thermal energy. Studies of fatigue samples indicate that the magnitude of the internal heat generation is a function of fatigue damage level. An analytical linear damped acoustic layer model is developed to specify the internal heat generation as a function of insonification amplitude, material damping, and sample geometry. The internal heat generation predicted by the model is compared to that calculated in a Finite Element analysis. The acoustic model is combined with the thermal diffusion equation to generate time temperature response curves.

Session 13

SESSION 13
TERAHERTZ IMAGING
H. Ringermacher, Chairperson
Meeting Room D

3:30 PM **Terahertz Ray Modeling for System and Material Characterizations**
---**C.-P. Chiou**[1], J. L. Blackshire[2], and R. B. Thompson[1], [1]Center for NDE, Iowa State University, Ames, IA 50011; [2]Air Force Research Laboratory, Wright Patterson Air Force Base, Dayton, OH 45433

3:50 PM **Nondestructive Evaluation of Aircraft Composites Using Terahertz Time Domain Spectroscopy**
---**C. D. Stoik** and M. J. Bohn, Air Force Institute of Technology, AFIT/ENP, Wright Patterson Air Force Base, Dayton, OH 45433; J. L. Blackshire, Air Force Research Laboratory, Materials and Manufacturing Directorate, Wright Patterson Air Force Base, Dayton, OH 45433

4:10 PM **Time Domain Terahertz Computed Axial Tomography for Nondestructive Evaluation**
---**D. A. Zimdars**, A. Chernovsky, and G. Fichter, Picometrix, 2925 Boardwalk Drive, Ann Arbor, MI 48104

4:30 PM **Time Domain Terahertz Nondestructive Evaluation of Aeroturbine Blade Thermal Barrier Coatings**
---**D. A. Zimdars**, A. Chernovsky, G. Fichter, and J. White, Picometrix, LLC, Ann Arbor, MI 48104; J. F. Whitaker, D. Das, and T. M. Pollock, University of Michigan, Ann Arbor, MI 48104

4:50 PM **Surface Plasmon THz Resonators for Security Applications**
---**N. Gopalsami**, H.-T. Chien, S. Bakhtiari, and A. C. Raptis, Argonne National Laboratory, Nuclear Engineering Division, Argonne, IL 60439

5:10 PM **Near Infra Red (NIR) Spectral Imaging for NDE**
---**G. G. Diamond**, D. A. Hutchins*, and P. Pallav, *Electrical and Electronics Division, School of Engineering, University of Warwick, Gibbet Hill Road, Coventry, CV4 7AL, United Kingdom

Terahertz Ray Modeling for System and Material Characterizations

---**Chien-Ping Chiou**[1], James L. Blackshire[2], and R. Bruce Thompson[1], [1]Center for NDE, Iowa State University, Ames, IA 50011; [2]Air Force Research Laboratory, Wright Patterson Air Force Base, Dayton, OH 45433

---Recently, the terahertz ray (T-ray) technology has emerged as a powerful NDE tool, and new inspection systems are being developed for many applications. The performance and applicability of these inspection systems, however, are often undetermined or suboptimal, and hence require further studies and refinements. In this work, we make use of novel computer modeling techniques to assist in such efforts for a time-domain spectroscopy system recently developed at Air Force Research Laboratory. Extensive experimental measurements were made to map out the T-ray beam pattern in free space as well as to scan a series of cured defect-free polyimide reference standards in through-transmission mode. The beam pattern data are first used to calibrate a point-source-synthesis beam model developed previously. Based on this calibration, the model can then be tested for T-ray propagation through interfaces between media, as provided in the reference standard data. Additional measurements are collected from cured polyimide samples containing flat-bottom holes, which allow further adjustment of the model to predict T-ray interactions with flaws. Once these testing processes are completed, the model can be inversely utilized for material characterization. One task under consideration is the effect of electromagnetic property changes due to heat damage in composite materials such as the cured polyimide samples.---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.

Nondestructive Evaluation of Aircraft Composites Using Terahertz Time Domain Spectroscopy

---**Christopher D. Stoik** and Matthew J. Bohn, Air Force Institute of Technology, AFIT/ENP, Wright Patterson Air Force Base, Dayton, OH 45433; James L. Blackshire, Air Force Research Laboratory, Materials and Manufacturing Directorate, Wright Patterson Air Force Base, Dayton, OH 45433

---Aircraft composites can be weakened by various defects, damage, and stress levels during a typical aircraft lifecycle, where routine maintenance of composites often requires rather complicated inspection and repair methods. Terahertz time domain spectroscopy (TDS) was assessed as a non-destructive evaluation technique for inspection of aircraft glass fiber composites. Various types of damage were studied for thin glass fiber reference strips including voids, delaminations, mechanical damage, and heat damage. Refractive indices and absorption coefficients in the terahertz frequency range were measured using terahertz TDS in transmission mode for comparison of damaged and undamaged material states. Preliminary results showed that localized heat damage did not change the material properties of the composite sample noticeably, however, changes in the terahertz signal were observed due to material blistering and coating loss. Simulated voids/delaminations, which were hidden within several samples, were located by TDS imaging using amplitude and phase analysis techniques. The approximate depth of the delaminations could be determined in the time domain by measuring the timing of Fabry-Perot reflections after the main pulse. There was also evidence that areas of damage from bending stress and simulated hidden cracks (linear slit voids) could be detected with terahertz TDS imaging.

Time Domain Terahertz Computed Axial Tomography for Nondestructive Evaluation
---**David A. Zimdars**, Artur Chernovsky, and Greg Fichter, Picometrix, 2925 Boardwalk Drive, Ann Arbor, MI 48104

---A rapid time domain terahertz (THz) computed axial tomography system is described. A confocal THz optical configuration is employed to scan objects up to 30 cm in diameter. Sinograms are collected at a rate of approximately 10 minutes per slice at 100 waveforms per second. A filtered back projection algorithm using an inverse Radon transform is used to reconstruct slices with linear voxel dimensions of less than 2 mm. The system is used to reconstruct three dimensional structure of aerospace components including: Kevlar soft shell fan containment systems, silica thermal protection tiles, and sprayed on foam thermal insulation.

Time Domain Terahertz Nondestructive Evaluation of Aeroturbine Blade Thermal Barrier Coatings
---**David A. Zimdars**, Artur Chernovsky, Greg Fichter, and Jeffrey White, Picometrix, LLC., Ann Arbor, MI 48104; John F. Whitaker, D. Das, and Tresa M. Pollock, University of Michigan, Ann Arbor, MI 48104

---Time domain terahertz (TD-THz) non destructive evaluation (NDE) imaging is used to two-dimensionally map the thickness of yttria stabilized zirconia (YSZ) thermal barrier coatings (TBC) on test coupons and post-service, worn, thermally stressed blades. Indications of thermal degradation can be seen. The method is non-contact, rapid, and requires no special preparation of the blade. In a monostatic configuration, a sequence of pulses is generated by reflection from each discontinuity in index of refraction. Through analysis of the return pulses, the material absorption and index of refraction properties of each layer can be determined.

Surface Plasmon THz Resonators for Security Applications

---**Nachappa Gopalsami**, Hual-Te Chien, Sasan Bakhtiari, and Apostolos C. Raptis, Argonne National Laboratory, Nuclear Engineering Division, Argonne, IL 60439

---Surface Plasmons (SP) are an exciting area of research for material property measurements at sub-wavelength scale. SPs are collective electronic excitations near the surfaces of metals, which may be resonantly excited by electromagnetic waves from optics to microwaves. The ability to control and concentrate electromagnetic energy in length scales much smaller than the excitation wavelength opens up tremendous opportunities for sensing and material research. This is particularly true in the THz region, as it is rich with spectral signatures for chemical and biological materials. In this talk, we will present theory, design, and implementation of a slit-based SP-THz resonator in the 0.3 THz range. We will next discuss how such a resonator may be used to detect chemical and biological materials with application to national security, as well as present approaches for super-resolution imaging of materials below Abbe limit. Specific advantages of SP-based sensors include: field enhancement, sub-wavelength resolution, nano-scale structures, ultra sensitivity and selectivity, and real-time, label-free detection.

Near Infra Red (NIR) Spectral Imaging for NDE

---**G. G. Diamond**, D. A. Hutchins*, P. Pallav, *Electrical and Electronics Division, School of Engineering, University of Warwick, Gibbet Hill Road, Coventry, CV4 7AL, United Kingdom

---A novel technique of NIR imaging is presented that gives access to most of the applications currently published as being solely suitable for terahertz waves. This technique also affords the means to provide simultaneous *in-situ* chemical-bond analysis and simultaneously combine chemical/spectral identification with imaging. The two separate features of the technique can be combined in a data fusion that produces a conventional image with chemical data etc superimposed (e.g. via false colours on the image) by imaging software. The technique itself uses NIR beams wavelengths found in ordinary domestic remote controls (circa 850 nm) and various signal recovery techniques commonly found in astronomy. This alternative technique can be realised by very simple and inexpensive electronics and is inherently far more portable and easy to use and no special sources are required. Transmission imaging results from this technique are presented from several industrial examples and various security applications and are compared and contrasted directly with their terahertz-derived counterparts. It would appear possible to very cheaply and simply emulate the performance of commercial terahertz systems at a fraction of the cost and with greatly reduced processing times. Also, unlike terahertz, this technique can penetrate bulk water and high humidity atmospheres and be used in transmission mode on biological and medical samples. To illustrate this point, several results are presented of non-ionising x-ray type images that even differentiate between separate types of soft tissue.

Session 14

SESSION 14
AIR-COUPLED TRANSDUCERS
D. K. Hsu, Chairperson
Meeting Room E

3:30 PM **Finite Element Simulation of the Generation and Detection by Air-Coupled Transducers of Guided Waves in Viscoelastic and Anisotropic Materials**
---**B. Hosten**, Laboratoire de Mécanique Physique, Bordeaux 1 University, UMR CNRS, 5469, 351 Cours de la Libération, 33405, Talence, Cedex, France

3:50 PM **Evaluation of Air Coupled Ultrasound for Composite Aerospace Structure**
---**G. Georgeson**, H. Tat, and R. Bossi, Boeing Phantom Works, P. O. Box 3707, MC 2T-50, Seattle, WA 98124-2207

4:10 PM **Phenomenally High Transduction Air/Gas Transducers for Practical Non-Contact Ultrasonic Applications**
---**M. C. Bhardwaj**, T. Eischeid, M. Langron, H. Boonie, and J. Ream, The Ultran Group, 3100 Research Drive, State College, PA 16801

4:30 PM **Non-Contact Ultrasound Based Guided Lamb Waves for Composite Structure Inspection: Some Interesting Observations**
---P. Karthikeyan, C. Ramdas, and **K. Balasubramaniam**, Center for Nondestructive Evaluation and Department of Mechanical Engineering, Indian Institute of Technology Madras, Chennai, 600 036, India; M. C. Bhardwaj, Ultran Group, State College, PA 16801

4:50 PM **Multi-Channel Air-Coupled Ultrasonics for Production NDE of Bonded Aluminum and Composite Aircraft Structures**
---**Jay M. Amos** and Donald Avila, Cessna Aircraft, M&P Engineering – Advanced NDE, P. O. Box 7704, M/S 1, Wichita, KS 67277

Finite Element Simulation of the Generation and Detection by Air-Coupled Transducers of Guided Waves in Viscoelastic and Anisotropic Materials

---**Bernard Hosten**, Laboratoire de Mécanique Physique, Bordeaux 1 University, UMR C.N.R.S. 5469, 351 Cours de la Libération, 33405 Talence Cedex, France

---The measured characteristics (efficiency and sensitivity) of two air-coupled transducers allow for the prediction of the absolute values of the pressure of the bulk waves generated in air and for the measurement of the pressure of the field radiated in air by guided waves propagating in a structure. With Finite Element software, the pressure field generated by an air-coupled transducer is simulated by introducing a right-hand side member in the Helmholtz equation, which is used for computing the propagation from the transducer to a plate. The simulated source is rotated in order to impose an angle of incidence with respect to the normal of the plate and generate the corresponding guided mode. Inside the plate, the propagation is simulated with the dynamic equations of equilibrium and a complex stiffness tensor to take into account the viscoelastic anisotropy of the material. For modeling the three-dimensional fields of the guided modes propagating in a two-dimensional non-symmetry plane, a 2.5 dimensional model is introduced. The model computes the value of the pressure field radiated in air by the plates for any guided modes and can predict the detectability of the system for a known defect in a structure. A test bed incorporating 2 air-coupled transducers is used to generate and receive various guided modes. Two plates made of Perspex and carbon-epoxy composite are tested. The pressure measured by the receiver at various positions is compared to the results of the model to validate it.

Evaluation of Air Coupled Ultrasound for Composite Aerospace Structure

---**G. Georgeson**, H. Tat, and R. Bossi, Boeing Phantom Works, P. O. Box 3707, MC 2T-50, Seattle, WA 98124-2207

---Current inspection of composite structure predominately employs water coupled ultrasonic technologies. Alternatives have been of interest to reduce cost and eliminate the water coupling, which can be undesirable for some components. However, non-contact air coupled ultrasound suffers from the high acoustic impedance mismatch characteristics of air to solid interfaces that require very high signal amplification at low noise to be useful. Advances in transducer technology, particularly MEMS, have improved the acoustic impedance mismatch at the transmission stage and the signal to noise at the reception stage. To evaluate these new technologies, cMUTs (capacitive micro machined ultrasound transducers) have been tested against other commercially available piezoelectric based air coupled transducers. The cMUTs have shown improved signal to noise ratio (SNR). Comparisons of Through Transmission Ultrasound (TTU) scanning of laminate and honeycomb test samples using conventional piezoelectric air coupled transducers, the cMUT air coupled transducers, and standard water coupled inspections will be shown. An additional issue for air coupled UT inspection is the need for a lean implementation for both manufacturing and in-service operations. For TTU scanning of structures magnetically coupling and transducer alignment schemes have been developed. This manipulation approach allows for the alignment of TTU transducers even when access to the backwall of the structure is limited. Concepts and applications for air coupled ultrasound utilizing magnetic coupling of transducers will be discussed.

Phenomenally High Transduction Air/Gas Transducers for Practical Non-Contact Ultrasonic Applications

---**M. C. Bhardwaj**, T. Eischeid, M. Langron, H. Boonie, and J. Ream, The Ultran Group, 3100 Research Drive, State College, PA 16801

---Efficient air/gas transduction transducers are highly desired for Non-Contact Ultrasonic (NCU) evaluation of: a) Early stage material formation -- rubbers, plastics, composites, green ceramics, powder metals, chemically-bonded materials, etc, b) Porous and liquid sensitive materials – foams, consolidated particles, composites, concrete, construction, pharmaceutical, hygroscopic materials, etc, c) Materials rolling on a production line, or d) Where contact with material is simply a nuisance. Conventional ultrasound (or any other NDT method) cannot match the possibilities that NCU presents! But, first we must have the suitable transducers. Since 1982 we have been relentlessly pursuing the development of these dream transducers when we introduced air/gas propagation devices from 100 kHz to >2.0 MHz. However, it was in 1997 a major advancement in transducer design occurred. Based upon multiple Z matching of piezoelectric material, with final layer perfectly matched to gas, new NCU transducers exude immense acoustic energy in air – US and International Patents and Pending. Produced from 50 kHz to 5.0 MHz, these devices have been successfully applied to test several materials. This development ushers in an important era in materials testing -- for cost-effective, energy-saving, and environment-friendly production of high quality materials. In this paper we present the salient features of NCU transducers, evidence of phenomenal efficiency, and examples of significant industrial and bio-medical applications. We will also share ideas for necessary R&D into this very important field of materials science and technology.

Non-Contact Ultrasound Based Guided Lamb Waves for Composite Structure Inspection – Some Interesting Observations

---P. Karthikeyan, C. Ramdas, and **Krishnan Balasubramaniam**, Center for Nondestructive Evaluation and Department of Mechanical Engineering, Indian Institute of Technology Madras, Chennai 600 036, India; Mahesh C. Bhardwaj, Ultran Group, State College, PA 16801

---The developments in high efficiency transducers, that have low acoustic impedance compared to conventional transducers, have resulted in an increased ability to couple ultrasound to and from air. This paper describes efforts of generation and reception of the fundamental Lamb modes employing non-contact ultrasound (NCU) probes made from Gas Matrix Piezo (GMP) material. These wave modes were generated using single side access to the composite structure using oblique incidence pitch catch mode. Two defective composite structure cases were considered, (a) delaminations of different lengths in a composite laminate, and (b) disband between the skin and the honeycomb in a sandwich panel. Both theoretical simulations (using Finite Element Models) and limited experiments were conducted. It was observed that the mode conversions occur at when the A0 mode interacts with the defects leading to the generations of sub-laminate S0 and A0 modes. Also, an interesting cross-over mode was also observed. In addition, the C-scan images of the delaminations show that (i) the images are not symmetric since the transmitter-over-the-defect signal is not equal to the receiver-over-the-defect signal, and (ii) there are strong interference effects that influence the interpretation of the C-scan images of the delamination, but not for the disbonds in the sandwich panel. This again was explained using the Finite Element simulations

Multi-Channel Air-Coupled Ultrasonics for Production NDE of Bonded Aluminum and Composite Aircraft Structures

---**J. M. Amos** and Donald Avila, Cessna Aircraft, M&P Engineering – Advanced NDE, P. O. Box 7704, M/S 1, Witchita, KS 67277

---With recent increasing rates of aircraft production, the rapid bond inspection of multi-layer adhesively bonded aluminum and composite structures has become essential. Although the large impedance mismatch of air-coupled UT makes the technique difficult with metal interfaces in particular, effective through-transmission inspections can be accomplished with reasonable sensitivity. In the NDE of bonded aluminum structures the detection of inter-laminar disbonds, foreign material, skin-to-core disbonds, core buckling and impact damage is of interest. The scanning rate of air-coupled UT is typically limited by relatively low PRF, driven by the long transit time in air. Many aircraft component designs aggravate this issue with stiffening elements (ribs, stringers) with significant vertical height that must be avoided during scanning with large transducer standoff distances. An eight channel TTU scanning system has been employed for a number of years which overcomes several of these limitations. Experimental results and comparisons from several techniques and test panels with engineered defects will be presented.

Session 15

SESSION 15

NDE FOR NEW MATERIALS/SITUATIONS

Meeting Room G

M. Shiwa, Chairperson

3:30 PM **Efforts in NDE of Biocomposites**
---**D. Utrata**, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

3:50 PM **Optimization of Radio Frequency Scanning Sensors for Nondestructive Evaluation of Wood Composites**
---**X. Liu**[1], J. Zhang[1], P. H. Steele,[1] and J. P. Donohoe[2], [1]Department of Forest Products, Mississippi State University, Mississippi State, MS 39762; [2]Department of Electrical and Computer Engineering, Mississippi State University, Mississippi State, MS 39762

4:10 PM **Near-Field Characterization of Reconfigurable Narrowband Antenna in the Proximity of the Human Body**
---**I. Elshafiey**, A. F. Sheta, M. Alkanhal, and A. Mohra, King Saud University, Department of Electrical Engineering, Advanced Technologies Research Center (ATRC), Riyadh, Saudi Arabia; A. AOrainy, King Abdulaziz City for Science and Technology, Electronics Research Institute, Riyadh, Saudi Arabia

4:30 PM **Ultrasonic Measure of Bubble Formation in Tissue for Decompression Sickness**
---**P. D. Panetta**[1], S. Guy[1], T. Lynch[1], J. Zhu[2], and B. Spiess[2], [1]Luna Innovations Incorporated, Hampton, VA; [2]Virginia Commonwealth University School of Medicine, Richmond, VA 23284

4:50 PM **Evaluation of Ultrasonic Fatigue Testing Process of High Strength Steel by Non-Linear Ultrasonic Analysis**
---**M. Shiwa**, Y. Furuya, and H. Yamawaki, National Institute of Materials Science, Innovative Materials Engineering, Tukuba, Ibaraki, Japan; K. Ito and M. Enoki, University of Tokyo, Department of Materials Engineering, Bunkyo-ku, Tokyo, Japan

Efforts in NDE of Biocomposites

---**David Utrata**, Center for NDE, Iowa State University, 1915 Scholl Road, Ames, IA 50011

---Biocomposites are a class of materials that are becoming increasingly attractive for their characteristic of replacing petroleum-based materials with materials that employ renewable components. Natural fibers such as kenaf and hemp may be incorporated into a polymer matrix, resulting in a product that has acceptable mechanical properties while being harmful to the environment than glass-fiber materials. While the chemical and material science fields continue to make great strides in developing the properties of such materials, anticipated needs for quality control and assurance of the large scale production of such materials has not proceeded. This presentation discusses the results of some efforts to apply nondestructive evaluation techniques to these "nontraditional" materials. Initial projects demonstrated the capability to provide qualitative analysis of wood- and fiber-based components for structural integrity. Later work involved attempts to link nondestructive inspection results with mechanical properties on a more quantitative basis.

Optimization of Radio Frequency Scanning Sensors for Nondestructive Evaluation of Wood Composites

---**Xiaojian Liu**[1], Jilei Zhang[1], Philip. H. Steele,[1] and J. Patrick Donohoe[2], [1]Dept. of Forest Products, Mississippi State University, Mississippi State, MS 39762; [2]Dept. of Electrical and Computer Engineering, Mississippi State University, Mississippi State, MS 39762

---Moisture content (MC) and specific gravity (SG) of wood-based composites affect their physical and mechanical properties.. A radio frequency (RF) scanning device has been developed as an effective nondestructive evaluation (NDE) tool for measuring MC and SG of wood-based composites. The RF sensor geometry optimization and its effective operational range were investigated experimentally and numerically to improve reliability and resolution of the RF scanning apparatus.

Near-Field Characterization of Reconfigurable Narrowband Antenna in the Proximity of the Human Body

---**Ibrahim Elshafiey**, Abdel Fattah Sheta, Majeed Alkanhal, and Ashraf Mohra, King Saud University, Department of Electrical Engineering, Advanced Technologies Research Center (ATRC), Riyadh, Saudi Arabia; Abdullah AOrainy, King Abdulaziz City for Science and Technology, Electronics Research Institute, Riyadh, Saudi Arabia

---Reconfigurable narrowband antennas have been suggested recently for use in various applications including mobile instruments. These devices are usually operated in the vicinity of human body, leading to mutual interaction between the RF system and the body tissues. Induced currents in the tissues constitute part of the radiating element and thus affect the radiation characteristics. The tissues also absorb part of the RF energy which should be characterized accurately to assure compliance with standards related to dose limits. A nondestructive evaluation method is developed to characterize this configuration using computational and experimental techniques. Modeling based on FDTD is performed of the antenna in free space and in proximity to human head. Radiation pattern and specific absorption rate (SAR) are computed. Results reveal a shift in center frequency, and variations in the matching and bandwidth which should be counteracted. Experimental setup is also used to characterize the SAR values in human head at 900 MHz and 1800 MHz. A six-degree-of-freedom robot is implemented to scan a head phantom using specialized measurement sensor and head simulating liquids. The developed system provides a tool for precise evaluation of radiation doses and thus could be used to guide the design of reconfigurable mobile systems.

Ultrasonic Measure of Bubble Formation in Tissue for Decompression Sickness

---**Paul D. Panetta**[1], Sam Guy[1], Ted Lynch[1], Jiepei Zhu[2], and Bruce Spiess[2], [1]Luna Innovations Incorporated, Hampton, VA; [2]Virginia Commonwealth University School of Medicine, Richmond, VA

---Decompression sickness is typically avoided by following protocols based on experience and statistics. However, following these protocols is no guarantee of avoiding decompression sickness and sometimes the advice cannot be followed in cases such as emergency rescues. The risk of developing decompression sickness depends on many factors including the depth and length of the dive, temperature, exertion and lack of fluid. Personal characteristics such as age, gender, percentage of body fat, and physical condition must also be considered and the risk becomes greater with older divers. This presentation will show results from animal studies that provide a measure of the formation of bubbles in tissue after a simulated dive. The ultrasonic backscattering measurements were performed from outside the body and provided an early detection of decompression sickness by measuring the backscattering from bubbles as they formed in tissues. The backscattering measurements were also sensitive to other changes in the tissue associated with the dive protocol. Experimental results compare favorably with bubble scattering theories and allow for the determination of the presence of bubbles and potentially their size and number.---This work was performed under a Navy Small Business Technology Transfer program, contract number N00014-07-M-0430.

Evaluation of Ultrasonic Fatigue Testing Process of High Strength Steel by Non-Linear Ultrasonic Analysis

---**Mitsuharu Shiwa**, Yoshiyuki Furuya, Hisashi Yamawaki, National Institute of Materials Science, Innovative Materials Engineering, Tukuba, Ibaraki, Japan; Kaita Ito and Manabu Enoki, University of Tokyo, Department of Materials Engineering, Bunkyo-ku, Tokyo, Japan

---Non-linear ultrasonic and acoustic emission (AE) signals were analyzed during ultrasonic fatigue testing by using Laser Doppler Velocity meter (LDV) and continuous AE waveform analysis system (1MHz/12bit). Notched specimens of a high strength low alloy steel were prepared for the ultrasonic fatigue test with exciting vibration frequency of 20 kHz. The detected surface velocity was longitudinal direction on the end of specimen with frequency range from 100 Hz to 500 kHz. On the waveform monitoring during fatigue test, a distorted exciting waveform was observed in final stage of the test. Then the burst type noise mixed with the distorted exciting waveform was observed just before the final failure. AE signal and upper harmonics of exciting frequency were analyzed by use FFT. As the result, after the intensity of 2nd and 3rd harmonics increased rapidly, AE events were detected continuously. It can be concluded that Non-linear ultrasonic waveform analysis both of AE signal and upper harmonics were effective monitoring tool for fatigue damage progression.

WEDNESDAY

WEDNESDAY, JULY 23, 2008

	Session 16 Guided Waves – Fund. and App. II *Meeting Room D*	Session 17 Probability of Detection *Meeting Room G*	Session 18 NDE of Armor and Armor Systems *Meeting Room E*	Session 19 Adhesive Bonds, Films and Coatings, and Welds *Meeting Room F*
8:30 AM				
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10:10	COFFEE BREAK			
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12:10 PM	LUNCH			
	Session 20 **NDE for Process Control** ***Meeting Room D***	**Session 21** **Benchmark** ***Meeting Room E***	**Session 22** **Nonlinear Acoustics – Mechanisms Controlling Beta** ***Meeting Room F***	**Session 23** **Civil Materials and Infrastructure** ***Meeting Room G***
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3:10	COFFEE BREAK			
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Session 24 – SPECIAL EVENING SESION – 8:00 PM – MEETING ROOM F

Session 16

SESSION 16

GUIDED WAVES – FUNDAMENTALS AND APPLICATIONS II

D. E. Chimenti, Chairperson
Meeting Room D

8:30 AM **Modeling of Guided Wave Propagation in a Layered Half-Space Using Distributed Point Source Method**
---S. Das and **T. Kundu**, Department of Civil Engineering and Engineering Mechanics, University of Arizona, Tucson, AZ 85721

8:50 AM **Modeling Propagation of Ultrasonic Guided Waves in the Layered Steel/Grout/Steel Structures**
---**L. J. Fradkin** and V. Zernov, London South Bank University, FESBE, 103 Borough Road, SE1 0AA, United Kingdom

9:10 AM **Sensitivity of the Ultrasonic Guided Waves to the Adhesion of Lap Joints: Finite Element and Experimental Investigations**
---**H. Lourme**[1], B. Hosten[1], P. Brassier[2], [1] Laboratoire de Mécanique Physique, Université Bordeaux 1, UMR CNRS, 5469, 351 Cours de la Libération, 33405 Talence Cedex, France; [2] ASTRIUM SPACE Transportation, BP20011, Avenue du Général Niox, 33165 Saint Médard en Jalles Cedex, France

9:30 AM **Propagation of Feature Guided Waves in a Plate With a Welded Joint**
---**Z. Fan** and M. J. S. Lowe, Imperial College, Mechanical Engineering, London, United Kingdom

9:50 AM **Composite Plate Inspection Using a Novel Guided Wave Skew Effect Method**
---**F. Yan** and J. L. Rose, The Pennsylvania State University, Department of Engineering Science and Mechanics, University Park, PA 16802

10:10 AM ***Break***

10:30 AM **Defect Detection in Plate Structures Using Coupled Rayleigh-Like Waves**
---B. Masserey and **P. Fromme**, Department of Mechanical Engineering, University College London, WC1E 7JE, United Kingdom

10:50 AM **Assessment of Fatigue Damage in Aluminum Plates Using Nonlinear Lamb Waves**
---C. Prüll, J.-Y. Kim, and **L. J. Jacobs**, School of Civil and Environmental Engineering, Georgia Institute of Technology, Atlanta, GA 30332; J. Qu, School of Mechanical Engineering, Georgia Institute of Technology, Atlanta, GA 30332

11:10 AM **Sparse Array Imaging of Change-Detected Ultrasonic Signals by Minimum Variance Processing**
---**J. E. Michaels** and J. S. Hall, Georgia Institute of Technology, School of Electrical and Computer Engineering, Atlanta, GA 30332; G. Hickman and J. Krolik, Duke University, Pratt School of Engineering, Electrical and Computer Engineering, Durham, NC 27708

11:30 AM **Guided Wave Annular Array Sensor Design for Improved Tomographic Imaging**
---**J. P. Koduru** and J. L. Rose, Pennsylvania State University, Department of Engineering Science and Mechanics, State College, PA 16802

11:50 AM ***Lunch***

Modeling of Guided Wave Propagation in a Layered Half-Space Using Distributed Point Source Method

---**Samik Das** and Tribikram Kundu, Department of Civil Engineering & Engineering Mechanics, University of Arizona, Tucson, AZ 85721

---Propagating guided waves in a layered half-space are modeled with the semi-analytical Distributed Point Source Method (DPSM). For nondestructive evaluation of solid structures using ultrasonic waves it is very important to have an ultrasonic field model for the damage-free structure. It can be used as a baseline or benchmark solution. Any distortion in the ultrasonic field from this baseline should indicate the presence of one or more anomalies inside the structure. Distributed Point Source Method which is a Green's Function based mesh-free technique is adopted here to generate the ultrasonic field inside the layer and the half-space when the layered structure is excited by an ultrasonic transducer of finite dimension. Unlike elastic half-space a layered half-space is a dispersive medium and several guided wave modes travel inside the layer. To generate a particular mode inside the layer, it is excited by an angled beam generated by a finite size transducer placed in water. Numerical examples are given for an aluminum half-space coated by an epoxy layer when the structure is interrogated by a bounded ultrasonic beam. Displacements and stresses inside the epoxy layer and the aluminum half-space are computed and presented as visual images.

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

---**Larissa Ju. Fradkin** and Victor Zernov, London South Bank University, FESBE, 103 Borough Road, 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 behaviour that can be used to choose the carrier frequency that focuses the ultrasonic energy on the prescribed portions of the structure.

Sensitivity of the Ultrasonic Guided Waves to the Adhesion of Lap Joints: Finite Element and Experimental Investigations

---**Hugues Lourme**[1], Bernard Hosten[1], Pascale Brassier[2], [1] Laboratoire de Mécanique Physique, Université Bordeaux 1, UMR C.N.R.S. 5469, 351 cours de la Libération, 33405 Talence Cedex, France; [2] ASTRIUM SPACE Transportation, BP20011, Avenue du Général Niox, 33165 Saint Médard en Jalles Cedex, France

---Despite considerable efforts in the last decades to find reliable NDT methods for the control of adhesive joints, the durability and the quality of the adhesive bonding remains troublesome to be determined by ultrasonic non-destructive methods knowing that both the cohesion and the adhesion aspects must be considered. In this paper, the adhesive lap joints between two aluminium plates are first investigated by a finite element approach to compute the transmission and reflection coefficients of Lamb modes and their conversion through the joint. The cohesion is taken into account by the characteristics of the glue layer and the adhesion by the interfacial conditions. Two methods are used to compute the energy dissipation: one based on the orthogonality relations and the other based on a 2D Fourier transform. The first method uses the displacements and the stresses given by the FE model in a cross section of the plate. The second uses the displacements at the surface to deduce the intrinsic amplitudes of each mode and can be used for modelling or for experiments. Both methods enable the computation of the energy going through the cross section and in consequence can be compared. Then they can be used to verify the sensitivity of the guided waves to the adhesion. This model is confronted to experimental measurements performed on adhesive lap joints for which the quality of the glue is such that the ultimate stress is known to have very different values. In order to get reproducible measurements, the detection of the fundamental ultrasonic guided modes are performed with air-coupled transducers or laser probes.

Propagation of Feature Guided Waves in a Plate With a Welded Joint

---**Zheng Fan** and Michael J. S. Lowe, Imperial College, Mechanical Engineering, London, United Kingdom

---An experimental observation on a large welded plate found that the weld can concentrate and guide the energy of a guided wave travelling along the direction of the weld. This is attractive for NDE since it offers the potential to quickly inspect the defects or corrosions along the long lengths of welds. 3D time step finite element simulations can be applied to demonstrate the guiding effect. However these simulations are very time consuming, and can only model the chosen frequency and wave mode, thus they are not sufficient to investigate the guided wave properties over ranges of parameters and feature geometries. In this paper, we use a Semi-Analytical Finite Element (SAFE) method to study the problem. With this method, only the cross-section which is normal to the direction of the wave propagation has to be meshed by finite elements and the waves are assumed to propagate harmonically. The solutions contain complex wave numbers which represent guided waves propagating along the weld and radiating energy in the side plates, and both phase velocity and attenuation of the guided modes can be extracted from the solutions. Two different weld guided modes, compression mode (similar to S0) and shear mode (similar to SH0), have been studied and compared at low frequency. The dispersion curves of these two modes have been generated by changing different frequencies, and the guiding phenomena can be explained by studying the mode shapes of the cross-section. Experimental study of the SH0-like weld guided mode, which is non-leaky and little dispersive, has been carried out to validate the modal study, showing very good agreement.

Composite Plate Inspection Using a Novel Guided Wave Skew Effect Method

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

---Ultrasonic guided wave skew effects introduced by material anisotropy of wave guides are usually considered undesirable in nondestructive evaluation (NDE). This paper presents a novel method of utilizing guided wave skew effects in defect detection for composite plates. A comb type transducer is designed to produce guided wave modes in composite plates. On the basis of skew angle dispersion curves, different wave modes with different skew angles are selected by means of applying different time delays to the transducer elements to inspect different directions in composite plates. The angular locations of the defects with respect to the wave launching direction can be determined without physically rotating the transducer. The scanning is fully electronic. Experiments on defect detection in a carbon/epoxy fiber-reinforced composite plate are conducted to validate the feasibility of the proposed method.

Defect Detection in Plate Structures Using Coupled Rayleigh-Like Waves

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

---The use of coupled Rayleigh-like waves in aluminium plates has been investigated experimentally and theoretically with a view towards applications for the non-destructive inspection of aircraft structures. Such waves can be generated using standard Rayleigh wave transducers at frequencies, so that the Rayleigh wavelength corresponds to approximately half the plate thickness. In that frequency-thickness range the Rayleigh-like wave, which can be interpreted as the superposition of the fundamental Lamb modes A0 and S0, transfers energy between both surfaces with a characteristic distance called the beatlength. A combination of an analytical model and Finite Difference (FD) calculations is used to describe the propagation of the Rayleigh-like wave and the reflection at small surface defects. In the experiments the reflected wave can be measured using either standard pulse-echo equipment or a laser vibrometer. The energy transfer between the plate surfaces results in a good sensitivity for the detection of small defects on both surfaces. Using a combination of evaluation in the time and frequency domain, the defect location and damaged plate side can be accurately determined. Due to the beating phenomenon, the Rayleigh-like wave can propagate past regions with surface defects or features. This allows for the remote detection of defects in areas where access is restricted by structural features, such as stiffeners and stringers. By selecting appropriate excitation frequency and position, a significant part of the energy can be transmitted behind the obstacle and reflected at the defect, allowing detection. This has been shown experimentally, where surface slots were detected behind multiple stiffeners by standard pulse-echo measurements.

Assessment of Fatigue Damage in Aluminum Plates using Nonlinear Lamb Waves

---Christoph Prüll, Jin-Yeon Kim, and **Laurence J. Jacobs**, School of Civil and Environmental Engineering, Georgia Institute of Technology; Jiainmin Qu, School of Mechanical Engineering, Georgia Institute of Technology, Atlanta, GA 30332

---Failure of engineering materials under cyclic loading typically consists of three stages, crack incubation, crack growth and fracture. In the crack incubation stage, the material has no detectable cracks so that fatigue damage cannot be quantified in this stage by existing nondestructive testing methods. Unfortunately, in many cases of practical interest, the incubation stage may take up as much as 80% of the total fatigue life of the material. It is therefore critically important to develop new techniques that are capable of quantifying the degree of fatigue damage in the crack incubation stage. Recently, nonlinear ultrasonic techniques have been used successfully to assess fatigue damage during the crack incubation state. Bulk, surface and Lamb wave techniques have been used for this purpose. In this paper, we focus on the use of Lamb waves to measure the cumulative fatigue damage in aluminum plates. The plates are machined into dog-bone test samples. The samples are then subjected to cyclic loading. The fatigue tests are interrupted at various numbers of loading cycles. At each interruption, ultrasonic Lamb wave measurements are performed and the corresponding second order harmonic generated by fatigue damage is measured. It is found that the amplitude of the second order harmonic is well correlated to the number of loading cycles. An engineering model is also developed to explain the correlation.

Sparse Array Imaging of Change-Detected Ultrasonic Signals by Minimum Variance Processing

---**Jennifer E. Michaels** and James S. Hall, Georgia Institute of Technology, School of Electrical and Computer Engineering, Atlanta, GA 30332; Granger Hickman and Jeffrey Krolik, Duke University, Pratt School of Engineering, Electrical and Computer Engineering, Durham, NC 27708

---Spatially distributed and compact arrays of permanently attached ultrasonic sensors are being considered for structural health monitoring systems. Most algorithms for analyzing the received signals are based upon change detection whereby baselines from the undamaged structure are subtracted from current signals of interest, and the residual signals are analyzed. In particular, beamforming algorithms applied to the residual signals have been shown to be effective for imaging damage in plate-like structures that support propagation of guided waves. Here we consider minimum variance processing of the residual signals, which is an adaptive beamforming method where the weights are adjusted at each pixel location prior to summing based upon actual and expected signal amplitudes. Numerical and experimental results from a sparse sensor array show that this processing method can provide a significantly improved signal-to-noise ratio by suppressing unwanted sidelobes in the image.

Guided Wave Annular Array Sensor Design for Improved Tomographic Imaging

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

---Guided wave tomography for structural health monitoring is fast emerging as a reliable tool for the detection and monitoring of hotspots in a structure, for any defects arising from corrosion, crack growth etc. To date guided wave tomography has been successfully tested on aircraft wings, pipes, pipe elbows, and weld joints. Structures practically deployed are subjected to harsh environments like exposure to rain, changes in temperature and humidity. A reliable tomography system should take into account these environmental factors to avoid false alarms. The lack of mode control with piezoceramic disk sensors makes it very sensitive to traces of water leading to false alarms. In this study we explore the design of annular array sensors to provide mode control for improved structural tomography, in particular, addressing the false alarm potential of water loading. Clearly defined actuation lines in the phase velocity dispersion curve space are calculated. A dominant in-plane displacement point is found to provide a solution to the water loading problem. The improvement in the tomographic images with the annular array sensors in the presence of water traces is clearly illustrated with a series of experiments. An annular array design philosophy for other problems in NDE/SHM is also discussed.

Session 17

SESSION 17
PROBABILITY OF DETECTION
E. Lindgren, Chairperson
Meeting Room G

8:30 AM **MH1823 POD Software – Summary of Capabilities (With Some Recent Enhancements in Support of NIAR)**
---**C. Annis**, Statistical Engineering, 36 Governors Court, Palm Beach Gardens, FL 33418-7161

8:50 AM **Variables Affecting Probability of Detection in Bolt Hole Eddy Current Inspection**
---**T. W. Krause** and H. Lemire, Royal Military College of Canada, Kingston, Ontario, Canada; M. Bunn and D. J. Butcher, Aerospace Telecommunications Engineering Support Squadron, Trenton, Ontario, Canada

9:10 AM **Model-Assisted Probability of Detection Evaluation for Eddy Current Inspection of Fastener Sites**
---**J. C. Aldrin**, Computational Tools, Gurnee, IL 60031; J. S. Knopp, E. A. Lindgren, and K. V. Jata, NDE Branch, Materials and Manufacturing Directorate, U. S. Air Force Research Laboratory, Wright Patterson Air Force Base, Dayton, OH 45433

9:30 AM **Laboratory POD Data Acquisition from Inner Layer Cracks in Simulated Airframe Structures**
---**B. F. Larson**, E. M. Madison, and N. Nakagawa, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

9:50 AM **Separating Signal from Noise to Correctly Estimate POD from Eddy Current Inspection Data**
---**M. Li** and W. Q. Meeker, Iowa State University, Center for NDE and Department of Statistics, Ames, IA 50011

10:10 AM ***Break***

10:30 AM **Models in the Design and Validation of Eddy Current Inspection for Cracking in the Shuttle Reaction Control System Thruster**
---J. C. Aldrin[1], P. A. Williams, and B. Wincheski[2], [1]Computational Tools, Gurnee, IL 60031; [2]NASA Langley Research Center, Hampton, VA 23605

10:50 AM **Joint Estimation of the Flaw Size Distribution and POD Function**
---P. W. Hovey, University of Dayton, 300 College Park Drive, Dayton, OH 45469-2316; **W. Q. Meeker**, Iowa State University, Department of Statistics, 304C Snedecor Hall, Ames, IA 50011

11:10 AM **Utilizing Field Service Inspection Results in Evaluating System Reliability**
---**P. W. Hovey**, University of Dayton, Department of Mathematics, 300 College Park Drive, Dayton, OH 45469-2316; J. Knopp, Nondestructive Evaluation Branch, Materials Directorate of the U.S. Air Force Research Laboratory

11:30 AM **Probability of Detection for Damage: Extending the Single Factor Flaw Model**
---**F. W. Spencer**, Sandia National Laboratories, Independent Surveillance Assessment and Statistics Department, Albuquerque, NM 87123-0829

11:50 AM **Progress in Developing Transfer Functions for Surface Scanning Eddy Current Inspections**
---J. Shearer, **E. Lindgren**, and J. Heebl, Air Force Research Laboratory, Nondestructive Evaluation Branch, Wright Patterson Air Force Base, Dayton, OH 45433-7718; J. Brausch, Air Force Research Laboratory, Materials Integrity Branch, Wright Patterson Air Force Base, Dayton, OH 45433

12:10 PM ***Lunch***

MH1823 POD Software - Summary of Capabilities (With Some Recent Enhancements in Support of NIAR)

---**Charles Annis**, Statistical Engineering, 36 Governors Court, Palm Beach Gardens, FL 33418-7161

---The 2006-2007 contract deliverables to update MIL-HDBK-1823 included the draft of the updated Handbook and algorithms necessary to implement the methods described in the Handbook, however software was not a deliverable item. Descriptions of statistical algorithms, with no convenient implementation of them, would be of limited utility, so the mh1823 POD software suite was written to help promulgate the handbook's methods. This paper is an overview of its capabilities, including a real-time demonstration of NDE data analysis using the software's drop-down, point-and-click menus.

Variables Affecting Probability of Detection in Bolt Hole Eddy Current Inspection

---**Thomas W. Krause** and Holly Lemire, Royal Military College of Canada, Kingston, Ontario, Canada; Mike Bunn and D. J. Butcher, Aerospace Telecommunications Engineering Support Squadron, Trenton, Ontario, Canada

---Physical variables affecting the probability of detection (POD) in a bolt-hole eddy current (BHEC) inspection were examined. The POD study involved simulated bolt holes in 7075-T6 aluminum coupons representative of wing areas of CC-130 and CP-140 aircraft. The data was obtained from 24 separate inspectors at different sites, but with the same eddy current equipment. The studied discontinuities consisted of 45 EDM notches and 72 laboratory grown fatigue cracks originating at the inner surface corner of the bi-layer structures. A subsequent laboratory examination of the physical features of cracks and notches was used to identify factors leading to differences in the POD of cracks and notches as a function of depth (extent of discontinuity on the far surface of the top plate). Length of the discontinuity (extent within the bolt hole) was identified as the significant variable producing signal variation. POD generated for cracks and notches based on length produced similar results for the two discontinuity types, except at the smallest depths and lengths, where POD for cracks was found to be higher than that of notches. Here the discontinuity length was no longer the most significant variable affecting signal amplitude and other physical factors needed to be considered.

Model-Assisted Probability of Detection Evaluation for Eddy Current Inspection of Fastener Sites

---**John C. Aldrin**, Computational Tools, Gurnee, IL 60031; Jeremy S. Knopp, Eric A. Lindgren, and Kumar V. Jata, NDE Branch, Materials and Manufacturing Directorate, U.S. Air Force Research Laboratory, Wright-Patterson Air Force Base, Dayton, OH 45433

---Probability of detection (POD) studies are used to evaluate the reliability of detecting cracks across a distribution of sizes. Due to the cost of manufacturing the number of samples required for a traditional study, empirical POD evaluation is often prohibitive. A new strategy for the design and execution of POD studies has been proposed using a model-assisted POD (MAPOD) approach. Demonstration studies are presented here for a class of aerospace structural inspection problems and consider the use of models in the POD evaluation. Eddy current measurements for varying crack length around fastener holes in a two-layer aluminum structure were studied using both experimental and simulated data. General agreement was achieved between experimental and full-model assisted (FMA) results for cracks located at both the first and second layers. However, sensitivity of the POD results was found to be dependent upon the NDE technique design and assumptions used in the model-assisted POD analysis. Parametric sensitivity studies were performed exploring the role of experimental data processing, model design and numerical error, crack feature measures, the model fit with experimental data and the presence of coherent noise in measurement data on the full-model assisted evaluation. Key insight is presented for improving the quality of future MAPOD evaluation studies.

Laboratory POD Data Acquisition from Inner Layer Cracks in Simulated Airframe Structures

---**Brian F. Larson**, Erin M. Madison, and Norio Nakagawa, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---This paper discusses the acquisition and processing of experimental data collected using a low frequency eddy current sliding probe to inspect aluminum, simulated airframe structure for inner layer cracks. This effort is part of a model-assisted probability of detection (MAPOD) study aimed at complex structure. Since the experimental data will be compared to idealized model-generated data, an automated scanning setup in the laboratory was used to produce results with minimal human factor variables and low measurement uncertainty. While good reproducibility of the data was achieved, the inherent nature of the multilayer, riveted structure resulted in unconventional signal variability, exhibiting significant scatter in the data, as well as systematic structural deviations. The signal variability required special statistical processing techniques to produce a meaning POD curve, which will be discussed in a separate paper.---This material is based upon work supported by the Federal Aviation Administration under Contract #DTFA03-98-D-00008, Delivery Order #0039 and performed at Iowa State University's Center for NDE as part of the Center for Aviation Systems Reliability program.

Separating Signal from Noise to Correctly Estimate POD from Eddy Current Inspection Data

---**Ming Li** and William Q. Meeker, Iowa State University, Center for NDE and Department of Statistics, Ames, IA 50011

---A traditional way to estimate probability of detection (POD) from quantitative inspection data involves estimating the relationship between signal response and flaw size using a linear regression model of the (possibly) transformed data. Noise response data, when available, is used to estimate the detection threshold to control the false alarm probability. One of the direct results from the traditional POD method is that the POD will be zero where there is no flaw. However, the POD for the limiting case of a very small flaw (or no flaw) is actually the false alarm probability (a positive number). In this paper, we will use both the noise data and the measured signal data to estimate the parameters of a combined model for signal and noise. The resulting POD estimate from the five-parameter model correctly provides an estimate of the positive probability of detection for small and zero flaw sizes.---This material is based upon work supported by the Federal Aviation Administration under Contract #DTFA03-98-D-00008, Delivery Order #0058 and performed at Iowa State University's Center for NDE as part of the Center for Aviation Systems Reliability program.

Models in the Design and Validation of Eddy Current Inspection for Cracking in the Shuttle Reaction Control System Thruster

---**John C. Aldrin**[1], Phillip A. Williams, and Buzz Wincheski[2], [1]Computational Tools, Gurnee, IL 60031; [2]NASA Langley Research Center, Hampton, VA

---Eddy current techniques have recently been developed to detect cracks in Shuttle Reaction Control System thruster components. An orthogonal dual coil probe has been designed to detect cracks approaching the acoustic cavity surface while remote field eddy current designs have been explored to find deeply buried flaws. Questions however exist on whether these designs are optimal. A case study is presented here for the use of multiple complimentary models to explore the best designs for crack detection. Two numerical methods, the finite element method and the volume integral method, were used to address the complex geometry of the part and perform parametric studies of potential transducer designs respectively. Sensitivity studies were performed to determine the ideal probe orientations and frequencies for varying crack lengths. Models for multiple coils configurations in both adjacent and orthogonal positions were also studied. Simulations were found to show agreement with prior experimental work. The selection of measurement models, variability in the probe orientation in the cavity, and noise associated with the measurement and part geometry were found to be critical to achieve the best probe designs. The value of using multiple models with experimental data for model-assisted probability of detection evaluation is also discussed.

Joint Estimation of the Flaw Size Distribution and POD Function

---Peter Hovey, University of Dayton, 300 College Park Drive, Dayton, OH 45469-2316; **William Q. Meeker**, Iowa State University, 304C Snedecor Hall, Department of Statistics, Ames, IA 50011

---Life prediction and inspection interval decisions in aerospace applications require knowledge of the size distribution of unknown existing cracks and the probability of detecting a crack (POD), as a function of crack characteristics (e.g., crack length). The POD for a particular inspection method is usually estimated on the basis of experiments on a given specimen set. These experiments cannot, however, duplicate the conditions of in-service inspections. Quantifying the size distribution of unknown existing cracks is more difficult. If reasonably precise crack size information is available on all finds, it is possible to estimate the joint distribution of crack size and signal strength. This joint distribution can then be used to estimate both the in-service POD and the size distribution of cracks. In this paper, we present a statistical model and methodology to do this estimation. We illustrate the methods on simulated data.---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.

Utilizing Field Service Inspection Results in Evaluating System Reliability

---**Peter W. Hovey**, University of Dayton, Department of Mathematics; Jeremy Knopp, Nondestructive Evaluation Branch, Materials Directorate of the US Air Force Research Laboratory

---Fatigue crack growth is a key contributor to a decline in reliability of aging aircraft. Knowledge of the distribution of crack sizes is essential to properly evaluate the ability of aging aircraft to continue to perform safely in future missions. The primary tool for determining the crack size distribution is nondestructive inspection. However, not all cracks will be detected, so interpreting the information in the sizes of detected cracks is difficult. This presentation will discuss several approaches to using the results of in-service inspections to quantify the POD function for the inspection system and the distribution of the sizes of the cracks present in aging aircraft.

Probability of Detection for Damage: Extending the Single Factor Flaw Model

---**Floyd W. Spencer**, Sandia National Laboratories, Independent Surveillance Assessment and Statistics Dept., Albuquerque, NM 87123-0829

---Traditionally, most probability of detection (POD) characterizations for NDI have been in terms of the detection rate expressed as a function of a single flaw characteristic. The application of onboard or embedded sensors for the purposes of health monitoring changes the probabilistic structure of the characterization. Instead of estimating the probability of detection conditioned on the presence of a flaw with a given characteristic, the probabilistic issue becomes one of detection as flaw conditions develop and change in time. In this paper we explore the changes in probabilistic modeling necessary to capture the monitoring aspect for NDE. Instead of asking - what is the probability of detecting a flaw of length “x”, we ask what is the probability that a flaw that develops and grows in time will be detected and, if detected, when? The latter question requires probabilistic thinking connected with flaw characterization in time that has not been used when POD is expressed in relation to a static flaw characteristic. The shifting of emphasis in the probability modeling is illustrated with several examples.

Progress in Developing Transfer Functions for Surface Scanning Eddy Current Inspections

---Joshua Shearer, **Eric Lindgren**, and Jason Heebl, Air Force Research Laboratory, Nondestructive Evaluation Branch, Wright-Patterson AFB, OH 45433-7718; John Brausch, Air Force Research Laboratory, Materials Integrity Branch, Wright-Patterson AFB, OH 45433

---As US Air Force (USAF) aircraft continue to age, additional inspections are required for structural components. The validation of new inspections typically requires a capability demonstration of the method using representative structure with representative damage. To minimize the time and cost required to prepare such samples, Electric Discharge machined (EDM) notches are commonly used to represent fatigue cracks in validation studies. However, the sensitivity to damage typically changes as a function of damage type. This requires a mathematical relationship to be developed between the responses from the two different flaw types to enable the use of EDM notched samples to validate new inspections. This presentation reviews progress being made to develop transfer functions for surface scanning eddy current for aluminum and titanium alloys found in structural aircraft components. Multiple samples with well characterized grown fatigue cracks and master gages with EDM notches, both with a range of flaw sizes, were used to collect flaw signals with USAF field inspection equipment. Data analysis resulted in a two-step transfer function, enabling sensitivity of new inspections to be determined using samples with EDM notches. The presentation provides plans for additional work to assess other inspection methods and flaw conditions.

Session 18

SESSION 18

NDE OF ARMOR AND ARMOR SYSTEMS

R. Brennan, W. Roy, and J. Adams, Co-Chairpersons
Meeting Room E

8:30 AM **NDE Issues Associated with the Dynamic Mechanical Response of Structural Ceramics**
---**J. W. McCauley**, Army Research Laboratory, AMSRD-ARL-WM, Aberdeen Proving Ground, MD 21005

8:50 AM **Extremely Wideband Ultrasonic Spectroscopy for Microstructure Characterization**
---**M. C. Bhardwaj**, The Ultran Group, 3100 Research Drive, State College, PA 16801; V. P. Karthi and K. Balasubramaniam, Indian Institute of Technology at Madras, Chennai, India

9:10 AM **High-Frequency Ultrasound NDE of Sintered SIC for Armor Ceramics**
---**A. R. Portune** and R. A. Haber, Rutgers University, Materials Science and Engineering, 607 Taylor Road, Piscatawat, NJ 08854-8065

9:30 AM **Nondestructive Evaluation (NDE) of Damaged Structural Ceramics Using Ultrasound (UT) and X-Ray Computed Tomography (XCT) Techniques**
---**R. E. Brennan**, W. H. Green, and J. M. Sands, United States Army Research Laboratory, Aberdeen Proving Ground, MD 21005-5069

9:50 AM **Evaluation of Ballistic Damage in an Encapsulated Ceramic Panel Via X-Ray Computed Tomography**
---W. Green and R. Carter, Army Research Laboratory, Aberdeen Proving Ground, MD

10:10 AM ***Break***

10:30 AM **Nondestructive Evaluation of Armor Using Process Compensated Resonant Testing**
---**R. Nath**, ITW Magnaflux, Quasar Business Unit, 5550 Midway Park Place N.E., Albuquerque, NM 87109

10:50 AM **Real-Time Active Protection Integrity Detection (RAPID) System for Body Armor**
---**H. Chung**, P. Qing, I. Li, and S. Beard, Acellent Technologies, Inc., 835 Stewart Drive, Sunnyvale, CA 94085; F.-K. Chang, Department of Aeronautics and Astronautics, Stanford University, Durand Building, 496 Lomita Mall, Stanford, CA 94305

11:10 AM **Passive Health Monitoring Coupled with Full-Field Active Inspection of Multi-Layered Composite Armor Structures**
---E. R. Brush, D. E. Adams, and **B. R. Zwink**, Purdue University, Department of Mechanical Engineering, West Lafayette, IN 47907-2031; S. M. Walsh, U. S. Army Research Laboratory, Aberdeen Proving Ground, MD 21005

11:30 AM **Nondestructive Evaluation Using THz Source Generated by Fiber Lasers**
---**S. Jiang**, AdValue Photonics, 4585 S. Palo Verde Road, Suite 405, Tucson, AZ 85714; W. Green, U. S. Army Research Laboratory, Aberdeen Proving Ground, MD 21005-5069

11:50 AM **A Portable Microwave Interference Scanning System for Nondestructive Testing of Multi-Layered Dielectric Materials**
---**K. F. Schmidt, Jr.**[1], J. R. Little, Jr.[1], W. A. Ellingson[2, 3], and W. Green[4], [1]Evisive, Inc., Baton Rouge, LA; [2]Argonne National Laboratory, Argonne, IL; [3]ERC Company, Indianapolis, IN; [4]Army Research Laboratory, Aberdeen Proving Ground, MD 21005-5069

12:10 PM ***Lunch***

NDE Issues Associated with the Dynamic Mechanical Response of Structural Ceramics

---**James W. McCauley**, Army Research Laboratory, ATTN:AMSRD-ARL-WM, APG, MD 21005

---In the early 1970s, structural ceramics began to emerge as viable candidates in several high performance/high temperature applications. In many of the applications it was necessary to do a 100% nondestructive evaluation (NDE) of every part. Finite Element Analysis also was being utilized to determine the quasi-static stress distributions in the various components. The methodology, however, was based primarily on quasi-static fracture mechanics with failure at the largest defect. The stress environment in dynamic impact events is significantly different, presenting new challenges to the NDE community. The stressed volume can be huge compared to a bend bar or tension specimen. In contrast to failure at the largest defect, the high rate activates a large distribution of defects with localized damage and failure occurring at many defects; so the tail of the defect distribution becomes much more important. There are both temporal and spatial distributions of strain rates and mixed stress states (compression, tension and shear) which can activate completely different plastic deformation, damage and failure mechanisms; in addition, the instantaneous stress at impact can be significantly higher than the failure stresses. Finally, there is a shock wave that precedes the damage zone, activating defects and other microstructural inhomogeneities and inclusions.

Extremely Wideband Ultrasonic Spectroscopy for Microstructure Characterization

---**Mahesh C. Bhardwaj**, The Ultran Group, State College, PA; V. P. Karthi and K. Balasubramanium, Indian Institute of Technology at Madras, Chennai, India

---In recent decades there has been widespread use of ultrasound for materials testing, primarily by utilizing time domain (time of flight, distance, and velocity) and amplitude measurements. This has virtually left out the exploration of ultrasonic spectroscopy – frequency-dependent ultrasound attenuation – and its value in materials characterization. Consider for example, when it is possible to measure frequency characteristics of a given material, one is able to discern subtle features not so easily determined by other ultrasonic measurements. We believe this is due to presumed unavailability or unreliability of extremely broadband ultrasonic transducers -- corresponding to white spectra of light waves. On the other hand, there has been enormous progress in the development of wide band ultrasonic pulsers and receivers and signal processing, which should facilitate ultrasonic spectroscopy. It is not well known that transducers characterized by very large bandwidths have been in existence since the 1980s. In this paper we present the applicability of broadband ultrasonic transducer, VSP-50 (characterized by <50 ns pulse width and spanning from 5 MHz to >65 MHz) for microstructure analysis of a number of Ti- alloys prepared by varying process parameters. We will show the sensitivity of frequency-dependent ultrasonic attenuation over ultrasonic velocity of these materials. Also presented in this paper are our ideas for future work in this important field of materials characterization, including potential application for the inspection of armor and armor systems.

High-Frequency Ultrasound NDE of Sintered SiC for Armor Ceramics

---**Andrew R. Portune** and Rich A. Haber, Rutgers University, Materials Science and Engineering, 607 Taylor Road, Piscatawat, NJ 08854-8065

---In order to further high frequency ultrasound as a diagnostic tool for determining the quality of dense ceramics, the correlation between a sample's microstructure and its ultrasound response must be fully understood. A series of sintered SiC tiles has been characterized using ultrasound C-scans at 15, 75, and 125MHz. The variance of the sample's elastic and attenuating properties has been imaged. Mechanical sectioning and SEM microscopy have been performed in order to correlate the sample's microstructure with the ultrasound data. A quantitative assessment of this data set advances the goal of determining the volumetric density of inhomogeneities present in the material.

Nondestructive Evaluation (NDE) of Damaged Structural Ceramics Using Ultrasound (UT) and X-Ray Computed Tomography (XCT) Techniques

---**Raymond E. Brennan**, William H. Green, and James M. Sands, United States Army Research Laboratory, Aberdeen Proving Ground, MD 21005-5069

---The ability to detect and quantify damage in structural ceramics and multi-material structural systems is critical for evaluating material performance. By assessing the degree of volumetric damage under varying material conditions, structural integrity can be compared and optimized. For the first set of experiments, drop tower impact testing was used to create incremental damage in a series of aluminum-backed alumina (Al2O3) tiles. A high strength steel hemispherical indenter was dropped from various heights to determine the impact velocity and energy conditions that caused failure in the tiles. For a suitable non-impact damage comparison, a multi-material structural system with no visible surface damage was obtained to determine the presence of internal damage that occurred during fabrication. Ultrasound C-scan imaging and x-ray computed tomography were utilized to evaluate damage in both the impacted Al2O3 structural ceramics and the multi-material system. Visual inspection of Al2O3 surface damage was compared to surface and bulk damage detected using the NDE methods. Quantitative evaluation of the UT and XCT images and data was used to assess and compare the degree of damage detected by each method. A comparison of the advantages and disadvantages of using each NDE method to inspect damage in structural ceramics is provided.

Evaluation of Ballistic Damage in an Encapsulated Ceramic Panel Via X-Ray Computed Tomography

---W. Green **and R. Carter**, Army Research Laboratory, Aberdeen Proving Ground, MD

---X-ray computed tomography (XCT) has been shown to be an important non-destructive evaluation technique for revealing the spatial distribution of ballistically-induced damage in ceramics. The level of detection and resolution of damage depends on the size of the sample and the parameters of the XCT approach (e.g., focal spot size, magnification, etc.). Previous and ongoing work in this area includes assessment of ballistically induced damage in both individual ceramic targets and ceramic armor panels. Ballistic damage in an encapsulated ceramic armor panel with a metal backing has been scanned and extensively evaluated using XCT 2-D and 3-D analysis. The purpose of using XCT evaluation in this study, and for damage assessment in general, is to better characterize and understand all of the detectable damage. This information can be used to correlate damage features and types with the physical processes of damage initiation and growth. XCT scans and analyses of damage in the panel will be shown and discussed. This will include virtual 3-D solid visualizations and some quantitative analysis of damage features.

Nondestructive Evaluation of Armor using Process Compensated Resonant Testing

---**Robert Nath**, ITW Magnaflux, Quasar Business Unit, 5550 Midway Park Place NE, Albuquerque, NM 87109

---The necessity for no-fault quality standards in the production of body and vehicle armor for our military personnel extends well beyond traditional manufacturing quality requirements. Only 100% NDT that is not subject to human observation and judgment error is acceptable. A test method must be used that correlates with the structural integrity of the component, as proven by destructive tests that emulate the performance in the field. This paper presents a technical overview of PCRT, an innovative, resonance-based nondestructive testing technique that quantitatively assesses the structural integrity of rigid components reliably and quickly. The discussion then is extended to the application of PCRT to testing armor plates and structures that combine armor plate with other material to enhance the anti-penetration performance and contain the products of ballistic impact. We will also be presenting the test method and the results of over two years of production application. To this date, no PCRT tested armor plates have been subsequently found to be defective.

Real-Time Active Protection Integrity Detection (RAPID) System for Body Armor

---**H. Chung**, P. Qing, I. Li, and S. Beard, Acellent Technologies, Inc., 835 Stewart Drive, Sunnyvale, CA 94085; F.-K. Chang, Department of Aeronautics and Astronautics, Stanford University, Durand Building, 496 Lomita Mall, Stanford, CA 94305

---Acellent Technologies has developed an easy-to-use, and cost-effective Real-time Active Protection Integrity Detection (RAPID) system for body armor used in field operations. The system employs acoustic ultrasound technology, and combined with signal processing algorithms and an acoustic wave generation hardware device, provides a viable solution for efficiently diagnosing armor integrity. RAPID is for detecting cracks within the armor structure, can sense interlayer delamination and disbonding, and can discern other types of damage. Our study shows that RAPID diagnostics can accurately locate the damage within the armor by quantifying the severity of the damage. A damage function has been generated for armor based on damage tests and compliance with standard NDE/NDT procedures, and was validated using digital x-ray and liquid dye penetration inspection by the Army Research Laboratory. The RAPID system is lightweight and offers a real-time, in-situ solution for damage detection of ballistic protective armor. The goal of the development is for: 1) increased safety to Army personnel; 2) reduced life-cycle costs and improved maintenance scheduling; 3) reduced costs for armor structural analysis and evaluation; and 4) increased armor reliability. The technology being developed could also be extended to better monitor the integrity of vehicle armor (or any similar systems).

Passive Health Monitoring Coupled with Full-Field Active Inspection of Multi-Layered Composite Armor Structures

---Ethan R. Brush, Douglas E. Adams, and **Brandon R. Zwink**, Purdue University, Department of Mechanical Engineering, West Lafayette, IN, 47907-2031; Shawn M. Walsh, U.S. Army Research Laboratory, Aberdeen, MD

---This paper presents the results of implementing vibration based damage detection techniques for in situ monitoring of composite armor materials. It is shown that exogenous impact forces can be passively detected, located, and quantified for specimens that simulate the properties of multi-layered armor. Damaging impact energies are applied to test specimens and the passively measured frequency response of the armor is used to estimate the level of damage incurred. A laser Doppler vibrometer is also utilized to show that nonlinear frequency modulation techniques are useful for active damage detection.

Nondestructive Evaluation Using THz Source Generated by Fiber Lasers

---**S. Jiang**, AdValue Photonics, 4585 S. Palo Verde Road, Suite 405, Tucson, AZ 85714; W. Green, U. S. Army Research Laboratory, Aberdeen Proving Ground, MD 21005-5069

---Nondestructive evaluation (NDE) and testing techniques for armor ceramics mainly include x-ray computed tomography (XCT), ultrasonic method, and microwave NDE. X-ray computed tomography (XCT) can acquire high-resolution data in high speed, but system is bulky and it's harmful to perform body armor detection in field. Ultrasonic methods and phase array ultrasonic technique are limited by their relatively low resolution. Microwave NDE also faces relatively low resolution issue. The paper will describe portable THz source for examining vehicle armor panel and body armor nondestructive evaluations. THz source is generated by nonlinear difference frequency generation in a GaSe crystal using high power fiber lasers as the pump source. THz output power is increased by increasing the average/peak power of Q-switched fiber lasers. This approach has many advantages including compact, high resolution, highly reliable, and safe to operator.

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

---**K. F. Schmidt, Jr.**[1], J. R. Little, Jr.[1], W. A. Ellingson[2, 3], and W. Green[4]
[1]Evisive, Inc., Baton Rouge, LA; [2]Argonne National Laboratory, Argonne, IL; [3]ERC Company, Indianapolis, IN; [4]Army Research Laboratory, Aberdeen Proving Ground, MD

---A portable, microwave interference scanning system, that can be used in situ, with one-sided, non-contact access, has been developed. It has demonstrated capability of damage detection on composite ceramic armor. Specimens used for validation included specially fabricated surrogates, and non-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 and discuss results obtained.---Work is supported by the US Army RDECOM ARL and US Army RDECOM TARDEC.

Session 19

SESSION 19

ADHESIVE BONDS, FILMS AND COATINGS, AND WELDS

S.-Y. Zhang and C. Dasch, Co-Chairpersons

Meeting Room F

8:30 AM **Ultrasonic Guided Wave Inspection of Adhesive Joints: A Parametric Study for a Step-Lap Joint**
---**P. K. Puthillath**, H. Kannajosyula, C. J. Lissenden, and J. L. Rose, Pennsylvania State University, Engineering Science and Mechanics Department, University Park, PA 16802

8:50 AM **Using Quantitative Ultrasonic NDE to Accurately Predict Adhesive Bond Strengths**
---**C. J. Dasch**, General Motors Research & Development, Warren, MI 48304; K. Lazarz, Ford Motors Company, Dearborn, MI 48120; R. Agarwal, Henkel Corporation, Madison Heights, MI 48071

9:10 AM **Broadband PVDF Focusing Ultrasound Transducers and Lamb Wave Measurements for the Nondestructive Determination of Elastic Constants of Thin Plates**
---**Y.-C. Lee**, L.-S. Wei, C.-H. Chung, National Cheng Kung University, Department of Mechanical Engineering, Tainan, Taiwan

9:30 AM **Monitoring of Cracking Behaviors of Plasma Played Ceramic Coatings by In-Situ Laser Acoustic Emission Technique**
---K. Taniguchi and M. Enoki, University of Tokyo, Department of Materials Engineering, Tokyo, Japan; **M. Watanabe** and S. Kuroda, National Institute for Materials Science, Composites and Coatings Center, Ibaraki, Japan

9:50 AM **Thermal Properties of Nanoscaled Bi-Layer Films Deposited on a Substrate Characterized by Transient Grating Technique**
---**H.-Y. Ju**, C.-Y. Zhang, Z. Li, D. Ma, and X.-J. Shui, Nanjing University, Lab of Modern Acoustics, Institute of Acoustics, Nanjing 210093, China

10:10 AM ***Break***

10:30 AM **Elastic Constants and sp2-Bonded Region of Nanocrystalline Diamond Thin Films**
---**H. Tanei**, N. Nakamura, H. Ogi, and M. Hirao, Osaka University, Graduate School of Engineering Science, Toyonakam Osaka, Japan; R. Ikeda, Research and Development, Asahi Diamond Industrial Company, Ltd., Ichihara, Chiba, Japan

10:50 AM **Resonant-Ultrasound Spectroscopy and Acoustic-Phonon Measurement for Studying Anisotropic Elastic Constants of Thin Films**
---**N. Nakamura**, T. Nakashima, H. Ogi, and M. Hirao, Osaka University, Graduate School of Engineering Science, Toyonaka, Osaka, Japan

11:10 AM **Pressure-Temperature Effects on Dispersion of Rayleigh's Waves on Coated Surfaces Using High Order Elastic Constants**
---**M. A. Hussain** and M. A. Doxbeck, Benet Laboratories, U.S. Army, 1 Buffington Street, Watervliet, NY 12189

11:30 AM **Detection of Lack of Fusion Weld Defects by Radiography**
---M. P. V. Souza, R. M. Almeida, and **J. M. A. Rebello**, Federal University of Rio de Janeiro, Metallurgy and Materials Department, Rio de Janeiro, RJ, Brazil; S. D. S. Petrobras, R&D Center, Rio de Janeiro, RJ, Brazil

11:50 AM **Evaluation of Laser Welding Using Sonic IR**
---**L. Feng**, W. He, and N. Tao, Capital Normal University, Department of Physics, Beijing, China

12:10 PM ***Lunch***

Ultrasonic Guided Wave Inspection of Adhesive Joints: A Parametric Study for a Step-Lap Joint

---**Padma Kumar Puthillath**, Haraprasad Kannajosyula, Cliff J. Lissenden and Joseph L. Rose, Pennsylvania State University, Engineering Science and Mechanics Department, University Park, PA 16802

---Adhesively bonded joints are used to connect structural members in aircraft. When subject to loads and environmental conditions these joints undergo deterioration. Being load bearing members, it becomes critical to develop reliable and non-destructive methods for inspecting these adhesive joints. Ultrasonic guided waves, with their mode and frequency tuning possibilities, form an attractive tool for such inspections. Guided wave behavior as observed through the dispersion phenomena is dependent on the waveguide dimensions. Since actual structural joints in aircraft involves adherends of different thicknesses and material, and joints of varied overlap lengths, a robust inspection methodology needs to be tunable for all conditions. A parametric study showing the effect of key joint parameters, for example the thickness of the adhesive, overlap length, and material parameters on the ultrasonic guided wave behavior is presented in this paper. In addition, the influence of defects like cohesive weakness, delamination and kissing bonds and their location on guided wave propagation is also investigated. The transmission of ultrasonic guided wave energy is used as a guideline in selecting optimal conditions for joint inspection.

Using Quantitative Ultrasonic NDE to Accurately Predict Adhesive Bond Strengths

---**Cameron J. Dasch**, General Motors Research & Development, Warren, MI 48304; Kim Lazarz, Ford Motors Company, Dearborn, MI; Rajat Agarwal, Henkel Corporation, Madison Heights, MI 48071

---Automotive structural adhesives are being used with greater frequency to enhance the strength of vehicle structures. There are areas where adhesives alone are used as the joining method. Because of performance requirements it is necessary to assure the strength of adhesive bonds based only on nondestructive inspection methods. In this work, ultrasonic maps of bond area and thickness are combined with an adhesive strength scaling law to predict the spatially-resolved peel strength of crash-toughened adhesive bonds. This work highlights the needs both to understand the failure mechanisms and to measure multiple properties in order to accurately predict the strength of a material system.

Broadband PVDF Focusing Ultrasound Transducers and Lamb Wave Measurements for the Nondestructive Determination of Elastic Constants of Thin Plates

---**Yung-Chun Lee**, Liu-Shin Wei, and Cheng-Hsien Chung, National Cheng Kung University, Department of Mechanical Engineering, Tainan, Taiwan

---This paper reports a nondestructive method for determining elastic constants of thin plates with thickness less than 500 um. The goal is to develop a fast and easily implemented method for accurate measurements of the dispersion curves of Lamb waves, and then used for the inverse determination of elastic constants. Focusing ultrasound transducers and V(z) defocusing measurement methods are applied for measuring the dispersion curves of thin plates over a wide range of frequency spectrum. To achieve high accuracy and wideband measurements of Lamb waves, several lens-less PVDF focusing transducers are fabricated. Both point-focused and line-focused PVDF transducers are fabricated for both isotropic and anisotropic plate samples, with a wide operating frequency from few to 100 MHz. A defocusing and V(z) measurement system and its data processing algorithm are established which allows quick and complete measurements of Lamb wave dispersion curves. For the determination of elastic constants from measured Lamb wave dispersion curves, numerical calculation and optimization analysis are performed. Thin glass plates of thickness from 100 to 500 um are measured and both Young's modulus and Poisson's ratio are successfully determined from few low order fundamental modes of Lamb waves. Thin silicon wafers with thickness around 300 to 500 um are also tested for determining all three elastic constants. Discussions on the measurement accuracy as well as potential applications for other types of nondestructive evaluation using the proposed PVDF transducers and measurement system will be addressed.

Monitoring of Cracking Behaviors of Plasma Played Ceramic Coatings by In-Situ Laser Acoustic Emission Technique

---Koichi Taniguchi and Manabu Enoki, University of Tokyo, Department of Materials Engineering, Tokyo, Japan; **Makoto Watanabe** and Seiji Kuroda, National Institute for Materials Science, Composites and Coatings Center, Ibaraki, Japan

---In recent years, a thermally sprayed coating becomes more important for many industrial applications because it can provide a substrate material with various kinds of insulations such as corrosion, wear, and oxidation resistance. In order to ensure reliability of coatings, it is necessary to understand cracking behaviors and microfracture criterion in terms of stress distribution and fracture morphology. In the present research, the cracking behavior of plasma sprayed ceramic coatings was monitored during cooling period just after deposition by detecting acoustic emission (AE) signals. Four laser heterodyne interferometers were applied as non-contact AE sensors. Al2O3 and NiCrAlY were sprayed onto a SUS304 disc as a top coat and a bond coat respectively by plasma spraying. Thickness of the deposited coatings and preheating temperature of the substrates were varied in order to study the differences of cracking behaviors. During cooling, many AE events could be detected and the locations of them were evaluated. Optical observation implied that these AE events corresponded to the cracks parallel to the interface. Transient heat conduction analysis was carried out to estimate the stress states at each AE events for various boundary conditions and the criterion of fracture was examined.

Thermal Properties of Nanoscaled Bi-Layer Films Deposited on a Substrate Characterized by Transient Grating Technique

---**Heng-yi Ju**, Chu-yi Zhang, Zhe Li, Di Ma, and Xiu-ji Shui, Nanjing University, Lab of Modern Acoustics, Institute of Acoustics, Nanjing 210093, China

---Thermal properties of bi-layered thin films with nano-scaled thickness (50 ~ 200 nm) deposited on silicon substrates (~ 700 μm) are characterized by nano-second transient grating technique. In the technique, an 8 ns pulsed laser is utilized as an excitation source to produce transient grating on the multilayered structures and a He-Ne laser is used to detect the grating. In the experiments, the 1- order diffraction beam from the grating is received by a photomultiplier and the output signal displays the thermal decay process within the multi-layered structures. To simulate the thermal behavior of the multi-layered structure irradiated by the transient grating, a 2-D multi-layered thermo-diffusion equation is analytically solved by an eigen-function expansion method. The temperature variations in the structures can be calculated numerically, and then applied to fit the experiment results, by which the thermal diffusivities of the bi-layer films deposited on a substrate can be evaluated simultaneously. In the calculations, the multi-parameter fitting is considered. The calculated results show that the thermal diffusivities are dependent on the thicknesses or deposition conditions of the nanoscaled films. The results demonstrate that the described experimental and theoretical methods are useful for simultaneously evaluating the thermal properties of nanoscaled bi-layer films.

Elastic Constants and sp2-Bonded Region of Nanocrystalline Diamond Thin Films

---**Hiroshi Tanei**, Nobutomo Nakamura, Hirotsugu Ogi, and Masahiko Hirao, Osaka University, Graduate School of Engineering Science, Toyonakam Osaka, Japan; Ryuji Ikeda, Research and Development, Asahi Diamond Industrial Co., Ltd., Ichihara, Chiba, Japan

---We determined the elastic constants of nanocrystalline diamond (NCD) thin films, and showed that the crystallographic structure and the volume fraction of the sp2-bonded region are closely related to the elastic constants. Few studies about the elastic constants of thin films have reported because of its difficulty of measurement and the elastic anisotropy of thin films. The elastic constants of NCD thin films, however, are important properties for designing the electronic devices and evaluating the microstructure, because they are sensitive to defects, incohesive bonded regions, and impurities. In this study, the NCD thin films were deposited by the hot-filament chemical-vapor-deposition method, incorporating nitrogen gas with various concentrations to decrease the grain size. The elastic constants are determined using resonant ultrasound spectroscopy coupled with laser-Doppler interferometry, and pump-probe method using femtosecond-pulse laser to generate and detect the ultrasound. The micromechanics calculation we developed can explain the results, which shows that the off-diagonal elastic constant C12 has strong correlation between the sp2 bonded regions.

Resonant-Ultrasound Spectroscopy and Acoustic-Phonon Measurement for Studying Anisotropic Elastic Constants of Thin Films

---**Nobutomo Nakamura**, Takeo Nakashima, Hirotsugu Ogi, and Masahiko Hirao, Osaka University, Graduate School of Engineering Science, Toyonaka, Osaka, Japan

---Anisotropic elastic constants of thin films are required for designing surface acoustic wave devices and optical devices to calculate the velocities of acoustic waves, and also to predict the thermal stress in layered structure. However, measurement of anisotropic elastic constants, especially the out-of-plane elastic constants, is not straightforward, and anisotropic elasticity of thin films has not been understood completely. In this study, we determine the anisotropic elastic constants using the resonant-ultrasound spectroscopy (RUS) and picosecond-laser-acoustic-phonon measurement (PSLA). Deposited thin films usually show transverse isotropy, and the in-plane elastic constant is different from that of the out-of-plane elastic constant. We determine them using RUS and PSLA, respectively. RUS measures the resonance frequencies of free vibrations of the film/substrate specimen to determine the in-plane elastic constants through an inverse calculation. PSLA measures the velocity of acoustic phonons that propagates in the film-thickness direction using the pump-probe photoacoustic method, and the out-of-plane elastic constant is determined. Combination of these methods enables us to detect the elastic anisotropy of thin films.

Pressure-Temperature Effects on Dispersion of Rayleigh's Waves on Coated Surfaces Using High Order Elastic Constants

---**Moayyed A. Hussain** and Mark A Doxbeck, Benet Laboratories, U.S. Army, 1 Buffington Street, Watervliet, NY 12189

---The present work is motivated by the need of obtaining mechanical and thermal properties of coating material on a substrate at high temperature and/or under initial uniform stress. These properties may differ considerably from the bulk properties of the layered media. These properties are used in other models e.g. in prediction of wear and erosion under harsh environments. Dispersion characteristics obtained from laser generated signal at different temperatures are used to obtain such properties. The signal is analyzed using wavelet transform and matched with velocities obtained from finite deformation solutions. By exploiting Finite Deformation Theory involving higher order elastic constants, implicit expressions for the change in longitudinal and transverse velocities of a material at elevated temperatures and pressure as a function of a uniform deformation parameter have been derived. Theoretical and experimental data are matched with a least-squares fit to obtain the 3rd order elastic constants. The experimental data was collected with a laser ultrasonic system at temperatures ranging from 20 – 300 C. This approach was used on samples of aluminum and coated specimen of tantalum on steel and chromium on steel. A mechanical model is explained to obtain the Gruneisen constant for Aluminum, Tantalum and Steel.

Detection of Lack of Fusion Weld Defects by Radiography

---Marcos P. V. Souza, Romulo M. Almeida, and **Joao M. A. Rebello**, Federal University of Rio de Janeiro, Metallurgy and Materials Department, Rio de Janeiro, RJ, Brazil; Sergio D. Soares Petrobras, R&D Center, Rio de Janeiro, RJ, Brazil

--It is currently accepted in the literature that radiography is not so sensitive as ultrasonics in the detection of the lack of fusion defects. Unfortunately, the radiographic inspection can barely detect lack of fusion and even only when this defect is associated to inclusions and voids of considerable size. However in a previous article ("Reliability of radiographic inspection of steel pipeline girth welds", QNDE Conference, 2007, Golden, Colorado) it was shown that it is possible to detect lack of fusion defects if, in the radiographic tests, the angle of incidence were the same angle which the weld bevel makes with the test piece surface; and this was employed for the same welds where radiography was unable to detect lack of fusion defects when the technique with the normal incidence of radiation cone beam was applied. The purpose of present work is to establish the smallest detectable defect using the angular beam incidence technique. A pipe with API X70 specification was used with two circumferential welds with defects artificially inserted. The defects inserted had a length of 30mm and four different heights (1, 2, 4 and 8 mm). Each height of defects appeared four times, making up a total of 16 defects. Two lines of research were taken up. The first applied the XRSIM software - a tool to simulate radiographs. This program established the optimal radiographic parameters for the lower limit of detection for this defect. The second line was experimental and radiographs were obtained using the parameters previously established by simulation. A x-ray equipment was used and the technique employed was single-wall exposure for single-wall viewing. Experimental results showed that this technique can successfully detect even the smallest defect of 1mm. Additionally, this same goal was attained when the manual and automated pulse-echo ultrasonic techniques were employed.

Evaluation of Laser Welding Using Sonic IR

---**Lichun Feng**, Wei He, and Ning Tao, Capital Normal University, Department of Physics, Beijing, China

---Laser welding is a novel method which has many benefits including fully automatic, small heat affected zone. But the small welded joint section made it difficult to inspect with conventional method such as ultrasonic. In Sonic IR method, sonic energy is transduced into heat where crack and friction locate. Compare with ultrasonic, thermography method is fast and non-contact. In this paper, five laser welding samples which have different welding parameters were inspected with Sonic IR method. The results showed that Sonic IR is a valid tool for laser welding inspection.

Session 20

SESSION 20
NDE FOR PROCESS CONTROL
M. Kreutzbruck, Chairperson
Meeting Room D

1:30 PM **Ultrasonic Liquid Steel Inclusion Monitor: Measurement Principles and Probe Design**
---**A. Currie** and S. Johnstone, Durham University, School of Engineering, Durham, United Kingdom; S. Millman, Teeside Technology Centre, Corus United Kingdom Ltd., Grangetown, Middlesbrough, United Kingdom

1:50 PM **High Resolution Eddy-Current Wire Testing Based on a GMR Sensor-Array**
---**M. Kreutzbruck**, Federal Institute for Materials Research and Testing, Department VIII, Nondestructive Testing, 12205 Berlin, Germany; K. Allweins, C. Strackbein, and H. Bernau, University of Giessen, Institute of Applied Physics, 35392 Giessen, Germany

2:10 PM **Microwave Measurement of Refractory Materials at High-Temperature**
---**S. Kharkovsky**, R. Zoughi, J. D. Smith, and B. Davis, Missouri University of Science and Technology (MST), Electrical and Computer Engineering Department, Rolla, MO 65401; R. A. Limmer, Johns Manville Corporation, Littleton, CO 80120

2:30 PM **How a Hybrid Laser-EMAT System is Being Used to Detect Surface and Internal Defects on Hot, Moving Steel**
---**I. Baillie**, Steelmaking & Continuous Casting Department, Corus Research, Development & Technology, Teesside Technology Center, Eston Road, Grangetown, Middlesbrough TS6 6US, United Kingdom

2:50 PM **An Improved Ultrasonic Technique for the Inspection of Cast Metal Structures**
---T. J. Batzinger, W. Faidi, **Z. Sun**, and M. Kumar, GE Global Research, 1 Research Circle, Nishkayuna, NY 12309; R. Barigazzi and F. Iozzelli, GE Oil and Gas

3:10 PM ***Break***

3:30 PM **Residual Stress Measurement in Friction Stir Welds Using Laser Ultrasonics**
---**D. Levesque**, M. Lord, and A. Blouin, Industrial Materials Institute, National Research Council Canada, Boucherville, Qc, Canada; L. Dubourg and P. Doran, Aerospace Manufacturing Technology Centre, National Research Council Canada, Montreal, Qc, Canada

3:50 PM **Elastic Characterization of Thin Layer Microstructures Using Resonance Modes Induced and Detected by Laser**
---**D. R. Franca*** and A. Blouin, Industrial Materials Institute, National Research Council of Canada, 75 boul. De Mortagne, Boucherville, Québec J4B 6Y4, Canada; *Current address: Department of Electrical Engineering, Faculty of Technology, University of Brasilia, Brasilia, DF 70919-970, Brazil

4:10 PM **Ultrasonic Measurement of Localized Elastic Properties and Thickness of Silicon Carbide Mirrors**
---K. V. Jata and J. T. Welter, Air Force Research Laboratory, Metals, Ceramics, and NDE Division, RXLP, WPAFB, OH 45469-0120; L. E. Matson, Air Force Research Laboratory, Metals, Ceramics, and NDE Division, RXLN, WPAFB, OH; **R. W. Martin** and S. Sathish, University of Dayton Research Institute, Structural Integrity Division, Dayton, OH 45469-0120

4:30 PM **Calculation of Elastic Anisotropy Using EMATs Validated by EBSD in Rolled Aluminium and Steel Sheet Samples**
---**S. D. Essex**, M. D. G. Potter, R. S. Dobedoe, and S. Dixon, University of Warwick, Department of Physics, Coventry, United Kingdom

Ultrasonic Liquid Steel Inclusion Monitor: Measurement Principles and Probe Design

---**A. Currie** and S. Johnstone, School of Engineering, Durham University, Durham, United Kingdom; S. Millman, Teeside Technology Centre, Corus United Kingdom Ltd., Grangetown, Middlesbrough, United Kingdom

---The goal of the project is to develop a disposable ultrasonic probe measurement system that will give particle size distributions for non-metallic inclusions in liquid steel after a one minute measurement. This will allow the opportunity to analyze several hundred kilograms of liquid steel. Two novel concepts for the ultrasonic evaluation of liquid steel that will produce information on particle size distribution for inclusions are suggested. Both these methods use a measured value such as attenuation and a theoretical description of acoustic wave theory to produce the size characterization of inclusions. One of these methods depends upon the representative estimation of inclusion size parameters for assumed particle distributions. The other technique relies on the detection of individual particles, via the scattered ultrasonic energy in the Rayleigh regime. Some similar work has taken place in the aluminum industry but it has been heavily based on experimentally obtained empirical data. Implementation difficulties are much greater in liquid steel. This paper will describe some of the theories developed and focus on their implementation via a novel design and testing of a disposable probe system. Liquid steel trials have taken place, and the results have been used to aid the design of subsequent prototypes.

High Resolution Eddy-Current Wire Testing Based on a GMR Sensor-Array

---**Marc Kreutzbruck**, Federal Institute for Materials Research and Testing, Department VIII, Nondestructive Testing, 12205 Berlin, Germany; Kai Allweins, Chris Strackbein, and Hendrick Bernau, University of Giessen, Institute of Applied Physics, 35392 Giessen, Germany

---Increasing demands in materials quality and cost effectiveness have led to advanced standards in manufacturing technology. Especially when dealing with high quality standards in conjunction with high throughput quantitative NDE techniques are vital to provide reliable and fast quality control systems. In this work we illuminate a modern electromagnetic NDE approach using a small GMR sensor array for testing superconducting wires. Four GMR sensors are positioned around the wire. Each GMR sensor provides a field sensitivity of 200 pT/Hz^0.5 and a spatial resolution of about 100 µm. This enables us to detect under surface defects of 100 µm in size in a depth of 200 µm with a signal-to-noise ratio of better than 400. Surface defects could be detected with a SNR of up to 10,000. Besides this remarkably SNR the small extent of GMR sensors results in a spatial resolution which offers new visualization techniques for defect localization, defect characterization and tomography-like mapping techniques. We also report on inverse algorithms based on either a Finite Element Method or an analytical approach. These allow for accurate defect localization on the µm scale and an estimation of the defect size.

Microwave Measurement of Refractory Materials at High-Temperature

---**Sergey Kharkovsky**, Reza Zoughi, Jeffrey D. Smith, and Bill Davis, Missouri University of Science and Technology (MST), Electrical and Computer Engineering Department, Rolla, MO 65401; Randy A. Limmer, Johns Manville Corporation, Littleton, CO 80120

---In glass manufacturing industry, furnaces are being operated at higher temperatures and for longer periods of time thus increasing the rate of wear on the furnace refractory lining (i.e., walls and floors). Consequently, there is a need to know the state of a refractory structure to prevent premature or unnecessary maintenance shutdowns. Recently, a frequency-modulated continuous-wave (CW) handheld radar operating in the frequency range of 8-18 GHz was designed and constructed for on-site inspection of refractory structures. The ability of the radar to detect boundaries between different refractory bricks (in a wall or floor structure) is highly dependent on the contrast among the dielectric properties (relative permittivity and loss factor) of the bricks as well as any changes that may occur in these properties as a function of increasing temperature. Change in the relative permittivity influences brick thickness measurement, while increase in loss factor can potentially mask reflections from different boundaries (i.e., increase in attenuation constant). This paper presents the results of an investigation in which two refractory materials (dense chrome and dense zircon) were subjected to increasing temperature in a furnace which this radar was used to evaluate their thickness and attenuation properties.

How a Hybrid Laser-EMAT System is Being Used to Detect Surface and Internal Defects on Hot, Moving Steel

---**Iain Baillie**, Steelmaking & Continuous Casting Department, Corus Research, Development & Technology, Teesside Technology Center, Eston Road, Grangetown, Middlesbrough TS6 6US, United Kingdom

---In the continuous casting process, liquid steel is cast into solid steel products, such as slabs, blooms and billets. Both surface and internal defects can arise in these as-cast products causing problems for downstream processes and customers. These problems could be minimized if the steel could be inspected on-line as a feedback control system could be developed to alert operators should any defects arise and relevant modifications to the process could then be made.
To assess steel quality, a pulsed Nd:YAG laser beam is used to generate broadband ultrasonic waves in the steel and an array of non-contact, water-cooled EMATs (ElectroMagnetic Acoustic Transducers) is used to detect the presence of both surface and internal defects. A comparison between experimentally measured and modeled data will be shown. The prototype Laser-EMAT system, is being developed for installation on the Pilot Plant Continuous Caster at Teesside Technology Centre. The results of the laboratory and pilot scale studies are reported in this paper where a moving billet sample was initially tested at room temperature and later heated to 850°C. A transverse defect was detected in both experiments on the moving billet.

An Improved Ultrasonic Technique for the Inspection of Cast Metal Structures

---**Thomas J. Batzinger**, Waseem Faidi, Zongqi Sun, and Manoj Kumar, GE Global Research, 1 Research Circle, Nishkayuna, NY 12309; Riccardo Barigazzi and Federico Iozzelli, GE Oil and Gas

---GE produces many industrial components using cast metals. Turbine castings, compressor castings, pump shells and other large industrial structures are constructed using materials such as cast steel and cast iron. Occasionally, defects are discovered during component machining. These defects may require the casting to be repaired or be scrapped depending on defect size and location. With the increasing cost to manufacture components, it is desirable to detect these defects prior to machining the component. Discovery of critical defects prior to machining will reduce the time spent and machining cost of a component that will ultimately be scrapped. The team at GE Global Research and GE Oil and Gas has developed an ultrasonic technique suitable for the detection of defects of diameter 0.5mm or larger in Nodular cast iron and in cast steel. Defects of diameter greater than 3mm are detected in Flake cast iron. This presentation will describe the development of this ultrasonic technique and the modeling effort used to provide insight. Finally, the presentation will show test results validating the performance of the ultrasonic technique developed for these cast materials.

Residual Stress Measurement in Friction Stir Welds Using Laser Ultrasonics

---**D. Levesque**, M. Lord, and A. Blouin, Industrial Materials Institute, National Research Council Canada, Boucherville, Qc, Canada; L. Dubourg and P. Doran, Aerospace Manufacturing Technology Centre, National Research Council Canada, Montreal, Qc, Canada

---Friction stir welding (FSW) is a solid-state, environmentally friendly joining process that produces high strength, good finish welds. It uses the heat generated from a friction tool to plasticize and bond metals in a highly controllable and repeatable manner. During the last few years, FSW has been gaining acceptance and has found various applications in aerospace, automotive and naval industries. As with other welding process, distortion in thin section structures usually occurs caused by buckling due to thermal residual stresses. This weld distortion can lead to loss of dimensional control and structural integrity. Techniques such as reduction of weld size, design modifications and thermal tensioning can be used to minimize residual stresses and related buckling. There is a need to evaluate in a nondestructive manner the level of residual stresses to support such techniques. In addition to the detection of discontinuities in FSW, laser-ultrasonics can be used to measure residual stresses induced by the FSW process. The method is based on monitoring the small velocity change of the laser generated surface skimming longitudinal wave produced by the stress. This wave propagates just below the surface and is found more sensitive to stress than Rayleigh wave. Work is under way to compare the residual stress profile measured perpendicular to the weld path with results from numerical simulations and strain gauge measurements.

Elastic Characterization of Thin Layer Microstructures Using Resonance Modes Induced and Detected by Laser

---**Demartonne Ramos França*** and Alain Blouin, Industrial Materials Institute, National Research Council of Canada, 75 boul. De Mortagne, Boucherville, Québec J4B 6Y4 Canada; *Current address: Department of Electrical Engineering, Faculty of Technology, University of Brasilia, Brasilia, DF 70919-970, Brazil

---Microstructures made of cantilever beams are essentials for designing a number of important practical devices. Proper design requires that the elastic properties (chiefly the Young's moduli) of the cantilever's thin layers be accurately known. The resonance method is an elegant approach for determining the Young's moduli in the thin layers domain. Through this method, Young's moduli of the layers are correlated to modal resonant frequencies of the microstructures. Here, a novel, simple and effective method of exciting resonance modes in microstructures is proposed. A laser pulse is pointed to arbitrary locations over the surface of the test structure (in this case, a MEMS board containing an array of cantilever beams). Elastic excitation of the whole board then forces the cantilevers to vibrate effectively, as a variety of resonance modes is simultaneously excited. The method is nondestructive, remote and totally free of sample preparation. In addition, no precise alignment of the generation laser beam with respect to the board is required. Full advantage of the remote nature of the proposed excitation method is taken when it is used together with a broadband laser detection system. Therefore, a homodyne Michelson interferometer is implemented. To validate the novel method, an original analytical procedure, based solely on frequency analyzes, is also developed for determining the Young's moduli of thin layers of two-layer cantilever beams. Results are in good agreement with published values.

Ultrasonic Measurement of Localized Elastic Properties and Thickness of Silicon Carbide Mirrors

---Kumar V. Jata and John T. Welter, Air Force Research Laboratory, Metals, Ceramics, and NDE Division, RXLP, WPAFB, OH 45469-0120; Larry E. Matson, Air Force Research Laboratory, Metals, Ceramics, and NDE Division, RXLN, WPAFB, OH; **Richard W. Martin** and Shamachary Sathish, University of Dayton Research Institute, Structural Integrity Division, Dayton, OH 45469-0120

---Silicon Carbide (SiC) mirrors have significant advantages compared to glass mirrors. They are less dense, possess very high elastic stiffness and have low thermal expansion coefficient over wide temperature range. The manufacturing process induces significant residual stress and thickness variation. The polishing process to produce high quality mirrors alters both the residual stress and thickness distribution. In some cases this might produce damage in the mirrors and limit its usability. At present there is a need for NDE techniques to evaluate the damage and ensure the quality of SiC mirrors. To address this issue, we have developed ultrasonic methods to measure the local variation in thickness, longitudinal and surface wave velocity on SiC mirrors. Measurements of thickness, longitudinal and surface wave velocity are presented along with x-ray diffraction residual stress measurements. The impact of the variations in the material properties are discussed with reference to the changes in residual stress distribution after polishing.

Calculation of Elastic Anisotropy Using EMATs Validated by EBSD in Rolled Aluminum and Steel Sheet Samples

---**Stephen D. Essex**, Mark D. G. Potter, Richard S. Dobedoe, and Steve Dixon, University of Warwick, Department of Physics, Coventry, United Kingdom

---Measuring the Orientation Distribution Function (ODF) accurately and quickly in a non-destructive manner has many benefits and applications within industry. The ODF is a measure of anisotropy, or texture, within metal sheet. The anisotropy can be calculated from the variation in S0 Lamb wave velocities at differing angles subtended to the Rolling Direction. The texture is quantitatively described by the Orientation Distribution Coefficients (ODCs) W400, W420 and W440. Electron Backscatter Diffraction (EBSD) is a technique performed in a SEM. It deciphers the crystallographic directions of crystals near-surface, and can be applied to a number of samples. It enables the accurate quantitative and qualitative description of microstructural properties such as grain size. By manipulating the Bunge-Euler angle data output from EBSD scans, we describe a method to extrapolate the effective elastic constants for thin Aluminum and Steel sheets, and can therefore produce a Lamb wave velocity prediction in a directly comparable form to the EMAT S0 Lamb wave velocity measurement system. Results show a good correlation between the predicted velocity trace from EBSD compared to that measured, and hence the respective ODCs, except in the circumstance where surface-to-bulk texture inhomogeneity exists.

Session 21

SESSION 21
BENCHMARK
L. Schmerr, Chairperson
Meeting Room E

1:30 PM **Finite Element Simulation of the WFNDEC's Second Benchmark Problem**
---K. Thiyagarajan, C. V. Krishnamurthy, **K. Balasubramaniam**, Indian Institute of Technology Madras, Centre for Nondestructrive Evaluation, Department of Mechanical Engineering, Chennai, India

1:50 PM **2008 ECT Benchmark Results: Modeling with CIVA of 3D Flaws Responses in Planar and Cylindrical Workpieces**
---**C. Reboud**, G. Pichenot, and S. Mahaut, CEA, LIST, Centre CEA de Saclay, Gif-sur-Yvette Cedex, F-91191, France

2:10 PM **Differential Bobbin Coil Signal Variation Due to a Circumferential Groove in a Tube**
---**T. Theodoulidis**[1] and J. R. Bowler[2], [1]Department of Engineering and Management of Energy Resources, West Macedonia University, Kozani, Greece; [2]Department of Electrical and Computer Engineering and the Center for NDE, Iowa State University, Ames, IA 50011

2:30 PM **A Proposed Benchmark Problem for Scatter Calculations in Radiographic Modelling**
---**G.-R. Jaenisch**, BAM (Federal Institute for Materials Research and Testing), Division VIII.3, Unter den Eichen 87, 12205 Berlin, Germany; A. Schumm, Electricité de France R&D, 1 avenue du general de Gaulle, 92141 Clamart, France; J. Tabary, CEA LETI, 17 rue des martyrs, 38054 Grenoble, France; P. Duvauchelle, INSA-Lyon, Laboratoire de Contrôle, Non Destructif par Rayonnements Ionisants, Bat Saint Exupéry, 20 avenue Albert Einstein 69 621 Villeurbanne Cedex, France

3:10 PM ***Break***

3:30 PM **Results of the 2008 UT Modeling Benchmark Obtained with CIVA: Responses of Flat-Bottom Holes at Various Depths Under Interfaces of Different Curvatures**
---**R. Raillon**, S. Mahaut, N. Leymarie, and S. Lonne, CEA, LIST, Centre CEA de Saclay, Gif-sur-Yvette Cedex, F-91191, France

3:50 PM **Model Prediction Results for 2008 Ultrasonic Benchmark Problems**
---**H.-J. Kim**, S.-J. Song, and J.-A. Park, Syungkyunkwan University, School of Mechanical Engineering, Suwon, Kyunggi-do, Korea

4:10 PM **Modeling the 2008 Ultrasonic Benchmark Problems**
---**L. W. Schmerr, Jr**.[1,2], R. Huang[1], [1]Center for NDE and the [2]Department of Aerospace Engineering, Iowa State University, Ames, IA 50011

4:30 PM **Assessment of Pulse Echo Response of Flat Bottom Holes Through Curved Interfaces Using the Patch Element Model**
---**G. M. S. Reddy**, C. V. Krishnamurthy, and K. Balasubramaniam, Indian Institute of Technology, Mechanical Engineering, Chennai, Tamil Nadu, India

4:50 PM **Simulations of the 2008 Ultrasonic Benchmark Study with Acoustic Ideas's Ultrasonic Modeler**
---**V. Lupien**, Acoustic Ideas, 27 Eaton Street, Wakefield, MA 01880

5:10 PM **Simulation of the 2008 Ultrasonic Benchmark Problems Using UTDefect**
---P.-A. Jansson and A. Bostrom, Chalmers University of Technology, Department of Applied Mechanics, Goteborg, Sweden

Finite Element Simulation of the WFNDEC's Second Benchmark Problem

---Kathirvel Thiyagarajan, C. V. Krishnamurthy, **Krishnan Balasubramaniam**, Indian Institute of Technology Madras, Centre for Nondestructive Evaluation, Department of Mechanical Engineering, Chennai, India

---The 2008 Eddy-Current benchmark problem posed by the World Federation of NDE Centers (WFNDEC) is discussed here with a proposed Finite Element based solution. A three-dimensional magnetic vector potential finite element formulation for the modelling of Inconel tube inspection using an external differential bobbin coil (Second benchmark problem) has been carried out for defects such as through-wall borehole and 3D longitudinal and circumferential notches. The objective of this benchmark problem is to find the eddy-current probe responses for the defects considered and compare these model prediction responses with experimental data provided by CEA, France.

2008 ECT Benchmark Results: Modeling with CIVA of 3D Flaws Responses in Planar and Cylindrical Workpieces

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

---ECT configurations proposed in the 2008 ECT modeling benchmark session are addressed in this paper using the eddy current modeling tool embedded into CIVA, which is a multi-technique simulation platform dedicated to NDT and developed at the French Atomic Energy Commission (CEA). The theoretical approach used in CIVA for ECT modeling is based on Volume integral Method (VIM) coupled with the Method of Moments (MoM) and thus leads to fast and accurate calculations in the case of canonical geometries. Symmetries of the configurations considered in this benchmark are moreover exploited by using the Dodd and Deed formalism for the field computations. After a presentation of the semi-analytical model, results obtained in all benchmark cases are discussed and compared with experimental data. New developments in CIVA are also briefly presented.

Differential Bobbin Coil Signal Variation Due to a Circumferential Groove in a Tube

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

---We have developed a general method for finding new solutions in eddy current nondestructive evaluation by introducing truncation boundaries in configurations that are otherwise unbounded. Consider the case of a tube containing a bobbin coil near a circumferential grove of rectangular cross section. The grove can be internal or external. The problem is axially symmetric and easily solved using numerical methods but we seek an approximate analytical solution. Take the axis of the system to be perpendicular to two truncation planes with the bobbin coil and grove roughly half way between them. On these planes, a boundary condition is applied; for example one can suppose that the tangential electric field is zero. In order to ensure that the predicted field is close that that expected in the corresponding unbounded domain problem, the planes are far apart and well away from the coil and grove. The solution between the planes is expressed as series expansions that are matched across cylindrical boundaries using the continuity properties of the electromagnetic field. This process gives the expansion coefficients in the series and ultimately the bobbin coil signals. The accuracy of the calculation is easily controlled by adjusting the distance between the truncation planes and/or the number of terms in the series expansions.---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.

A Proposed Benchmark Problem for Scatter Calculations in Radiographic Modelling

---**Gerd-Ruediger Jaenisch**, BAM (Federal Institute for Materials Research and Testing), Division VIII.3, Unter den Eichen 87, 12205 Berlin, Germany; Andreas Schumm, Electricité de France R&D, 1 avenue du général de Gaulle, 92141 Clamart, France; J. Tabary, CEA LETI, 17 rue des martyrs, 38054 Grenoble, France; P. Duvauchelle, INSA-Lyon, Laboratoire de Contrôle, Non Destructif par Rayonnements Ionisants, Bat Saint Exupéry, 20 avenue Albert Einstein, 69 621 Villeurbanne Cedex, France

---Code Validation is a permanent concern in computer modelling, and has been addressed repeatedly in eddy current and ultrasonic modelling. 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 modelling, the scattered radiation prediction. Many NDT applications can not neglect scattered radiation, and the scatter calculation thus is important to faithfully simulate the inspection situation. Our benchmark problem covers the wall thickness range of 10 to 50mm for single wall inspections, with energies ranging from 100 to 500keV in the first stage, and up to 1 MeV with wall thicknesses up to 70mm in the extended stage. A simple plate geometry is sufficient for this purpose, and the scatter data is compared on a photon level, without a film model, which allows for comparisons with reference codes like MCNP. We compare results of three Monte Carlo codes (MC-Ray, Sindbad and Moderato) as well as an analytical first order scattering code (VXI), and confront them to results obtained with MCNP. The comparison with an analytical scatter model provide insights into the application domain where this kind of approach can successfully replace Monte-Carlo calculations.

Results of the 2008 UT Modeling Benchmark Obtained with CIVA: Responses of Flat-Bottom Holes at Various Depths Under Interfaces of Different Curvatures

---**R. Raillon**, S. Mahaut, N. Leymarie, and S. Lonne, CEA, LIST, Centre CEA de Saclay, Gif-sur-Yvette Cedex, F-91191, France

---The paper presents the results obtained, for the configurations proposed in the 2008 UT modeling benchmark, with the ultrasonic simulation code dedicated to the prediction of echographic responses of flaws and integrated into the CIVA software platform. UT configurations addressed here are similar to those performed in 2007 in order to better understand some responses obtained last year. Experimental results proposed concern the responses of flat bottom holes at different depths inside surface curved blocks (concave or convex) inspected with an immersion probe in normally incidence. These test configurations aim at investigating the influence of surface curvature upon the amplitude and shape of the flaw responses. The results concern also the probe characterization (knife edge and side drilled holes responses). Comparison of the simulated and experimental results is discussed.

Model Prediction Results for 2008 Ultrasonic Benchmark Problems

---**Hak-Joon Kim**, Sung-Jin Song, and Jin-A Park, Syungkyunkwan University, School of Mechanical Engineering, Suwon, Kyunggi-do, Korea

---The World Federation of NDE Centers (WFNDEC) has addressed two types of problems for the 2008 ultrasonic benchmark study: 1) surface curvature effects on the ultrasonic responses of flat-bottomed holes, and 2) responses of side-drilled holes at various depths in a steel block. To solve this year ultrasonic benchmark problems, multi-Gaussian beam models will be adopted for calculation of insonifying fields on the flat-bottomed holes and the side-drilled holes. And, Kirchhoff approximation and FDM will be applied for prediction of far-field scattering amplitudes from the flat-bottomed holes and side-drilled holes. By integration of those subsidiary models, we will predict the responses of the flat-bottomed holes and the side-drilled holes. For study on surface curvature effects, the predicted responses of flat-bottomed holes will be normalized by the predicted signal of a flat-bottomed hole at 12.7 mm with planar interface. Also, for the side-drilled hole study, we will predict the responses of the side-drilled hole using Kirchhoff approximation and FDM to investigate a multiple scattering effect. In this presentation, comparison results to the experiments and model based responses will be presented.

Modeling the 2008 Ultrasonic Benchmark Problems

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

---The first part of the 2008 benchmark is a study of the influence of surface curvature on the response of a flat-bottom hole. We will use multi-Gaussian beam models, flaw scattering models based on the Kirchhoff approximation, and measurement models to simulate the curvature effects. We will examine the capabilities of these various models for predicting the measured responses and the underlying incident and scattered wave fields. The second part of the benchmark involves the response of side-drilled holes at various depths. We will use similar beam models, flaw scattering models, and measurement models for this part of the study.---This work was supported by the NSF Industry/University Cooperative Research Center at Iowa State University.

Assessment of Pulse Echo Response of Flat Bottom Holes Through Curved Interfaces Using the Patch Element Model

---**G. Madhu Sudhan Reddy**, C. V. Krishnamurthy, and Krishnan Balasubramaniam, Indian Institute of Technology, Mechanical Engineering, Chennai, Tamil Nadu, India

---We report the calculation of the ultrasonic field distribution due to a transducer placed above a curved interface using the frequency domain Patch Element Model (PEM), developed at CNDE. The assessment employs an optimized algorithm to determine the points of reflection/refraction on any planar or curved interface between two media. Fields can be evaluated at any specified point be it near-field or far-field except at critical points. Pulse Echo responses of 0.8 mm diameter Flat Bottom Hole (FBH) at depths ¼", ½", ¾", 1", 1.5", 2" and 3" through convex and concave surfaces each of radius 2" and 8" and planar surface are determined with a focused transducer of diameter 12.47 mm with a focal length of 172.9 mm, having a central frequency of 4.8 MHz. PEM calculations were also carried out on 1" deep FBHs (dia.'s 0.5 mm, 1 mm, 1.5 mm, 2 mm) in Aluminum specimen with convex surface of radius 37.5 mm. Validation of these calculations with in-house experiments for a 5 MHz, 0.375" diameter planar immersion transducer will be presented. Discussion of the results will be presented in the context of the Ultrasonic Benchmark Problem 2007/2008 suggested by the WFNDE.

Simulations of the 2008 Ultrasonic Benchmark Study with Acoustic Ideas's Ultrasonic Modeler

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

---Simulations of time-domain echoes using Acoustic Ideas's Ultrasonic Modeler are presented from flat-bottom holes at different depths as measured through cylindrical interfaces with a spherically focused transducer and for side-drilled holes at different depths as measured by a spherically focused transducer through a planar interface. Of particular interest in this work is Ultrasonic Modeler's use of a Biot-Tolstoy based ultrasonic scattering kernel. A primer in Biot-Tolstoy theory and its potential advantages for arbitrary complex geometry are presented. Intuitive physical interpretations for the agreement with data are provided where possible.

Simulation of the 2008 Ultrasonic Benchmark Problems Using UTDefect

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

---The computer program UTDefect is used to solve some of the 2008 ultrasonic benchmark problems. UTDefect is a program for simulation of ultrasonic testing of homogeneous components, isotropic as well as anisotropic. Different types of ultrasonic transducers, including immersion testing, are available. Scattering from various defects of simple shape is modelled using solutions that are essentially exact. Results can be obtained for a fixed frequency or in the time domain. The problem of scattering from a side-drilled hole is solved using separation of variables. For the flat-bottomed hole only the case of a planar interface between the fluid and the component is modelled. In this case the hole is approximated by a penny-shaped crack parallel to the interface. This should work well for normal incidence as long as the diameter is not too small compared with the wavelength. To solve the scattering problem a hypersingular integral equation method is employed. For the benchmark problems the results obtained from UTDefect are in fairly good agreement with the experimental data from CEA.

Session 22

SESSION 22

NONLINEAR ACOUSTICS—MECHANISMS CONTROLLING BETA

J. Cantrell, Chairperson
Meeting Room F

1:30 PM **Acoustic Rectification in Dispersive Media**
---**J. H. Cantrell**, NASA Langley Research Center, Nondestructive Evaluation Sciences Branch, Hampton, VA 23681

1:50 PM **Experimental Issues in the Measurement of Nonlinearity Parameter from Static Displacement (DC Component) Generation Experiments**
---K. Thimmavajjula and **K. Balasubramaniam**, Center for Nondestructive Evaluation and Department of Mechanical Engineering, Indian Institute of Technology Madras, Chennai, India 600036

2:10 PM **Characterizing Fatigue Damage in Metallic Materials Using Nonlinear Ultrasound**
---J.-Y. Kim and L. J. Jacobs, Georgia Institute of Technology, School of Civil and Environmental Engineering, Atlanta, GA 30332; **J. Qu**, Georgia Institute of Technology, School of Mechanical Engineering, Atlanta, GA 30332

2:30 PM **Nonlinear Effects of Surface Wave Interaction with Cracks**
---**S. I. Rokhlin**, The Ohio State University, Edison Joining Technology Center, 1248 Arthur E. Adams Drive, Columbus, OH 43221

2:50 PM **Characterization of Cold Rolled Austenitic Stainless Steel Plates Using Nonlinear Ultrasonic Technique**
---A. Viswanath, B. P. C. Rao, **T. Jayakumar**, and B. Raj, Indira Gandhi Centre for Atomic Research, Nondestructive Evaluation Division, Kalpakkam, Tamil Nadu, 603 102, India

3:10 PM ***Break***

3:30 PM **Nonlinear Characterization of Friction Stir Weld Joints**
---A. Sanford, Jr., M. Pedrick, C. Domack, **M. J. McKenna**, Luna Innovations Incorporated, Hampton, VA 23666; D. M. Sabados and G. Workman, University of Alabama, Huntsville, AL 35801; D. Reiss and M. Suits, NASA Marshall Space Flight Center, Huntsville, AL 35801

3:50 PM **A Perturbation Approach to Treat Nonlinear Hysteretic Damage in Finite Structures**
---**D. A. Mendelsohn**[1] and C. Pecorari[2], [1]The Ohio State University, Department of Mechanical Engineering, Columbus, OH 43210; [2]AF, Agatan 40, 582 22 Linköping, Sweden

4:10 PM **On the Observation of Acousto-Elastic Hysteresis in Kinking Nonlinear Elastic Solids**
---P. Finkel, A. Zhou, S. Basu, **O. Yeheskel***, and M. Barsoum, Drexel University, 3141 Chestnut Street, Philadelphia, PA 19104; *NRCN

4:30 PM **Parametric Resonance for Materials Characterization**
---**L. Adler** and S. Rokhlin, Ohio State University, Department of Industrial, Welding and Systems Engineering, Columbus, OH 43085

4:50 PM **Wide Band Time Reversal Acoustic Nonlinear Diagnostics**
---**A. Sutin**, Stevens Institute of Technology, Hoboken, NJ 07030; T. J. Ulrich, J. A. Tencate, and P. A. Johnson, Los Alamos National Laboratory, EES-11 (Geophysics), Los Alamos, NM 87544

Acoustic Rectification in Dispersive Media
---**John H. Cantrell**, NASA Langley Research Center, Nondestructive Evaluation Sciences Branch, Hampton, VA 23681

---It is shown that the shapes of acoustic radiation-induced static strain and displacement pulses (rectified acoustic pulses) are defined locally by the energy density of the generating waveform. The locality leads to an independence of the rectified pulses on the total propagation distance, in contrast to harmonic generation. Dispersive properties are introduced analytically by including a dispersive term in the phase of the particle velocity solution to the nonlinear wave equation. The dispersion causes an evolutionary change in the shape of the energy density profile that leads to the generation of solitons experimentally observed in fused silica. Implications to the measurement of the acoustic nonlinearity parameter in dispersive media are discussed.

Experimental Issues in the Measurement of Nonlinearity Parameter from Static Displacement (DC Component) Generation Experiments
---Karthik Thimmavajjula and **Krishnan Balasubramaniam**, Center for Nondestructive Evaluation and Department of Mechanical Engineering, Indian Institute of Technology Madras, Chennai, India 600036

---Nonlinear Ultrasonics is emerging as an invaluable nondestructive technique for early material damage detection. The method uses the phenomenon of distortion of the wave and generation of higher order harmonics and static displacement (DC Component) when a finite amplitude ultrasonic wave propagates through a material which has accumulated nonlinearities. The nonlinearity parameter which characterizes the material can be estimated from either second harmonic generation or the DC Component generation measurements. The latter technique has the advantage that it reduces considerably the instrumentation at the receiver side and also the nonlinearity parameter can be evaluated using the time domain measurement unlike the harmonic generation which requires frequency domain measurement. This paper discusses some of the experimental issues concerning the measurement of the nonlinearity parameter from DC Component experiments. Firstly the abnormal variation of the extracted nonlinearity parameter at low input powers is discussed and systematic experiments are reported to explain the cause of the abnormal variation. Secondly the abnormal variation of the extracted nonlinearity parameter at low number of cycles of the input tone burst is reported. The range of input parameters where the measurements need to be performed to extract the true nonlinearity parameter of the material is discussed.

Characterizing Fatigue Damage in Metallic Materials Using Nonlinear Ultrasound

---Jin-Yeon Kim and Laurence J. Jacobs, School of Civil and Environmental Engineering, Georgia Institute of Technology, Atlanta, GA 30332; **Jianmin Qu**, School of Mechanical Engineering, Georgia Institute of Technology, Atlanta, GA 30332

---This talk presents an overview of recent progress on the use of nonlinear ultrasonic techniques to quantitatively characterize fatigue damage in metallic materials. In particular, we will focus on methodologies that are based on measuring higher order harmonics to track microstructure changes in the material due to fatigue damage. As a single frequency wave propagates in a metallic material with fatigue damage, higher harmonic frequencies are generated. This higher harmonic generation is quantified with a nonlinearity parameter β which is intrinsic to the material microstructure. Recent experimental measurements have indisputably established the close correlation between β and the degree of damage. Since β can be measured using nonlinear ultrasound, such a correlation enables the nondestructive characterization of the fatigue life of a metallic component. Various nonlinear ultrasonic techniques based on bulk, Rayleigh and Lamb waves will be discussed and reviewed. Measurement results will be presented for aluminum alloys and Ni-base super alloys subjected to quasi-static monotonic tension and low-cycle fatigue. Recent progress on developing quantitative physics-based models to relate β to material microstructure changes has followed two somewhat different approaches. One is to directly relate β to the dislocation substructure, and the other is to relate β to cumulative plastic strain developed in the material. The former provides a clear physical interpretation of β, while the latter allows for the characterization of material state and the estimation of the remaining fatigue life of a component based on nondestructive nonlinear ultrasonic measurements. Both approaches will be discussed and their predictions are compared to experimental measurements.

Nonlinear Effects of Surface Wave Interaction with Cracks

---**S. I. Rokhlin**, The Ohio State University, Edison Joining Technology Center, 1248 Arthur E. Adams Drive, Columbus, OH 43221

---This paper addresses experimental and theoretical aspects of nonlinear and parametric effects of surface acoustic wave interaction with partially closed fatigue cracks. Under low frequency modulation load applied to the structure such a crack may be considered as an imperfect interface in a solid under different clamping conditions modified by external loading. The loading induces change of interfacial conditions and/or crack length leading to wave mixing (modulation). This concept can be applied for structural health monitoring where small, newly-initiated cracks or damage precursors are constrained by the surrounding elastic medium; therefore in-service loads change the crack closure state and produce nonlinear modulation of reflected ultrasonic pulses. Potentially these in-service loads may be simultaneously recorded and synchronized with probing (monitoring) ultrasonic signatures. The measurements were performed for different crack lengths, variable static crack closure stresses, and different stress modulation levels in the modulation frequency range from 10Hz to 10kHz. In this frequency range the external dynamic action can be considered quasi-static. The appearance of the modulation is an indication of the fatigue damage. The fatigue crack initiation and propagation and opening-closure behavior are related to harmonic amplitudes. It is turned out that the application of low amplitude modulation load enhances the sensitivity of detection of partially closed fatigue cracks helping to discriminate the initiation of small cracks.---The work was partially sponsored by the AFRL.

Characterization of Cold Rolled Austenitic Stainless Steel Plates Using Nonlinear Ultrasonic Technique

---Adurthi Viswanath, Bhagi Purna Chandra Rao, **Tammana Jayakumar**, and Baldev Raj, Indira Gandhi Centre for Atomic Research, Non Destructive Evaluation Division, Kalpakkam, Tamil Nadu, 603 102, India

---This paper presents the research work carried out to characterize microstructural changes in cold rolled austenitic stainless steel specimens using nonlinear ultrasonic (NLU) technique. Stainless steel plates cold rolled up to 60% in steps of 10% have been used and NLU measurements have been carried out using an experimental set up consisting of high power rf tone burst generator, digital storage oscilloscope, narrow band transmitter (5 MHz), broad band receiver (10 MHz), filters and data acquisition module interfaced to a personal computer. The power spectrum of the transmitted /received time-domain signals has been used to determine the magnitudes of fundamental and harmonic, A1 and A2 respectively. The nonlinear parameter, beta has been determined from the slope of the linear-fit plot between a.A1 square and A2 where a is the specimen thickness. Studies on specimens cold rolled to different levels have revealed that the beta parameter is found to increase systematically with percentage cold work. An overall 100% increase in the beta parameter has been observed for 60% cold worked specimen as compared to the virgin material. Microscopy has been performed to observe the changes in microstructures with cold work. The increase in the beta parameter is attributed to the combined effect of increase in dislocation density, evolution of dislocation sub-structure, grain elongation and formation of strain induced alpha dash-martensite. The presence of ferromagnetic alpha dash-martensite phase has been confirmed using eddy current method. This paper discusses the NLU technique, its application to characterize the cold rolled microstructures and its comparison with other possible methods including hardness.

Nonlinear Characterization of Friction Stir Weld Joints

---A. Sanford, Jr., M. Pedrick, C. Domack, and **M. J. McKenna**, Luna Innovations Incorporated, Hampton VA 23666; Dawn M. Sabados and Gary Workman, University of Alabama, Huntsville, AL 35801; Donald Reiss and Michael Suits, NASA Marshall Space Flight Center, Huntsville AL 35801

---Friction Stir Welding (FSW) is a key technology element of NASA's Constellation Program to develop the next generation of launch and manned exploration vehicles. FSW is also already used in fabrication of the Space Shuttle external fuel tank and components of Delta launch vehicles. In partnership with the Marshall Space Flight Center, Luna Innovations Incorporated (Luna) and its academic partners at the University of Alabama – Huntsville (UAH) extended the application of technology originally developed for the U. S. Army to provide high resolution, phase-sensitive ultrasonic materials characterization on FSW joints. During a STTR Phase I, Luna acquired extremely promising data on FSW specimens using a nonlinear measurement technique previously demonstrated to be sensitive to microstructural changes and residual stresses in conventional welds. The technique was successfully demonstrated in the Phase I project on samples made from aluminum-lithium alloy 2195 to see defects from lack-of-penetration and kissing bonds. High-resolution ultrasonic C-scans of the FSW joints provided an initial basis for comparison of the nonlinear results. This work was done in conjunction with computer-aided numerical modeling and simulation including finite element analysis, and specimen testing using conventional nondestructive inspection techniques by UAH.

A Perturbation Approach to Treat Nonlinear Hysteretic Damage in Finite Structures

---**Daniel. A. Mendelsohn**[1] and Claudio Pecorari[2], [1]The Ohio State University, Department of Mechanical Engineering, Columbus, OH 43210; [2]ÅF, Ågatan 40, 582 22 Linköping, Sweden

---Nonlinearities with hysteresis due to localized damage may enter the mathematical description of the dynamics of a material system via suitable boundary conditions (BC). If the material system has no characteristic dimension, a standard perturbation approach in a small parameter measuring the magnitude of the nonlinearity works and the first order correction comprises a family of higher order harmonics not present in the case of "classical" nonlinearities. If the material system has finite length, such an approach fails because it does not describe the expected shift of any of the resonant frequencies. nor the existence of an infinite set of harmonics for each resonant frequency. We present an alternative approach, in the context of a vibrating beam with nonlinear, hysteretic spring BCs for an infinitesimally thin damaged region (plane) of reduced stiffness. The key parameters are the slope of the linear unloading, the initial and final slopes of the quadratic reloading phase, and the size of the hysteresis loop. For each resonant mode of the linear problem a Fourier expansion of the nonlinear free-vibration solution and harmonic balancing leads to a shifted fundamental and a series of higher harmonics at all multiples of the shifted and complex fundamental frequency.

On the Observation of Acousto-Elastic Hysteresis in Kinking Nonlinear Elastic Solids

---P. Finkel, A. Zhou, S. Basu, **O.Yeheskel***, and M. Barsoum, Drexel University, 3141 Chestnut Street, Philadelphia, PA 19104; *NRCN

---Using bulk acoustic waves we studied nonlinear mechanical properties and hysteresis of acousto-elastic effect in kinking nonlinear solids. Kinking non-linear elastic solids are a newly identified but ubiquitous class of solids so called because their mechanical response is non-linear and hysteretic. This behavior is a result of the formation of fully reversible, dislocation-based kink bands upon loading and their spontaneous disappearance upon unloading. Herein, for the first time, we show direct nonlinear hysteretic scattering and attenuation of ultrasonic waves in representative kinking nonlinear solids (e.g. Co, Ti3SiC2). We attribute this dynamic behavior to interaction of the acoustic waves with dislocation in the kink bands. The relevance of these findings to possible sensor applications of hysteretic nonlinear elastic solids is briefly discussed.

Parametric Resonance for Materials Characterization

---**Laszlo Adler** and Stanislav Rokhlin, Ohio State University, Department of Industrial, Welding and Systems Engineering, Columbus, OH 43085

---While studying finite amplitude ultrasonic wave resonance in a one dimensional liquid filled cavity, formed by a narrow band transducer and a plane reflector, fractional harmonics of the driver's frequency were observed (1,2) in addition to the expected high harmonics. Subsequently it was realized that the system was one of the many examples where parametric resonance takes place and the observed fractional harmonics are parametrically generated. Parametric resonance occurs in any physical system which has a periodically modulated natural frequency. The generation mechanism also requires a sufficiently high threshold value of the driving amplitude and the system becomes nonlinear. Further increase of the driving amplitude above the threshold produces additional fractional harmonics and at a certain value an almost continuous spectrum is produced and the phenomenon becomes chaotic. An overview of selected parametric resonance systems will be presented. Our recently developed (3) frequency modulated angle beam ultrasonic method for adhesive bond evaluation is an additional example of the use of a resonance parametric system. The acoustic resonator is formed by an adhesive layer with the resonance frequency affected by the bond quality between the adhesive and the substrates. In this case the interfacial stresses (due to an external low frequency excitation) may or may not produce parametric shift of the resonance depending on the quality of the interfacial bond.---This work supported by NASA .

Wide Band Time Reversal Acoustic Nonlinear Diagnostics

---**Alexander Sutin**, Stevens Institute of Technology, Hoboken, NJ 07030; Timothy J. Ulrich, James A. Tencate, and Paul A. Johnson, Los Alamos National Laboratory, EES-11 (Geophysics) , Los Alamos, NM 87544

---Time reversal acoustics (TRA) techniques provide a means to focus energy at a localized spatial location with amplitudes sufficient to induce measurable nonlinear effects in regions where defects and does so over a wide frequency band. Due to spatial focusing, time reversal enables local probing of the feature nonlinearity. The nonlinear feature is imaged by two methods: 1) the phase-inversion method whereby combining two signals of opposite sign cancel the linear response; and 2) the varied amplitude method based on measurement of the tested part response with low [elastically linear] and high [elastically nonlinear] amplitudes of excitation, followed by subtraction of the normalized signals. The procedure leaves the nonlinear response for any kind of nonlinearity. The methods work well for nonlinear NDE of thin plates where a non-contact laser Doppler Vibrometer can be used for measuring the surface vibration induced by TRA wave-focusing. We present results that include crack and delamination diagnostics in epoxy graphite composites, diffusion bonded metallic disks and impact surface damage in glass. Scanning electron microscopy and optical images are also shown to illustrate the types of damage features detected using these methods. This work supported by Institutional Support (LDRD) at Los Alamos.

Session 23

SESSION 23

CIVIL MATERIALS & INFRASTRUCTURE

H. Sabbagh, Chairperson
Meeting Room G

1:30 PM **Using Air-Coupled Sensors to Evaluate Depth of a Surface-Breaking Crack in Concrete**
---S.-H. Kee and **J. Zhu**, The University of Texas, Department of Civil, Architectural, and Environmental Engineering, 1 University Station, C1748, Austin, TX 78712-0273

1:50 PM **Characterization of Concrete Delamination Defects Using the Impact-Echo Method**
---J. S. Popovics, S.-W. Shin, and **T. Oh**, University of Illinois, Department of Civil & Environmental Engineering, 205 N. Mathews St., MC-250, Urbana, IL 61801

2:10 PM **Effects of Solar Loading on Thermographic Imaging of Subsurface Defects in Concrete**
---**G. Washer**, R. Fenwick, and N. Bolleni, University of Missouri – Columbia, Civil & Environmental Engineering Department, Columbia, MO 65211; J. Harper, Missouri Department of Transportation, Jefferson City, MO 65101

2:30 PM **An Adaptive Frequency Domain Finite Element Model for Surface Wave Testing of Pavements**
---**N. Ryden**, Lund University, Engineering Geology, Faculty of Engineering, Sweden; M. Castaings, Laboratoire de Mécanique Physique, Université Bordeaux 1, France

2:50 PM **Developments in Magnetic Sensing for Corrosion Monitoring of Metals**
---**G. E. Gallo** and J. S. Popovics, University of Illinois, Department of Civil & Environmental Engineering, Urbana, IL 61801; P. L. Chapman and M. D. Johnson, University of Illinois, Department of Electrical & Computer Engineering, Urbana, IL 61801

3:10 PM ***Break***

3:30 PM **Capacitive Probe for Nondestructive Inspection of External Post-Tensioned Ducts**
---**F. Taillade**, Laboratoire Central des Ponts et Chaussées, Metrology Instrumentation Division, 58 bid Lefebvre, 75732 Paris, Cedex 15, France

3:50 PM **Characterization of Microstructure in Cement Paste Using Backscattered Diffuse Ultrasound**
---**M. Goueygou**, Institute of Electronics, Microelectronics and Nanotechnology, IEMN UMR CNRS 8520, Villeneuve d'Ascq, France; J. Popovics and K. Hall, UIUC, Department of Civil Engineering, Urbana, IL 61801; M. Oelze, UIUC, Department of ECE, Urbana, IL 61801

4:10 PM **Evaluation of MASW Data Testing Configuration for Analysis of Asphalt Pavements**
---**S. P. Alzate-Diaz** and J. S. Popovics, The University of Illinois, Civil & Environmental Engineering, 205 N. Mathews St., MC-250, Urbana, IL 61801

4:30 PM **Mode Conversion of SH Guided Waves at Defects for Pipeline Inspection**
---**S. A. Uribe**, N. Nakamura, H. Ogi, and M. Hirao, Osaka University, Graduate School of Engineering Science, Toyonaka, Osaka 560-8531, Japan

4:50 PM **Microwave Characterization of Typical Australian Wood-Based Biomass Materials**
---**S. Ramasamy** and B. Moghtaderi, The University of Newcastle, Department of Chemical Engineering, Priority Research Centre for Energy, Callghan, Newcastle, Newsouthwales 2308, Australia

Using Air-Coupled Sensors to Evaluate Depth of a Surface-Breaking Crack in Concrete

---Seong-Hoon Kee and **Jinying Zhu**, The University of Texas, Department of Civil, Architectural, and Environmental Engineering, 1 University Station, C1748, Austin, Texas 78712-0273

---Previous studies show that surface wave transmission ratio across a surface breaking crack in concrete can be used as an indicator of the crack depth. However, due to inconsistent sensor coupling condition on rough concrete surface, reliable measurement of the transmission ratio is still a challenging task. In this study, the air-coupled sensing method is proposed as a solution to this problem. Without direct contact between sensors and the testing surface, the air-coupled sensing not only allows rapid testing speed, but also enables more consistent signal measurement owing to removal of sensor coupling variation. The latter feature is especially valuable to wave transmission measurement. This paper first presents results from a numerical analysis (FEM model). Based on the results, a simplified algorithm is proposed for surface wave transmission ratio calculation. A calibration curve between the transmission ratio and normalized crack depth (actual crack depth/wavelength) is obtained. Experimental study using the air-coupled sensing method verifies the validity of the curve.

Characterization of Concrete Delamination Defects Using the Impact-Echo Method

---John S. Popovics, Sung-woo Shin, and **Taekeun Oh**, University of Illinois, Department of Civil & Environmental Engineering, 205 N. Mathews St., MC-250, Urbana, IL 61801

---A persistent problem for reinforced concrete bridge structures is deterioration owing to steel reinforcement corrosion. In particular, the corrosion of steel in bridge decks is problematic, and often leads to high repair costs and loss of service of the structure. The deck damage is manifested as a large area near-surface delamination, which is usually filled with air. The impact-echo method has been shown to be effective in locating the delamination defects, although the method cannot provide complete information about the defect. In this paper, the behavior of delamination defects when tested by the impact-echo method is examined. Experimental and numerical (FEM) simulations are presented to illustrate the effects of varying defect geometry and depth, and position, with respect to that of the defect, of the source and receiver. The results confirm that flaw geometry and position of the receiver are important factors in controlling the impact-echo response. Suggestions to incorporate the findings toward the development of a contact-less impact-echo scanning system are finally presented.

Effects of Solar Loading on Thermographic Imaging of Subsurface Defects in Concrete

---**Glenn Washer**, Richard Fenwick, and Naveen Bolleni, University of Missouri - Columbia, Civil & Environmental Engineering Department, Columbia, MO 65211; Jennifer Harper, Missouri Department of Transportation, Jefferson City, MO 65101

---The detection of subsurface defects in concrete using infrared cameras relies on thermal variations in the ambient environment to provide heat flow. Solar loading can provide significant thermal energy that enables the imaging of subsurface defects. This paper presents results of a study to determine the optimum environmental conditions for conducting thermal inspection of concrete bridges. This study has included continuous monitoring of a large concrete specimen under ambient environmental condition in central Missouri. The thermal contrast of subsurface targets in the specimen has been analyzed to determine the optimum conditions and time for detection of subsurface features as a function of depth. Environmental conditions that result in the largest contrast in surface temperature are discussed.

An Adaptive Frequency Domain Finite Element Model for Surface Wave Testing of Pavements

---**Nils Ryden**, Lund University, Engineering Geology, Faculty of Engineering, Sweden; Michel Castaings, Laboratoire de Mécanique Physique, Université Bordeaux 1, France

---Surface wave testing of pavements is a promising non-destructive technique for obtaining both the thickness and the stiffness of all layers in a pavement construction. A simplified theoretical 1D layered model is often used for the inversion of measured dispersion curves. Due to the large velocity contrast between layers and wide frequency range utilized finite element simulations of surface wave testing of pavements can be computationally demanding and therefore challenging to use during the iterative inversion procedure. We have developed an efficient frequency domain 2D finite element model based on an adaptive mesh and size of absorbing boundaries. The viscoelastic properties of the asphalt layer are modelled using a complex modulus to account for frequency dependent stiffness and damping properties of the asphalt material. Results from the model are verified by comparing phase velocities and attenuation due to leakage to normal mode dispersion curves. Experimental data is used to demonstrate the efficiency of the developed model for a joint inversion of phase velocities, damping, and resonant properties of guided waves in a pavement construction. In addition the proposed model can be used to further optimize measurements and quantify the effect of different potential defects in surface wave testing of pavements.

Developments in Magnetic Sensing for Corrosion Monitoring of Metals

---**Gonzalo E. Gallo** and John S. Popovics, University of Illinois, Department of Civil & Environmental Engineering, Urbana, IL 61801; Patrick L. Chapman and Melanie D. Johnson, University of Illinois, Department of Electrical & Computer Engineering, Urbana, IL 61801

---Reinforcement corrosion is a serious problem for the civil infrastructure, thus creating a need for efficient sensing techniques to determine corrosion extent and rate in situ. Recent efforts to apply giant magneto-resistive response (GMR) magnetometers and eddy current sensors for corrosion sensing are described. These methods overcome some difficulties faced by traditional NDE and sensing techniques for corrosion, especially since no physical or electrical contact with the corroding metal is required. An active testing configuration that monitors corrosion activity remotely in aluminum samples is explored. These results serve as the basis for further developments for non-contact corrosion magnetic sensing, and future developments for this technology are finally proposed.

Capacitive Probe for Nondestructive Inspection of External Post-Tensioned Ducts

---**Frédéric Taillade**, Laboratoire Central des Ponts et Chaussées, Metrology Instrumentation Division, 58 bid Lefebvre, 75732 Paris, Cedex 15, France

---The paper presents an analysis of the capabilities and characteristics of the capacitive sensor used to evaluate the injection in the external post-tensioned ducts. Numerical simulations, based on an analytical model and a finite element calculus, give the sensitivity of the capacitive sensor. The sensitivity depends of the materials enclosed into duct: void, white paste (no hardened grout with a high water content), cement grout, water and of the investigation area. This analysis shows that the capacitive sensor can detect easily some defects as void, white paste. Measurements on the laboratory specimen (with known defects) are in good agreement with the results of the numerical simulations. In situ investigation on a bridge in France shows examples of detection of voids and white paste with the capacitive sensor, which were confirmed by the opening of the duct.

Characterization of Microstructure in Cement Paste Using Backscattered Diffuse Ultrasound

---**M. Goueygou**, Institute of Electronics, Microelectronics and Nanotechnology, IEMN UMR CNRS 8520, Villeneuve d'Ascq, France; J. Popovics and K. Hall, UIUC, Department of Civil Engineering, Urbana, IL 61801; M. Oelze, UIUC, Department of ECE, Urbana, IL 61801

---In heterogeneous media, ultrasonic waves become progressively incoherent as the propagation path increases and the response of the medium is made essentially of structure noise. Although this noise appears random, it carries some information about the medium. The quantitative ultrasound technique (QUS) in medical imaging is based on the assumption that the incoherent response results from single scattering from a large number of uncorrelated, identical scatterers. As a result, the backscattered energy can be related to parameters of the microstructure , namely the average scatterer size and the acoustic concentration. In this paper, the QUS technique is applied to characterize voids in cement paste. In cement-based materials, voids consist of capillary pores, air bubbles and cracks with a wide range of sizes, from a few nanometers to a few hundreds of micrometers. The geometry and connectivity of these voids is important to predict concrete durability. Experiments are conducted on two series of cement paste samples: a pair of regular samples with two levels of capillary porosity and a pair of air-entrained samples with two concentrations of air bubbles. The samples are placed in a water tank and scanned at 5MHz in pulse-echo mode. Velocity, attenuation, transmission coefficient and backscattering cross section are measured. Then, a Gaussian model is used to estimate the parameters of the microstructure from the back-scattered energy. Finally, the microstructure is analyzed from digital images of sample cuts. In the air-entrained samples, the mean scatterer size is correctly estimated and a clear difference in the acoustic concentration is observed in both samples, although this difference is higher than expected. In regular cement paste, the ultrasonically estimated scatterer size is too high to correspond to capillary pores. In this case, the scattered energy may originate from clumps of flocculated cement paste.

Evaluation of MASW Data Testing Configuration for Analysis of Asphalt Pavements

---**Sara P. Alzate-Diaz** and John S. Popovics, The University of Illinois, Civil & Environmental Engineering, 205 N. Mathews St., MC-250, Urbana, IL 61801

---The development of multi-channel surface waves (MASW) analysis in recent years is promising for accurate non-destructive characterization of asphalt (HMA) pavements. However, it is known that result accuracy depends on data acquisition parameters, optimum number of signal traces, and the range of Poisson's ratio evaluated. Although MASW analyses normally assume elastic material behavior, HMA pavements exhibit noted temperature dependency and visco-elastic response. This paper investigates the application of MASW to pavements in order to characterize the effects of testing configuration, material temperature and pavement structure on the results. Experimental results from full-scale composite section and a full-depth HMA pavements are reported for a wide range of material temperatures. The results show that these parameters affect MASW response behavior, and this data interpretation and accuracy.

Mode Conversion of SH Guided Waves at Defects for Pipeline Inspection

---**Silvina A. Uribe**, Nobutomo Nakamura, Hirotsugu Ogi, and Masahiko Hirao, Osaka University, Graduate School of Engineering Science, Toyonaka, Osaka 560-8531, Japan

---Pipeline systems are largely founded in the industry and the detection of material wear caused mainly by corrosion remains an important topic for the nondestructive evaluation area. At present, the inspection by EMATs is based on amplitude changes in the received waves reflected at defects. In order to develop a more accurate method for pipeline inspection, the group velocities of shear-horizontal (SH) guided wave propagating in a plate were studied. The group velocity of SH modes highly depends on the plate thickness, and there exists the cut-off-thickness, bellow which the corresponding mode cannot propagate. Therefore, when the SH wave impinges an affected area the time of propagation will change depending upon the depth and the length of the flaw. Because of the thickness change in the material, mode conversion also occurs. It was indeed observed that the travelling time of the SH-wave mode varies with the depth of the defects, and when the thickness becomes thinner than the cut-off-thickness, it suddenly decreases because of the mode conversion from higher SH mode to a lower one. This result indicates that it is plausible to evaluate the material wear by this method.

Microwave Characterization of Typical Australian Wood-Based Biomass Materials

---**Shanmuganathan Ramasamy** and Behdad Moghtaderi, The University of Newcastle, Department of Chemical Engineering, Priority Research Centre for Energy, Callghan, Newcastle, Newsouthwales 2308, Australia

---Many application of microwave energy to wooden materials require a reliable estimation of permittivity, which is the physical parameter of crucial importance in the absorption of electromagnetic energy. Wood-based biomass materials are of significant importance in a number of application areas particularly in: (i) power generation, (ii) fire safety, and (iii) manufacturing. In the present study the dielectric measurements were carried out for typical Australian wood species like slash pine (Pinus elliottii), a soft wood, and spotted gum (Eucalyptus maculata), a hard wood, based on Von Hippel's transmission line method. The influence of extractive removal is also studied and compared with the virgin wood samples. Measurements were performed at 9.5 GHz for virgin wood samples and extractive-free wood samples. Experiments were carried out at room temperatures ranging from 28-32□ C and atmospheric pressure. The dielectric properties of wood species were determined for three principle structural directions (i.e. longitudinal, tangential and radial) and different moisture contents. Moisture content varied from 0% to 15% for virgin wood samples and from 3 – 6.6 % for extractive-free wood samples at atmospheric equilibrium condition. Results indicated that for both wood species the dielectric constant was affected by moisture content, structural direction and density. The dielectric properties of both wood species were found to be quantitatively similar. In general, for virgin wood sample the dielectric constant was found to increase with moisture content and density whereas a similar trend is obtained at higher moisture content for extractive-free wood sample. The values of dielectric constant in the longitudinal direction were generally higher than those in the transverse direction for both types of wood species.

Session 24

SESSION 24
SPECIAL EVENING SESSION
J. Popovics, Chairperson
Meeting Room F

8:00 PM International Needs for Infrastructure NDE

The Aging of Infrastructure is a world wide problem of increasing importance, with the specifics varying from region to region depending on the age and nature of critical structures. It is clear that the NDE and SHM tools being developed by the QNDE community can play an important role in addressing the Aging Infrastructure problem, and the special evening session is designed to provide perspective to the developers of that technology through an overview of the international needs. A panel of speakers with experience with the unique situations in different regions of the world will first make a series of short presentations. This will be followed by a general discussion period.

THURSDAY

THURSDAY, JULY 24, 2008

	Session 25 **Ultrasonic Phased Arrays I** ***Meeting Room D***	**Session 26** **Structural Health Monitoring I** ***Meeting Room E***	**Session 27** **Model-Based Inversion** ***Meeting Room F***	**Session 28** **NDE for Materials Deformation** ***Meeting Room G***
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 – MAIN HALL C

	Session 30 **Structural Health Monitoring II** ***Meeting Room F***	**Session 31** **Ultrasonic Phased Arrays II** ***Meeting Room D***	**Session 32** **NDE for Engineered Materials** ***Meeting Room G***	**Session 33** **Visualization Techniques** ***Meeting Room E***
3:10	COFFEE BREAK			
3:30				
3:50				
4:10				
4:30				
4:50				
5:10				
5:30	ADJOURN			

Session 25

SESSION 25
ULTRASONIC PHASED ARRAYS I
Bob Addison, Chairperson
Meeting Room D

8:30 AM **Improvements in Phased-Array Technologies**
---**P. Dumas**, Imasonic SAS, ZA rue des Savourots, 70190 Voray-sur-l'Ognon, France; G. A. Neau, Bercli, LLC, 2813 Seventh Street, Berkeley, CA 94710

8:50 AM **Development of an Efficient, Conformable Array Structure**
---**J. W. Mackersie** and A. Gachagan, University of Strathclyde, Centre for Ultrasonic Engineering, Department of Electronic and Electrical Engineering, Glasgow, United Kingdom; G. Harvey, Rolls-Royce plc, Aero Repair and Overhaul, East Kilbride, United Kingdom

9:10 AM **Inspection of Components with Irregular Surfaces Using a Comformable Ultrasonic Phased Array**
---**J. Russell**, R. Long, and P. Cawley, Imperial College, Mechanical Engineering, London, United Kingdom; N. Habgood, Rolls-Royce pic, Derby, United Kingdom

9:30 AM **Maximum Contrast Autofocus – Ultrasonic Imaging Using a Flexible Array**
---**A. J. Hunter**, B. W. Drinkwater, and P. D. Wilcox, University of Bristol, Department of Mechanical Engineering, Queens Building, University Walk, Bristol, BS8 1TR, United Kingdom

9:50 AM **Flexible Arrays for the Ultrasonic Inspection of Complex Parts**
---G. Toullelan, A. Nadim, **O. Casula**, and P. Dumas, CEA LIST, Centre de Saclay, F-91191 Gif sur Yvette, France

10:10 AM ***Break***

10:30 AM **Strain Mapping in Metals Using Ultrasonic Array Speckle Images**
---**A. I. Bowler**, B. W. Drinkwater, and P. D. Wilcox, University of Bristol, Department of Mechanical Engineering, Bristol, England, United Kingdom

10:50 AM **Design of Curved Annular Arrays for High-Frequency Imaging**
---**E. Kuehnicke**, Technische Universitaet Dresden, Fakultaet Elektrotechnik, Institut fuer Festkoerperelektronik (IFE), D-01062 Dresden, Germany

11:10 AM **Selectivity Enhancement of Subharmonic Phased Array for Crack Evaluation (SPACE)**
---K. Yamanaka and **Y. Ohara**, Tohoku University, Department of Materials Processing, Sendai, Miyagi, Japan

11:30 AM **Ultrasonic Phased Array Tools for Large Area Composite Inspection During Maintenance and Manufacturing**
---**J. Habermehl** and A. Lamaare, Olympus NDT, Quebec City, Canada; D. Roach, Sandia National Labs, Albuquerque, NM 87101

11:50 AM **Welding Process Feedback and Inspection Optimization Using Ultrasonic Phased Arrays**
---**D. L. Hopkins** and W. B. Davis, Lawrence Berkeley National Laboratory, Berkeley, CA 94703; G. A. Neau, Bercli, LLC, Berkeley, CA 94703

12:10 PM ***Lunch***

Improvements in Phased-Array Technologies
---**Philippe Dumas**, Imasonic SAS, ZA rue des Savourots, 70190 Voray-sur-l'Ognon, France; Guillaume A. Neau, Bercli, LLC, 2813 Seventh Street, Berkeley, CA 94710

---Reduction of production and maintenance costs is an economic necessity in a large number of industrial sectors, making development of fast and reliable inspection solutions a major thrust for the NDT community. First used for medical applications, phased-array technology is now used extensively in industry, providing tremendous improvements in resolution while reducing inspection times. However, the restriction in the number of active channels that can be used simultaneously has been a limitation for many applications. New architectures in phased-array systems have been developed to overcome this limitation. Full-parallel phased-array systems allow a large number of channels to be used at the same time. Inspections requiring several large arrays to be used simultaneously are now possible, as are inspections requiring focusing using a large number of elements. On the probe side, new generations of matrix and conformable arrays have been developed. Matrix probes are used to steer and focus the ultrasonic beam in three dimensions. Conformable arrays are used for coupling to irregular surfaces. Technical advances in phased arrays and probes are described, along with new manufacturing methodologies for probes. Examples are presented where these technologies have been successfully used to reduce inspection time or to inspect what were previously blind zones.

Development of an Efficient, Conformable Array Structure
---**John W. Mackersie** and Anthony Gachagan, University of Strathclyde, Centre for Ultrasonic Engineering, Department of Electronic and Electrical Engineering, Glasgow, United Kingdom; Gerald Harvey, Rolls-Royce plc, Aero Repair and Overhaul, East Kilbride, United Kingdom

---The inspection of non-planar surfaces encountered in NDT poses difficulties that can only be satisfactorily addressed by a transducer whose active surface is comprised of an efficient conformable piezoelectric material. This paper describes a novel composite 2D array structure in which each element is a fine-scale array of piezoceramic fibers in a random orientation. Device flexibility is imparted by the relatively soft flexible polymer phase which separates the elements. A comprehensive modelling program, using the finite element package PZFlex, has produced the resulting structure which is termed a Composite Element Composite Array Transducer or CECAT. To facilitate the initial characterization of the devices, the primary investigations have implemented the transducers as 1D arrays by the application of appropriate electrode patterns. However, the 2D physical arrangement gives the material excellent conformability over surfaces with two axes of curvature, e.g. an elbow or the root of a welded nozzle. Experimental measurements of electrical impedance and surface displacement are presented which demonstrate the high sensitivity of the devices. In addition, pulse-echo tests show comparable performance to a commercial rigid, 2MHz transducer when operated into a steel test sample.

Inspection of Components with Irregular Surfaces Using a Conformable Ultrasonic Phased Array

---**Jonathan Russell**, Robert Long, and Peter Cawley, Imperial College, Mechanical Engineering, London, United Kingdom; Noel Habgood, Rolls-Royce pic, Derby, United Kingdom

---A conformable phased array device has been developed for the inspection of components with irregular surface geometry. This low-cost device uses a standard phased array coupled to the pipework surface via a fluid-filled, low-loss membrane. A single device is used for surface measurement and inspection, allowing rapid scanning of components with irregular surfaces without the need for multiple angled probes and time consuming mechanical scanning. A comparison of experimental and simulated results obtained using conventional ultrasonic techniques and the conformable phased array device around the weld region of welded pipes is given. These results demonstrate a number of potential improvements that are achievable when using the conformable phased array device.

Maximum Contrast Autofocus – Ultrasonic Imaging Using a Flexible Array

---**Alan J. Hunter**, Bruce W. Drinkwater, and Paul D. Wilcox, University of Bristol, Department of Mechanical Engineering, Queens Building, University Walk, Bristol, BS8 1TR, United Kingdom

---This paper considers the autofocus problem for non-destructive testing and evaluation of specimens with complicated geometries using conformable ultrasonic arrays. We present an algorithm for autofocusing imagery obtained from a flexible array with unknown geometry. The relative positions of the array elements are parameterized using a cubic spline function and the spline control points are estimated by iterative maximization of an image contrast metric via simulated annealing. The resultant spline gives an estimate of the array geometry and the profile of the surface that it has conformed to, allowing the generation of a well-focused, high quality image. The algorithm is demonstrated on experimental data obtained using a flexible array prototype.

Flexible Arrays for the Ultrasonic Inspection of Complex Parts

---Gwenael Toullelan, Arnaud Nadim, **Olivier Casula**, and Philippe Dumas, CEA LIST, Centre de Saclay, F-91191 Gif sur Yvette, France

---Due to the varying geometry of the inspected parts (elbow, nozzles, butt weld…), mismatch between the part and the wedge may appear during the scanning of conventional probes. Consequently, the transmitted field is more or less disturbed and can lead to wrong flaw localization and characterization. Since several years flexible arrays are developed at CEA LIST and constitute a powerful solution to overcome these problems. The array is composed of piezoelectric elements moulded into a disk of flexible resin. The design of the elements arrangement is designed by using the simulation software CIVA. In operation, an embedded instrumentation measures in real time the position of the elements of the array. From this data, the acquisition system calculates in real time the delay laws which are applied to the elements and which compensate the variations of the encountered surface. Finally, the CIVA data reconstruction functionalities can be applied to display acquisition data in the 3D geometry. In this communication we present recent developments on this technique and show examples of applications. In particular results are shown on industrial inspections of complex 3D mock-ups using the 3D flexible array piloted by a robot.

Strain Mapping in Metals Using Ultrasonic Array Speckle Images

---**Adam I. Bowler**, Bruce W. Drinkwater, and Paul D. Wilcox, University of Bristol, Department of Mechanical Engineering, Bristol, England, United Kingdom

---The full-field non-destructive measurement of internal displacement and strain fields is of interest in many engineering applications. This paper describes an approach to measuring internal displacements and strains in metals which uses the correlation of ultrasonic speckle images of the internal structure of the material. This has the key advantage over optical surface displacement and strain measurement techniques in that internal information can be obtained. Experiments are described which use a 1-D ultrasonic array to map 2-D displacement fields for uniform translation and uniaxial compression of a metallic bar. The full matrix of transmit-receive signals from the array was post-processed to generate speckle images using a Fourier-domain imaging algorithm. Block-search cross-correlation was used to find the displacements of small sub-images corresponding to regions within the bar. Potential applications include characterizing crack networks and creep damage detection.

Design of Curved Annular Arrays for High – Frequency Imaging

---**Elfgard Kuehnicke**, Technische Universitaet Dresden, Fakultaet Elektrotechnik, Institut fuer Festkoerperelektronik (IFE), D-01062 Dresden, Germany

---For ultrasound microscopy in NDT, the design and performance of high-frequency curved annular arrays are discussed. To optimize the curvature, element size, sparse and controlling of the array, an approach was developed. It enables sound field simulations of single-element transducers in complex structures. The field of a complete array is the superposition of the delayed fields of all elements. The time harmonic field is used for optimization, whereas the transient field is calculated for evaluation, only. The simulations yield the following results for a fluid medium: In comparison to a plane sparse annular array, a curved array produces a shorter focal distance and a higher lateral resolution. For instance, the focal depth of a 35MHz-curved array with only 10 elements, an aperture of 5mm and a curvature radius of 5mm can be varied between 4 to 14mm with a lateral resolution of up to 60 microns (-6dB-beamwidth). A 35MHz array with an aperture of 5mm should also be applicable for testing solid structures by immersions technique. The calculations show that a curved array with 20 elements is necessary to realize a -6dB zone of 110 to 160 microns for a 0 to 2mm imaging depth in a steel object.

Selectivity Enhancement of Subharmonic Phased Array for Crack Evaluation (SPACE)

---Kazushi Yamanaka and **Yoshikazu Ohara**, 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 visualizing open and closed parts. Thus far, SPACE has used short tone burst as an input wave to achieve high temporal resolution. However, since the input wave has a broadband spectrum, the subharmonic frequency components of a linear scattering signal when stronger than those of a nonlinear signal may be leaked into subharmonic images, degrading the selectivity. To enhance the selectivity we propose a novel phased array algorithm using a long tone burst with a narrowband spectrum. Here, the image of a scatterer is elongated towards the direction opposite to the center of a receiving array (RA). The inclination angle can be changed by changing the position of the RA. Since the invariant part of the images obtained with different RA positions is only the position of the scatterer, it should give a true scatterer image with an improved temporal resolution. In this study, we show a simple implementation of this algorithm, a multiplication of images with different RA positions, by numerical simulation and experiment.

Ultrasonic Phased Array Tools for Large Area Composite Inspection During Maintenance and Manufacturing

---**Jason Habermehl** and Andre Lamarre, Olympus NDT, Quebec City, Canada; Dennis Roach, Sandia National Labs, Albuquerque, NM

---Aircraft manufacturers, maintenance service providers, and airline operators have recently started to use the ultrasonic phased-array technology to ensure the quality of their composite parts during maintenance and manufacturing. Olympus NDT has developed various solutions with its phased-array instruments like the OmniScan PA and the Focus LT to meet the most demanding requirements. Phased-array probes and holders were specifically designed for the inspection of composite flat panels and corners. These tools combined with composite specific software features provide greater productivity with respect to scanning and defect characterization such as sizing while maintaining a high degree of reliability. This paper summarizes the advantages and the benefits obtained by the use of this technology on samples provided by Sandia National Labs.

Welding Process Feedback and Inspection Optimization Using Ultrasonic Phased Arrays

---**Deborah L. Hopkins** and William B. Davis, Lawrence Berkeley National Laboratory, Berkeley, CA 94703; Guillaume A. Neau, Bercli, LLC, Berkeley, CA 94703

---Previous work has demonstrated the ability to use ultrasonic phased arrays to provide high-resolution images of the welding interface for resistance spot welds in galvanized steel. For high-volume manufacturing applications including automotive, the business case for NDT is greatly improved if reliable process-feedback data can be derived in conjunction with go/no-go inspection results. Examples presented here show how data extracted from the ultrasonic signals can be used to provide process feedback on the wear and alignment of the welding electrodes; map surface conditions including the depth, size and shape of the indentations; and detect distortion of the sheet metal, which is indicative of over welding and/or poor fitup between parts. Analysis of the welding interface identifies expulsion, voids and cracks in the weld nugget, and conditions associated with burnt welds. In addition to measurements on production parts, modeling results are used to demonstrate how weld inspections can be optimized using beam forming strategies that help overcome the influence of surface conditions and part distortion. For example, how focal laws can be adapted to maintain the focal spot at the desired position when there are changes in thickness, and how to avoid beam splitting that occurs at the edges of indentations.

Session 26

SESSION 26
STRUCTURAL HEALTH MONITORING I
S. Krishnaswamy, Chairperson
Meeting Room E

8:30 AM **Acoustic Techniques for Structural Health Monitoring of Wind Turbine Rotor Blades**
---B. Frankenstein, L. Schubert, F. Schubert, J. Augustin, and **N. Meyendorf**, Fraunhofer IZFP-D, Dresden, Germany

8:50 AM **Post-Earthquake Performance Monitoring of a Typical Highway Overpass Bridge**
---A. Iranmanesh, S. A. Bassam, and **F. Ansari**, University of Illinois at Chicago, Chicago, IL 60680-7994

9:10 AM **Quantification of SHM Sensor Array Performance**
---**A. J. Croxford**, P. D. Wilcox, and B. W. Drinkwater, University of Bristol, Department of Mechanical Engineering, Bristol, United Kingdom

9:30 AM **Analysis of Global Ultrasonic Sensor Data from a Full Scale Wing Panel Test**
---**J. E. Michaels**, R. Martin, and T. E. Michaels, Georgia Institute of Technology, School of Electrical and Computer Engineering, Atlanta, GA 30332-0250

9:50 AM **Evaluation of a Strategy to Minimize Temperature Effects During Sparse-Array Guided Wave SHM of Real Complex Structures**
---**T. Clarke**, F. Simonetti, and P. Cawley, Imperial College, 682 Mechanical Engineering, Imperial College, Exhibition Road, London SW7 2AZ, United Kingdom

10:10 AM ***Break***

10:30 AM **Self Calibrated STMR Array for Material Characterization and SHM of Orthotropic Plates**
---**J. Vishnuvardhan**, A. Muralidharan, C. V. Krishnamurthy, and K. Balasubramaniam, Center for Nondestructive Evaluation and Department of Mechanical Engineering, Indian Institute of Technology Madras, Chennai, India

10:50 AM **Ultrasonic Structural Health Monitoring: A Model-Driven Probablilty of Detection Study**
---**A. C. Cobb**, J. E. Michaels, and T. E. Michaels, Georgia Institute of Technology, School of Electrical and Computer Engineering, Atlanta, GA 30332

11:10 AM **Transition from Guided Wave Based Non-Destructive Testing to Structural Health Monitoring**
---H. Sohn[1,2], S. B. Kim[2], S. J. Lee[2], D. Dutta[2], H. J. Park[1], C. G. Lee[1], A. Agrawal[2], C. M. Yeom[1], S. H. Park[1], and Y. K. Ahn[1], [1]Department of Civil and Environmental Engineering, KAIST, Daejeon, Korea; [2]Department of Civil and Engineering, Carneigie Mellon University, Pittsburgh, PA

11:30 AM **Structural Health Monitoring of Composite Laminates with Embedded Piezoelectric Fibers**
---C. J. Lissenden and P. K. Puthillath, Penn State University, Engineering Science and Mechanics, University Park, PA 16802; J. L. Blackshire, Air Force Research Laboratory, NDE Branch, Wright-Patterson Air Force Base, OH 45433-7817

11:50 AM **Novel Piezoelectric Fiber Transducers for Mode Selective Excitation and Detection of Lamb Waves**
---**B. Koehle**r, B. Frankenstein, F. Schubert, and M. Barth, Fraunhofer IZFP, Dresden Branch, Dresden, Germany

12:10 PM ***Lunch***

Acoustic Techniques for Structural Health Monitoring of Wind Turbine Rotor Blades
---Bernd Frankenstein, Lars Schubert, Frank Schubert, Jörn Augustin, and **Norbert Meyendorf,** Fraunhofer IZFP-D, Dresden, Germany

---Approximately 7% of Germany's electric power consumption is generated by wind turbines. In the next years this amount shall be more than doubled. Approximately 18,000 wind turbines in large wind parks sometimes close to residential areas have to survive extreme mechanical loads, fatigue, and harsh environmental conditions. Damage can result in total loss of a rotor blade or even harm people. Problems will be increasing for offshore systems that are under construction. Safety and reliability of these systems require periodic NDE inspections and for economic reasons a condition based maintenance. In order to specify the rotor blade repair requirements monitoring of the structure integrity by SHM systems is an absolute must. Several solutions for rotor blade monitoring are under consideration for example based on fiber optical techniques. The paper will demonstrate that piezoelectric sensors show several advantages and higher sensitivity for strain and load measurements. Similar sensors are capable of applying periodic acousto ultrasonic inspections and continuous monitoring using acoustic emission. Wireless network nodes have been developed that can be implemented at turbine wings. These systems are especially useful for monitoring of critical locations like glued joints. The performance of the sensor network has been demonstrated during a static load test with a section of a rotor blade. The paper will report how defects that have been generated during the test have been detected and localized in real time during the experiment.

Post-Earthquake Performance Monitoring of a Typical Highway Overpass Bridge
---Amirhossein Iranmanesh, Seyed A. Bassam and **Farhad Ansari**, University of Illinois at Chicago, Chicago, IL 60680-7994

---Bridges form crucial links in the transportation network especially in high seismic risk regions. Severity of global and local structural damage in a bridge determines the ability of a bridge to carry traffic load after an earthquake. This research aims to provide a quantitative methodology for post-earthquake performance monitoring of the bridges. This method can be used immediately after an earthquake to assess the performance and capacity states of a typical highway overpass bridge. To achieve this purpose the results acquired from shaking table tests of a large scale 4-span bridge subjected to progressively increasing amplitudes of seismic motions were analyzed. Development of an efficient monitoring system included high resolution long gauge displacement fiber optic sensors which were designed for post-seismic evaluation of typical concrete highway bridges in seismic zones. A finite element model was developed using Opensees program to simulate the response of the bridge and the abutments. Nonlinear dynamic analyses were conducted using the shaking table and actuator motions during each event of the test. The model was calibrated and modified to predict the bent displacements of the modeled bridge in an acceptable consistence with the measured bent displacements obtained from experimental analysis results. Following each seismic event due to reduction in structural strength, the tangential stiffness matrix of the whole structure is changed. The nonlinear static push over analysis using current damaged stiffness matrix provides the lateral and vertical capacities of the bridge after each event. The global damage measures were computed on the basis of individual bent damage measures. The bridge global damage measure was correlated to the bridge performance and capacity state.

Quantification of SHM Sensor Array Performance

---**Anthony J. Croxford**, Paul D. Wilcox, and Bruce W. Drinkwater, University of Bristol, Department of Mechanical Engineering, Bristol, United Kingdom

---In order to specify the performance of a guided wave structural health monitoring system it is important to have an understanding of the inherent signal to noise ratio that can be expected from any given sensor network. While this has been studied for single pairs of sensors, this has not been carried out where multiple sensor pairs are interacting. This paper quantifies the signal to noise performance of various multiple sensor geometries. This is done through study of both the worst case noise and worst case signal inherent in each of the described geometries. This is then used to draw conclusions about sensor placement, geometry and spacing for practical guided wave shm.

Analysis of Global Ultrasonic Sensor Data from a Full Scale Wing Panel Test

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

---A full scale wing panel fatigue test was undertaken in 2007 as a part of the DARPA Structural Integrity Prognosis System (SIPS) program. Both local and global ultrasonic sensors were installed on the wing panel and data were recorded periodically over a period of about one month. The local ultrasonic sensors interrogated a small number of selected fastener holes, and the global ultrasonic sensors were arranged in a spatially distributed array surrounding an area encompassing multiple fastener holes of interest. The global ultrasonic sensor data is the focus of the work reported here. Waveforms were recorded from all pitch-catch sensor pairs both as a function of static load while fatiguing was paused and dynamically during the fatiguing process. The time windows over which the waveforms were recorded were long enough to include most of the reverberating energy. Partway through the test artificial defects were temporarily introduced by gluing masses onto the surface of the wing panel, and waveforms were recorded immediately before and after. The overall fatigue test was terminated while cracks originating from the fastener holes were still relatively small and before they reached the surface of the wing panel. Both detection and localization results are shown for the artificial damage, and the overall repeatability and stability of the signals are analyzed. Also shown is an analysis of how the reverberating signals change as a function of applied load. The fastener hole fatigue cracks were not detected by the global transducer array, which is not surprising given the final sizes of the cracks as determined by later destructive analysis.

Evaluation of a Strategy to Minimize Temperature Effects During Sparse-Array Guided Wave SHM of Real Complex Structures

---**Thomas Clarke**, Francesco Simonetti, and Peter Cawley, Imperial College, 682 Mechanical Engineering, Imperial College, Exhibition Road, London SW7 2AZ, United Kingdom

---Sparsely distributed sensors generating and receiving guided waves are among the most promising techniques for Structural Health Monitoring. These systems provide good coverage of complex structures with a reduced number of transducers, since certain guided wave modes have the ability to transmit through a variety of structural features and therefore reach long propagation distances. However, the time-traces obtained from such structures are too complex to be directly analyzed due to the presence of overlapping signals from benign reflectors, such as ribs, stiffeners, thickness changes etc. Baseline subtraction eliminates the need for interpretation of raw time signals, but variations in temperature cause changes in the signals, leading to high levels of residual after direct subtraction and consequently poor detectability of defects. A baseline subtraction-based signal processing strategy consisting of the combination of two temperature compensation techniques found in the literature was evaluated on a variety of specimens. This strategy is based on a lookup database of signals taken at environmental conditions commonly faced by the structure; however, an increase in the maximum allowable temperature step between baselines, and hence a reduction in the number of baselines needed to achieve reliable defect detection, is obtained by combining this with a method which compensates for temperature-induced change in wave velocity. The maximum allowable temperature step between baselines is shown to be a function of signal complexity, mode purity and the propagation distance required (expressed in wavelengths of the desired mode). This signal processing strategy was applied to the inspection of real metallic structures with sparse arrays, giving promising results.

Self Calibrated STMR Array for Material Characterization and SHM of Orthotropic Plates

---**J. Vishnuvardhan**, Ajith Muralidharan, C. V. Krishnamurthy, and Krishnan Balasubramaniam, Center for Nondestructive Evaluation and Department of Mechanical Engineering, Indian Institute of Technology Madras, Chennai, India

---A full ring Single Transmitter Multiple Receiver (STMR) array patch had been used for Structural Health Monitoring (SHM) of anisotropic materials where the elastic moduli, correspond to the virgin sample, were used in the calculations. In the present work an in-situ SHM has been successfully demonstrated using a novel compact sensor patch (Double ring single quadrant small footprint STMR array) through simultaneous reconstruction of the elastic moduli, material symmetry, orientation of principal planes and defect imaging. The direct received signals were used to measure Lamb wave velocities, which were used in a slowness based reconstructed algorithm using Genetic Algorithm to reconstruct the elastic moduli, material symmetry and orientation of principal planes. The measured signals along with the reconstructed elastic moduli were used in the phased addition algorithm for imaging the damages present on the structure. To show the applicability of the method, simulations were carried out with the double ring single quadrant STMR array configuration to image defects and are compared with the images obtained using simulation data of the full ring STMR array configuration. The experimental validation has been carried out using 3.15 mm quasi-isotropic graphite-epoxy composite. The double ring single quadrant STMR array has advantages over the full ring STMR array as it can carry out in-situ SHM with limited footprint on the structure.

Ultrasonic Structural Health Monitoring: A Model-Driven Probability of Detection Study

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

---Ultrasonic interrogation of metal alloys has been demonstrated to be effective for monitoring of fatigue-induced damage in a structural health monitoring (SHM) framework. However, traditional probability of detection (POD) approaches as used for nondestructive evaluation (NDE) are not applicable given both the fixed nature of the ultrasonic probes and the inherently different sources of variability. Thus, given a particular ultrasonic SHM method, a model-driven methodology for POD is necessary as opposed to an experimental approach. Here we consider a methodology for the development of model-based and experimentally verified POD curves for ultrasonic SHM applications. A Monte Carlo simulation of fatigue damage, combined with a model relating damage to ultrasonic response, is used to assess the variations associated with the crack geometry itself. Variations associated with the fatigue process, environmental effects and electronic noise are approximated from experimental observations of the ultrasonic response. The specific application analyzed here is a method for monitoring fatigue cracks originating from fastener holes. Specifically, an energy-based feature of the ultrasonic waveforms is correlated through modeling with crack size. POD curves are then developed for three dimensions of the fatigue cracks: surface length, maximum depth, and total area.

Transition from Guided Wave Based Non-Destructive Testing to Structural Health Monitoring

---**Hoon Sohn**[1,2], Seung Bum Kim[2], Sang Jun Lee[2], Debaditya Dutta[2], Hyun Jun Park[1], Chang Gil Lee[1], Abhinav Agrawal[2], Cheol Min Yeom[1], Seung Hee Park[1], and Yun Kyu Ahn[1], [1]Department of Civil and Environmental Engineering, KAIST, Daejeon, Korea; [2]Department of Civil and Engineering, Carneigie Mellon University, Pittsburgh, PA

---Non-destructive testing (NDT) techniques based on guided wave propagation have been widely used in well controlled laboratory environments for detecting local defects such as crack, corrosion and delamination. There is a trend to adapt these well established NDT techniques to structural health monitoring applications. However, there are several technical challenges that need to be overcome before such transition can be successfully accomplished: (1) Because a SHM paradigm demands continuous and online monitoring of a target structure, it produces a plethora of data to be analyzed. Therefore, the capacity to automatically process the data, particularly for autonomous damage diagnosis, is essential for online SHM; (2) Online monitoring calls for permanent installation of sensors on or within the target structure. However, the sensors themselves could be often the weakest link in the entire system, and it necessitates sensor self-diagnosis schemes and elegant power and data transmission strategies; (3) Because operational and environmental variations such as temperature changes that the target structure is subjected to could have adverse effects on SHM, their influences should be properly accommodated in the SHM paradigm to minimize false alarms. In this study, a new SHM paradigm called “reference-free” transducer and structural self diagnosis is introduced to make such transition from guided wave based NDT to online SHM more attainable.

Structural Health Monitoring of Composite Laminates with Embedded Piezoelectric Fibers

---**Cliff J. Lissenden** and Padma P. Puthillath, Penn State University, Engineering Science and Mechanics, University Park, PA 16802; James L. Blackshire, Air Force Research Laboratory, NDE Branch, Wright-Patterson Air Force Base, OH 45433-7817

---Active structural health monitoring of plate-like structures can be performed with ultrasonic guided waves. The activation of ultrasonic guided waves from embedded piezoelectric fibers in carbon fiber reinforced polymer (CFRP) laminated plates is investigated. Finite element analysis simulations of wave propagation from an array of embedded parallel piezoelectric fibers are presented. A quasi-isotropic CFRP having piezoelectric fibers embedded at the midplane is studied. The number and spacing of piezoelectric fibers is varied in order to activate different modes at different frequencies. The simulation results (i) characterize the displacement profile through the thickness of the CFRP plate, (ii) enable visualization of mode excitability, and (iii) demonstrate the source influence. Simulation results are compared with those from a surface mounted comb transducer to demonstrate differences and similarities. The source influence is explored for circular fibers polarized and activated radially and square fibers polarized and activated transversely. The results indicate that the embedded fibers have a strong potential for either hot spot monitoring or distributed monitoring of large areas. However, due to the size, spacing, and activation of embedded fibers the source influence causes the mode excitability to differ from that of a conventional comb transducer.

Novel Piezoelectric Fiber Transducers for Mode Selective Excitation and Detection of Lamb Waves

---**Bernd Koehler**, Bernd Frankenstein, Frank Schubert, and Martin Barth, Fraunhofer IZFP, Dresden Branch, Dresden, Germany

---One of the most widely applied methods for Structural Health Monitoring of plate like structures, shells and tubes is based on the transmission and reception of guided elastic waves. But, dispersion of various wave modes leads to complex signals which are difficult to interpret. Piezoelectric fiber patches (PFP) have been developed which can be used to excite and detect Lamb waves. These are of low thickness having the potential to be integrated into structures. This paper deals with a novel method to excite PFP. By this method a Lamb modes can be both excited and detected selectively. In addition, also directivity can be realized. These sensors can be used to simplify the interpretation of the acoustic signals considerably.

Session 27

SESSION 27
MODEL BASED INVERSION
J. Knopp, Chairperson
Meeting Room F

8:30 AM **Crack Shape Inversion Using Eddy Current and Alternating Potential Drop Measurements**
---**J. Bowler**, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

8:50 AM **A Model-Based Inversion Using State Space Representation and Tree Search Techniques**
---**X. Liu**, Y. Deng, Z. Zeng, and L. Udpa, NDE Laboratory, Department of Electrical and Computer Engineering, Michigan State University, East Lansing, MI 48824; J. S. Knopp, U.S. Air Force Research Laboratory (AFRL/MLL), Wright-Patterson AFB, OH 45433

9:10 AM **Crack Detection Using Natural Frequency Reduction Due to Change In Compliance**
---**M. A. Hussain** and M. A. Johnson, Benet Laboratories, US Army, 1 Buffington Street, Watervliet, NY 12189-4000

9:30 AM **Particle Filter Based Multisensor Fusion for Solving Electromagnetic NDE Inverse Problems**
---**T. M. Khan** and P. Ramuhalli, Michigan State University, Department of Electrical and Computer Engineering, East Lansing, MI 48824

9:50 AM **Modeling Anisotropic Grain Noise in Eddy-Current NDE: Reliability Assessment of Inverse Problems**
---**E. H. Sabbagh**, H. A. Sabbagh, and R. K. Murphy, Victor Technologies, LLC, Bloomington, IN; A. Sheila-Vadde, GE, India; Technology Center, Bangalore, India; M. P. Blodgett and J. Knopp, Air Force Research Laboratory (AFRL/RXLP), Wright-Patterson AFB, OH 45433-7817; J. C. Aldrin, Computational Tools, Gurnee, IL 60031

10:10 AM ***Break***

10:30 AM **Application of Model-Based Inversion to Eddy-Current NDE of Heat-Exchanger Tubing**
---**H. A. Sabbagh**, R. K. Murphy, and E. H. Sabbagh, Victor Technologies, LLC, Bloomington, IN; J. C. Aldrin, Computational Tools, Gurnee, IL 60031

10:50 AM **Model-Based Inversion in Eddy Current Image Processing**
---**J. C. Aldrin**, Computational Tools, Gurnee, IL 60031; J. S. Knopp and K. V. Jata, NDE Branch, Materials and Manufacturing Directorate, U.S. Air Force Research Laboratory, Wright-Patterson AFB, OH 45433

11:10 AM **Temperature Distribution Measurement of Heated Materials by Ultrasound Inversion Method Combined with Finite Difference Calculation**
---**I. Ihara** and M. Takahashi, Nagaoka University of Technology, Department of Mechanical Engineering, Nagaoka, Niigata, Japan

11:30 AM **Obtaining Thickness Profiles from Tomographic Inversion of Guided Wave Travel Times**
---**J. G. P. Bloom**, E. A. Luiten, and A. W. F. Volker, TNO Science and Industry, Flow Control & Instrumentation, Delft, The Netherlands

12:10 PM ***Lunch***

Crack Shape Inversion Using Eddy Current and Alternating Potential Drop Measurements

---**John Bowler**, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---The shape of a crack can be determined from eddy current probe impedance measurements using an iterative method that minimizes an error functional. The overall least square error, quantifying the difference between model predictions and experimental measurements, is suitable for the task. It is dependent on a function representing the shape of the crack. In the inversion process, one seeks a model crack that makes the error function a minimum. The numerical process can be based on a standard gradient algorithm such as one that uses a conjugate gradients method. An essential requirement in such a scheme is to be able to compute the variation in the predicted signal due to a variation in the crack profile. This information allows one to compute a gradient of the error with respect to a flaw variation. Once the gradient is known, one can vary the flaw iteratively in such a way that the error functional is reduced. In this presentation we show how apply this approach can be applied to eddy current and alternating current potential drop data.---This material is based upon work supported by the NSF/IU Program at the Center for NDE, Iowa State University.

A Model-Based Inversion Using State Space Representation and Tree Search Techniques

---**Xin Liu**, Yiming Deng, Zhiwei Zeng, and Lalita Udpa, Michigan State University, NDE Laboratory, Department of Electrical and Computer Engineering, East Lansing, MI 48824; Jeremy S. Knopp, U.S. Air Force Research Laboratory (AFRL/MLLP), Wright-Patterson AFB, OH 45433

---This paper presents a signal inversion algorithm using the Element-Free Galerkin (EFG) method as forward model. The advantage of EFG method is that it relies only on a set of nodes, instead of a complex mesh to discretize the solution domain. Consequently, a major advantage over the traditional Finite Element Method (FEM) is that in the inversion procedure, re-meshing is avoided resulting in increased efficiency and accuracy of the solution. A key component of iterative model-based inversion procedures is the defect updating scheme. In this paper the solution domain is represented by a constrained state space using a tree structure and defect updating is performed using a tree expansion search method. Results of implementation are presented for surface and subsurface, two-dimensional (2-D) and 3-D defects.

Crack Detection Using Natural Frequency Reduction Due to Change in Compliance

---**Moayyed A. Hussain** and Mark A. Johnson, Benet Laboratories, U.S. Army, 1 Buffington Street, Watervliet, NY 12189-4000

---The dynamics of the cracked structural members especially beams and rods have been investigated by many researchers. The crack is simulated using spring model connecting two segments of the structure or the beam, where compliance of the spring is based on the stress intensity factor. This compliance reduces all the natural frequencies of the structure by softening. This property can be used to detect and identify modes and location of the crack. For beams and rods it has been found that for small perturbation corresponding to small cracks, only information needed is the ratios of the frequencies. Using such a perturbation analysis an exact expression has been obtained for the inverse problem of location of the crack in terms of ratios of various frequencies. Objective in the present investigation is to extend the ideas to cylinders of finite extent and length. These cylinders may be subjected to either axial, flexural or torsion vibration of small amplitude or may be subjected to pulse loading leading to coupled axial transverse and torsion vibrations, which can be studied using spectral analysis. Theories of various modes of vibrations are presented and experimental results are obtained for a large number of natural frequencies.

Particle Filter Based Multisensor Fusion for Solving Electromagnetic NDE Inverse Problems

---**Tariq M. Khan** and Pradeep Ramuhalli, Michigan State University, Department of Electrical and Computer Engineering, East Lansing, MI 48824

---Flaw profile estimation from single sensor measurements is a typical ill-posed inverse problem in electromagnetic NDE. However, the availability of measurements from more than one sensor (using possibly different measurement modes) can enhance solution accuracy. This paper proposes a novel technique based on the use of sequential Monte Carlo methods (also called particle filters) for fusing multiple NDE measurements to solve the inverse problem. Such filters use a recursive state space approach and formulate the problem of flaw profile estimation in the framework of the classical discrete-time tracking problem. The formulation uses two models – a state transition model and a measurement model – and these models are used recursively to estimate posterior probability densities of flaw parameters conditioned on the measurements. This approach is computationally efficient and robust to noise. In this paper, this framework is extended to fuse multiple measurements for accurate inversion. The proposed approach uses multiple measurement models (one for each measurement mode) and uses these models within the recursive estimation framework. Initial results on simulated eddy current NDE measurements indicate feasibility of the proposed technique as well as a significant improvement in accuracy.

Modeling Anisotropic Grain Noise in Eddy-Current NDE: Reliability Assessment of Inverse Problems

---**Elias H. Sabbagh**, Harold A. Sabbagh, and R. Kim Murphy, Victor Technologies, LLC, Bloomington, IN; Aparna Sheila-Vadde, GE, India; Technology Center, Bangalore, India; Mark P. Blodgett and Jeremy Knopp, Air Force Research Laboratory (AFRL/RXLP), Wright-Patterson AFB, OH 45433-7817; John C. Aldrin, Computational Tools, Gurnee, IL 60031

---In recent research we used the proprietary volume-integral code, VIC-3D(c), to develop a numerical model of microstructural noise in a titanium-like crystal of hexagonal symmetry, and then used the model to perform a number of numerical experiments with random conductivity distributions. In this presentation we apply the model to solve inverse problems in which the size of a surface-breaking flaw is estimated in the presence of the noise generated by the random conductivity. The crucial role of sensitivity parameters and other `estimation metrics' in assessing the quality of the inversion will be discussed.

Application of Model-Based Inversion to Eddy-Current NDE of Heat-Exchanger Tubing

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

---We apply model-based inversion to problems of relevance to the nuclear power industry. We have acquired data for heat-exchanger tubes from the Electric Power Research Institute (EPRI), and the Naval Surface Warfare Center, Carderock Division, and have then developed model-based standards for the inversion of these data using our proprietary code, VIC-3D(c). The EPRI data are from round-bottom, inner-diameter (ID) pit standards, and are acquired using a standard eddy-current instrument. After undergoing a preprocessing step that includes feature extraction with clutter removal and scan-step correction, these data are then transformed into impedance data for inversion by means of a simple linear transformation. The Carderock data, which are due to a through-wall round hole, are already impedances and do not require this preprocessing step. Results of the inversion process that show excellent agreement with the measured data will be presented. Finally, we introduce certain `estimation-theoretic metrics,' and describe their utility in model-based inversion.

Model-Based Inversion in Eddy Current Image Processing

---**John C. Aldrin**, Computational Tools, Gurnee, IL 60031; Jeremy S. Knopp and Kumar V. Jata, NDE Branch, Materials and Manufacturing Directorate, U.S. Air Force Research Laboratory, Wright-Patterson AFB, OH 45433

---To improve the ability of eddy current nondestructive evaluation to characterize fatigue cracks and corrosion in multilayer structures, new data analysis methods are required. The inspection of fastener sites for fatigue cracks in particular can be hindered by geometric characteristics of the part including adjacent fasteners, part edges, subsurface structure and surface anomalies. The objective of this paper is to present a model-based image processing approach that fits approximate models based on first-principles to image data with adjacent fastener site and panel edge features. To obtain the global solution in near real time, a solution strategy is presented incorporating a heuristic approach using a physical understanding of the sources of greatest error, an estimation approach that quickly solve for the hole and edge model parameters with outlier rejection, and an iterative approach to improve the model fit for overlapping fastener site and part edge regions. Model refinements are also presented that better address error associated with adjacent holes and poor hole centering due to cracks. Using this approach, improvements in the visual representation of image data for crack detection and the reliability of features for crack characterization were achieved.

Temperature Distribution Measurement of Heated Materials by Ultrasound Inversion Method Combined with Finite Difference Calculation

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

---In various fields of engineering, there are increasing demands for monitoring the internal temperature distribution of heated materials. Ultrasound, because of its capability to probe the interior of materials and high sensitivity to temperature, is expected to be useful in measuring the internal temperature of materials. In this work, a new ultrasound inversion method for monitoring the temperature distribution inside materials being heated is presented. The principle of the method is based on the temperature dependence of the velocity of the ultrasound propagating through the material. The inversion method consisting of an ultrasonic pulse-echo measurement and a finite difference calculation has been developed to determine the one-dimensional temperature distribution in a heated plate. To demonstrate the practical feasibility of the inversion method, we have applied this method to the temperature monitoring of a steel plate of 30 mm thickness being heated by contacting with 973 K molten aluminum. Ultrasonic pulse-echo measurements are performed for the steel during heating and the inversion method is used to determine the temperature distribution inside the steel. The temperature distribution and its variation determined by the ultrasonic method almost agree with those measured using thermocouples installed in the steel.

Obtaining Thickness Profiles From Tomographic Inversion of Guided Wave Travel Times

---**Joost G. P. Bloom**, Erik A. Luiten, and Arno W.F. Volker, TNO Science and Industry, Flow Control & Instrumentation, Delft, The Netherlands

---Guided wave tomography is a promising technique for the monitoring of corrosion over large areas. Guided waves have a wave speed that depends in certain frequency-thickness regimes on the local thickness of the waveguide they follow. Therefore, the travel time of the guided wave over a fixed distance contains information about the thickness profile along its path. By measuring the travel time over multiple paths in such a way that the complete waveguide is covered and applying tomographic inversion to the measured values, a thickness profile of the waveguide can be recovered. Two challenges of guided wave tomography are compensation for dispersion and parameterization of the surface of the waveguide. Removing the strong dispersive behavior is essential to accurately determine the travel times. Smart parameterization is needed to obtain accurate, high-resolution thickness profiles. This paper demonstrates the application of guided wave tomography on plates and pipes and discusses several methods for dispersion removal and parameterization.

Session 28

SESSION 28

NDE FOR MATERIALS DEFORMATION

A. Frishman, Chairperson
Meeting Room G

8:30 AM **Finite Element Analysis of In-Situ Ultrasonic Creep Monitoring Methods**
---**M. J. Guers** and B. R. Tittmann, The Pennsylvania State University, Department of Engineering Science and Mechanics, University Park, PA 16802-6812

8:50 AM **Ultrasonic Method for Prediction of Residual Life of Creep Damaged Materials**
---**D.-Y. Kim**, H.-J. Kim, S.-J. Song, B.-J. Kim, and B.-S. Lim, Sungkyunkwan University, School of Mechanical Engineering, Suwon, Kyunggi, Korea

9:10 AM **Creep-Induced Microstructural Changes and Acoustic Damping in a Martensite Stainless Steel**
---**T. Ohtani**, Shonan Institute of Technology, Department of Mechanical Systems Engineering, Fujisawa, Kanagawa, Japan; F. Yin, National Institute of Materials Science, Innovative Materials Engineering Laboratory, Tsukuba, Ibaraki, Japan; Y. Kamada, Iwate University, Nondestructive Evaluation and Science Research Center, Morioka, Iwate, Japan

9:30 AM **Non-Contact Acousto-Thermal Signature (NCATS) and Acoustic Damping Investigations of Plastically Strained Ti-6Al-4V Alloy**
---K. V. Jata and J. T. Welter, AFRL/RXLP, NDE Branch, Dayton, OH 45433; **S. Sathish**, N. D. Schehl, and T. R. Boehnlein, University of Dayton Research Institute, 300 College Park, Dayton, OH 45469-0127

9:50 AM **Ultrasonic Characterization of Tensile Deformation in AISI Type 316 Stainless Steel**
---A. Kumar, C. K. Mukhopadhyay, **T. Jayakumar**, and B. Raj, Indira Gandhi Centre for Atomic Research, Nondestructive Evaluation Division, Kalpakkam, Tamil Nadu, India

10:10 AM ***Break***

10:30 AM **A Scaling Law for Nondestructive Evaluation of Shot Peening Induced Surface Material Property Deviations**
---**A. M. Frishman**, C. C. H. Lo, Y. Shen, and N. Nakagawa, Iowa State University, Center for NDE, Ames, IA 50011

10:50 AM **Nondestructive Evaluation of Fatigue Damage for SUS316 by Using Electromagnetic Methods**
---**M. Oka** and T. Yakushiji, Oita National College of Technology, 1666 Maki, Oita, 870-0152, Japan; Y. Tsuchida and M. Enokizono, Oita University, 700 Dannoharu, Oita, 870-1192, Japan

11:10 AM **Self-Calibrated Swept Frequency Eddy Current Measurements for Characterization of Near Surface Material Conditions**
---**C. C. H. Lo**, Y. Shen, and N. Nakagawa, Iowa State University, Center for NDE, Ames, IA 50011; A. M. Frishman, Iowa State University, Dept. of Physics and Astronomy, Ames, IA 50011

11:30 AM **Near-Surface Residual Stress-Profiling with High Frequency Eddy Current Conductivity Measurement**
---**S. Hillmann**, H. Heuer, and N. Meyendorf, Fraunhofer Institute for Nondestructive Testing, Dresden, Germany; H.-U. Baron and J. Bamberg, MTU Aero Engines, GmbH, Munich, Germany

11:50 AM **Shot-Peening Intensities vs. Eddy Current Signals as Seen in Iterative Treatment-Measurement Experiment**
---**N. Nakagawa**[1], A. M. Frishman[1,2], Y. Shen[1], and C. C. H. Lo[1], [1]Center for NDE, ISU, Ames, IA 50011; [2]Dept. of Physics and Astronomy, ISU, Ames, IA 50011

12:10 PM ***Lunch***

Finite Element Analysis of In-Situ Ultrasonic Creep Monitoring Methods

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

---Finite element analysis is a well established technique for studying ultrasonic wave propagation in NDE applications. In particular, finite element analysis allows variations in specimen geometry and transducer configurations to be studied without the cost of manufacturing a large number of physical prototypes. In this research, several transducer and creep specimen configurations were investigated to determine how well each setup performed for creep length monitoring. In addition to transducers mounted directly on the creep specimen, remote monitoring via a waveguide was also studied for creep testing in hostile environments.

Ultrasonic Method for Prediction of Residual Life of Creep Damaged Materials

---**Dong-Yeol Kim**, Hak-Joon Kim, Sung-Jin Song, Bum-Joon Kim, and Byeong-Soo Lim, Sungkyunkwan University, School of Mechanical Engineering, Suwon, Kyunggi, Korea

---In the previous study, residual life time of creep damaged 9Cr-2W steel specimens were evaluated using attenuation of ultrasound and area fraction of precipitates. Because attenuation coefficients and area fraction of precipitates were increased as increasing their aging time. However, cause of increasing attenuation of ultrasound is not only increased precipitates but also grain growth. Thus, to find more clear relation between area fraction of precipitates and attenuation of ultrasound from the measured data, grain growth effects on the attenuation ultrasound have to be corrected. For that purpose, in the study, we will calculate attenuation of ultrasound because of grain growth using the single scattering model. Then, using predicted attenuation coefficient for grain boundaries, we will extract attenuation coefficients for area fraction of precipitates from the measured ultrasonic data of creep damaged 9Cr-2W steel specimens. In this presentation, we will briefly discuss single scattering model and procedure for correcting effects of grain scattering on attenuation coefficients. And then, relation between attenuation of ultrasound and area fraction of precipitates and comparison result of residual life time predicted by area fraction of precipitate to ultrasonic method will be presented.

Creep-Induced Microstructural Changes and Acoustic Damping in a Martensite Stainless Steel

---**Toshihiro Ohtani**, Shonan Institute of Technology, Department of Mechanical Systems Engineering, Fujisawa, Kanagawa, Japan; Fuxing Yin, National Institute of Materials Science, Innovative Materials Engineering Laboratory, Tsukuba, Ibaraki, Japan; Yasuhiro Kamada, Iwate University, Nondestructive Evaluation and Science Research Center, Morioka, Iwate, Japan

---We studied the microstructure evolution of a martensitic stainless steel (JIS-SUS403) during creep by monitoring ultrasonic attenuation. After obtaining a series of creep samples with various strains under a tensile stress of 120 MPa at 873K, we removed small samples from the creep samples and measured free vibration resonance frequencies and attenuation coefficients with electromagnetic acoustic resonance (EMAR). EMAR is a combination of the resonant acoustic technique with a non-contact electromagnetic acoustic transducer (EMAT). The attenuation measurement is inherently free from any energy loss, resulting in pure attenuation in a metal sample. Furthermore, we observed the evolution of microstructure with electron backscatter diffraction (EBSD) and transmission electron microscopy (TEM). The result from the small samples shows the same trend as our previous result from larger sample. We propose a non-destructive method using EMAR to evaluate creep damage in small specimens sampled from structural metals in-service.

Non-Contact Acousto-Thermal Signature (NCATS) and Acoustic Damping Investigations of Plastically Strained Ti-6Al-4V Alloy

---Kumar V. Jata and John T Welter, AFRL/RXLP, NDE Branch, Dayton, OH 45433; **Shamachary Sathish**, Norm D. Schehl, and Thomas R. Boehnlein, University of Dayton Research Institute, 300 College Park, Dayton, OH 45469-0127

---In the context of developing NDE techniques to investigate evolution of microstructure and damage, studies have been undertaken to measure plastic strain in Ti-6Al-4V samples using NCATS methodology. The efficiency of the conversion of acoustic energy to thermal energy has been measured in samples subjected to different levels of plastic strain. Since the efficiency of conversion of acoustic energy to heat is related to acoustic damping, a new capability to measure acoustic damping during NCATS measurements has been developed. The results of NCATS and acoustic damping measurements on samples subjected to different levels of plastic strains in Ti-6Al-4V will be presented. The effect of plastic strain on maximum temperature increase, temperature-time response, and acoustic damping will be discussed.

Ultrasonic Characterization of Tensile Deformation in AISI Type 316 Stainless Steel

---Anish Kumar, Chandan Kumar Mukhopadhyay, **Tammana Jayakumar**, and Baldev Raj, Indira Gandhi Centre for Atomic Research, Non Destructive Evaluation Division, Kalpakkam, Tamil Nadu, India

---Ultrasonic velocity and attenuation measurements in thickness direction, have been carried out at the centre of the specimen during tensile deformation of an AISI type 316 stainless steel specimen of 5 mm thickness. Ultrasonic longitudinal wave velocity was found to increase up to ~550 MPa true stress followed by a continuous decrease. Ultrasonic attenuation also exhibited a sharp drop beyond ~550 MPa true stress. The tensile test was stopped and the specimen was unloaded just before the ultimate tensile stress (UTS) so that no necking was observed in the specimen. The specimen was then made plane parallel and ultrasonic measurements were carried out at 2 mm interval from the shoulder region to the centre of the gauge length. The curved portion of the specimen depicted the deformation due to tensile load to different true stress values. In the curved portion also, ultrasonic attenuation exhibited a sudden drop beyond ~550 MPa true stress. The analysis of the tensile flow behavior using Ludwig's equation exhibited that this true stress value (~550 MPa) corresponded to the critical true strain (0.17) for crossover from planar slip to cross slip or cell formation. The present study indicated that ultrasonic measurements during tensile deformation provide insight into deformation mechanisms.

A Scaling Law for Nondestructive Evaluation of Shot Peening Induced Surface Material Property Deviations

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

---Recently, eddy current measurement has been proposed as a nondestructive technique for characterizing surface and sub-surface material conditions (e.g. residual stresses and cold wok) in surface-treated aerospace materials such as nickel-base superalloys. For successful implementation of this technique it is necessary to have a theoretical understanding of material conditions under investigation. This paper presents a theory of shot-induced material property deviations near the component surface. Our analysis shows that, with shot peening being the common cause, there exists a universal scaling law among seemingly unrelated material property deviations under various peening conditions. We explicitly present scaling behaviors of several material property deviations under various Almen intensities, and validate the predicted scaling relations against experimental data. In particular, swept high frequency eddy current data for the shot induced impedance deviations of a series of shot peened Inconel 718 samples are presented, showing agreement with the scaling predictions. The scaling law could be used as a tool in assuring consistency of eddy current measurement, providing us with an independent method of verifying direct correlation between the shot-induced deviations of mechanical properties and conductivity. It is also useful as a tool to control peening processes, by predicting cold work profile and to some extent the residual stress profile at various Almen intensities.---This material is based upon work supported by the Air Force Research Laboratory under contract #FA8650-04-C-5228 at Iowa State University Center for NDE.

Nondestructive Evaluation of Fatigue Damage for SUS316 by Using Electromagnetic Methods

---**Mohachiro Oka** and Terutoshi Yakushiji, Oita National College of Technology, 1666 Maki, Oita, 870-0152, Japan; Yuji Tsuchida and Masato Enokizono, Oita University, 700 Dannoharu, Oita, 870-1192, Japan

---A lot of parts made of austenitic stainless steels are being used in the manufacturing plant such as a chemical plant and a power plant. Recently, it is reported that some accidents happened because of fatigue damage of those parts. To avoid accidents, it is very important to know the state of deterioration of parts made of them. Accordingly, we are studying fatigue evaluation methods by using electromagnetic methods such as the remanent magnetization method, the eddy current method, the resistivity method, and so on. These methods obtained a good result in SUS304 that was the semi-stable austenite steel. Though this method was very easy, the eddy current method to measure the inductance of the pancake type coil with the LCR meter obtained the good result. This method was called the inductance method by us. However, it is thought that the change of permeability by fatigue damage is slight because the austenitic phase of SUS316 is steady compared with SUS304. To develop a novel nondestructive evaluation method for fatigue damage evaluation in SUS316, we applied the inductance method. From our experimental results, this method obtained the good result as same as SUS304. In this paper, the experimental results of the fatigue damage evaluation of SUS316 using the inductance method will be reported.

Self-Calibrated Swept Frequency Eddy Current Measurements for Characterization of Near Surface Material Conditions

---**C. C. H. Lo**, Y. Shen, and N. Nakagawa, Iowa State University, Center for NDE, Ames, IA 50011; A. M. Frishman, Iowa State University, Department of Physics and Astronomy, Ames, IA 50011

---We report on a self-calibrated, swept frequency eddy current (SFEC) technique for characterization of surface and subsurface material conditions with specific applications to detecting residual stresses in shot-peened superalloys and surface oxidation in engineering components. The technique involves measuring lift-off normalized V-component signal to suppress the lift off noise and instrumentation effect. Previously, we encountered a noise problem at the lower end of the frequency band for a detection coil designed to operate at high frequencies. Our approach uses multiple dissimilar coils that operate in different but overlapping frequency bands. Theoretical study shows that the V-component signals are insensitive to coil dimensions. Therefore, the V-component signals in the neighboring bands coincide with each other at the overlapping frequencies, resulting continuous broad-band data. We demonstrate the technique on two surface-modified materials, namely a series of Inconel 718 samples shot peened at 4A to 8A, and an Ag-1.5at%Al alloy subjected to surface oxidation. For each sample set, we explicitly show that the V-component signals measured by two dissimilar sets of coils and instruments do overlap, confirming that the signals are insensitive to coil dimensions and instrumentation. The bulk conductivities of the samples were determined by inverting the low frequency data. The bulk results were then used to constrain the model-based inversion of the high frequency data to yield conductivity profiles, from which the residual stress profile of the shot-peened Inconel 718 and the oxidization depth of the Ag-Al alloy are inferred.---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, and supported in part by the NSF Supplementary Funding to the CNDE Program.

Near-Surface Residual Stress-Profiling with High Frequency Eddy Current Conductivity Measurement

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

---The lifetime of aero engine components can be extended by applying an additional strain to the material. Typical aero engine-alloys like Nickel-Base Superalloys or Titanium Alloys can be surface-treated by use of shot peening to induce the compressive strain near the surface. However, in order to calculate the remaining time of operation for critical aero engine components, a quantitative determination of strain gradients near the surface has to be carried out periodically. We propose to measure the depth-profile of residual stresses non-destructively by use of high frequency eddy current techniques. This paper presents results obtained with an experimental set-up based on a high precision impedance analyzer. Test samples prepared from IN718 DA by shot peening of different intensities can be easily distinguished. By sweeping the frequency from 100 kHz up to 100 MHz a depth profile for the electrical conductivity from 50 µm to 500 µm can be obtained. The measured conductivity profile is a resultant from residual stresses, cold work, surface roughness and the texture of the material. Possibilities of separation of these effects will be discussed. In addition, first results for strain profiling obtained with industry applicable NDE instrument will be presented.

Shot-Peening Intensities vs. Eddy Current Signals as Seen in Iterative Treatment-Measurement Experiment

---**N. Nakagawa**[1], A. M. Frishman[1,2], Y. Shen[1], and C. C. H. Lo[1], [1]Center for Nondestructive Evaluation, Iowa State University, Ames, IA 50011; [2]Department of Physics and Astronomy, Iowa State University, Ames, IA 50011

---We report on progress in swept high frequency eddy current (SHFEC) technique for characterization of material conditions, or specifically residual stress, on shot-peened superalloy surfaces. Our aim here is to demonstrate the sensitivity of our measurement for practical shot peening intensities, i.e. at 4~6A. First, we present our improved probe and instrumentation sufficiently sensitive to resolve the surface conditions at these low Almen intensities, where our earlier measurements encountered noise problems. Our new printed circuit board probe integrates a pair of coils (12 mm diameter, forming an AC bridge), and on-board electronics which acts as impedance buffers and maintains the cabling impedance at characteristic 50 ohm between the probe board and the instruments. We have thus reduced the instrumentation noises. Second, we present the result of an iterative treatment-measurement experiment, performed on a 2”-by-3” Inconel 718 block specimen, initially polished to a mirror finish. After an initial baseline SHFEC measurement, we performed shot peening, an Almen strip deflection measurement, and a SHFEC measurement as one iteration cycle, and repeated the cycles multiple times at predetermined intervals. We then draw several conclusions from the resulting SHFEC signals (i.e. lift-off normalized vertical-component signals) plotted against the Almen intensities, including a) the SHFEC signals increase monotonically in correlation with the Almen intensity increase, and b) the SHFEC signals exhibit sufficient deviations to resolve 4~6A intensities, while c) the SHFEC signals indicate saturation of the Inconel 718 response against peening, but the saturation occurs much later in the iteration than indicated by the A-series Almen strip.---This material is based upon work supported by the Air Force Research Laboratory under contract # FA8650-04-C-5228 at Iowa State University Center for NDE.

Session 29

SESSION 29 – POSTERS

EDUCATION, COMPOSITE MATERIALS, NDE FOR STEELS (MOSTLY), CONCRETE, SIGNAL/IMAGE/RISK PROCESSING

Main Hall C

1:30 PM

Education

A University Course on the Physical Principles of Ultrasound Nondestructive Evaluation
---**V. Genis**, Drexel University, Goodwin College of Professional Studies, One Drexel Plaza, 3001 Market Street, Suite 100, Philadelphia, PA 19104

Composite Materials

High-Frequency Ultrasound of Armor-Grade Alumina Ceramics
---**S. Bottiglieri** and R. A. Haber, Rutgers University, Materials Science and Engineering, Piscataway, NJ 08854

Ultrasound Method of Multi-Layer Material Thickness Measurement
---Y. V. Kuts, V. S. Yeremenko, and E. V. Monchenko, National Aviation University, Kyiv 03058, Ukraine; **A. G. Protasov**, National Technical University of Ukraine "KPI", Nondestructive Testing, Department, Kyiv 03056, Ukraine

Feasibility on Generation Mechanism of Ultrasonic Shear Wave for the Detection of Stacking Orientation Defect in CFRP Composite Laminates
---**K.-H. Im**, Woosuk University, Department of Automotive Engineering, 490, Hujung-ri, Samrae-up, Wanju-kun, Chonbuk, 565-701, Korea; H.-J. Kim and S.-J. Song, Sungkyunkwan University, School of Mechanical Engineering, Kyonggi-do, 440-746, Korea; D. K. Hsu, Iowa State University, Center for NDE, Ames, IA 50011; K.-S. Lee and I.-Y. Yang, BK21 Education Center of Mould Technology for Advanced Materials & Parts, Chosun University, 375 Seosuk-dong, Dong-gu, Kwangju 501-759; Korea; Je-Woong, Park Department of Naval Architecture and Ocean Engineering, Chosun University, Gwangju 501-759, Korea

Mechanical Hysteresis as NDE Tool for Evaluating Composite Honeycomb Damage
---**C. D. Foreman**, V. Dayal, D. J. Barnard, and D. K. Hsu, Iowa State University, Center for Nondestructive Evaluation, 1915 Scholl Road, Ames, IA 50011-3042

Ultrasonic Nonlinear Characterization of the Stainless Steel Wire Reinforced Aluminum Composite
---C. S. Kim, Penn State University, Engineering Science and Mechanics, PA 16802; T. S. Park, Seoul National University of Technology, Department of Mechanical Engineering, Seoul, Korea; D. H. Kim, Seoul National University of Technology, Department of Mechanical Engineering, Seoul, Korea; I. K. Park, Seoul National University of Technology, Department of Mechanical Engineering, Seoul, Korea

Eddy Current Assessment of Engineered Components Containing Nanofibers
---**R. Ko**, W. Hoppe, and J. Pierce, University of Dayton Research Institute Structural Integrity Division, 300 College Park, Dayton, OH 45469-0120

NDE for Steels (Mostly)

Experimental Determination of the Electric Conductivity and Magnetic Permeability of Different Steels and Its Application to Steel Identification in a Pipe Mill
---G. A. Sánchez, **J. I. Etcheverry**, and N. Bonadeo, TenarisSiderca R&D, Campana, Pcia. Buenos Aires, Argentina

Characterization of the Level of Plastic Deformation in Cold-Rolled Ti-6Al-4V Samples by Thermoelectric Power Measurements
---**H. Carreon**, A. Medina, and A. Ruiz, Universidad Michoacana, Instituto de Investigaciones Metalúrgicas, Morelia, Michoacan, Mexico

Effects of Crack Morphology and Closure on Ultrasonic Response
---**R. A. Roberts**, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50014

Inspection of Internal Defects in Cold-Rolled Steel Sheets Using Lamb Wave
---**S.-W. Choi**, G. Kim, and J. Bae, POSCO, Instrumentation & Control Research Group, Pohang, Gyeongbuk, Korea

Characterization of Fatigue Damage in A36 Steel with Nonlinear Rayleigh Waves
---**S. E. Duncan** and L. J. Jacobs, Georgia Institute of Technology, School of Civil and Environmental Engineering, Atlanta, GA 30332-0355; J.-Y. Kim and J. Qu, Georgia Institute of Technology, G. W. Woodruff School of Mechanical Engineering, Atlanta, GA 30332

Ultrasonic Testing for the Evaluation on the Decarburization of SA 106 Carbon Steel
---**H. S. Shin** and M. H. Song, Materials Engineering Department, Korea Institute of Nuclear Safety, Daejeon, Korea; H.-J. Kim and S.-J. Song, Sungkyunkwan University, School of Mechanical Engineering, Suwon, Kyunggi-do, Korea; S. S. Kang, Reactor Engineering Research Department, Korea Institute of Nuclear Safety, Daejeon, Korea; J. K. Park, Department of Materials Science and Engineering, Korea Adv. Inst. of Science and Technology, Daejeon, Korea

Application of Laser-Generated Ultrasound for Evaluation of Wall-Thinning in Carbon Steel Elbow
---**D.-Y. Kim**, J.-H. Lee, D.-H. Lee, and Y.-J. Ha, Pusan National University, Graduate School of Mechanical Engineering, Jangjeon-dong, Gumjeong-gu, Busan

Non-Contact Magnetostrictive Lamb-EMAT Designs and Applications for Health Monitoring of Piping
---**I. K. Park**, Seoul National University of Technology, Department of Mechanical Engineering; T. S. Park and Y.-K. Kim, Seoul National University of Technology, Graduate School of Energy and Environment; Y.-J. Kang, Chonbuk National University, Dept. of Mech. Design Engineering, Korea

Application of Impulse Resonant Acoustic Spectroscopy (IRAS) for Crack Detection in Pipes
---**A. Sutin**, Stevens Institute of Technology, Hoboken, NJ 07901; Y. Kin, Purdue University, Calumet, IN; S. Drivdahl and C. Drenth, Boart Longyear Company, Salt Lake City, UT

Evaluation of Leak Signal of High Temperature and Pressure Pipeline Using AE Sensor and Accelerometer Sensors
---**J.-H. Kim**, J.-H. Lee, B.-M. Song, Y.-H. Kim, Pusan National University, Research Institute of Mechanical Technology, Graduate School of Mechanical Engineering, 30 JangJeon-Dong, GeumJeong-Gu, Busan, 609-703, Korea

Surface Defects on GA Steel Sheets and Detection
---**J. Bae**, G. Kim, and S.-W. Choi, POSCO, Instrumentation & Control Research Group, Pohang, Gyeongbuk, Korea

Formation of Stress Corrosion Cracks in Austenitic Stainless Steel and Their Evaluation Using Subharmonic Phased Array for Crack Evaluation (SPACE)
---**H. Endo**, K. Sasaki, S. Yamamoto, Y. Ohara, and K. Yamanaka, Tohoku University, Department of Materials Processing, Sendai-City, Miyagi, Japan; T. Mihara, University of Toyama, Department of Mechanical and Intellectual Systems Engineering, Toyama-City, Toyama, Japan

Concrete

Application of Ultrasonic Rayleigh Surface Waves to Characterize Asphaltic Concrete
---**C.-W. In**, J.-Y. Kim, L. Jacobs, and K. Kurtis, Georgia Institute of Technology, Civil and Environmental Engineering, Atlanta, GA 30332-0355

Influence of Surface Properties on the Detection and Quantification of Voids in Concrete Structures
---C. Maierhofer, M. Röllig, and **M. Kreutzbruck**, Federal Institute for Materials Research and Testing (BAM), Department VIII Nondestructive Testing, Berlin, Germany; R. Arndt, Federal Highway Administration, Turner Fairbank Highway Research Center, Georgetown Pike, VA

Signal/Image/Risk Processing

Thickness Determination of a Plate with Varying Thickness Using an Artificial Neural Network for Frequency-Time Representation of Lamb Waves
---C. Treesatayapun and **A. Baltazar**, Centro de Investigación, y Estudios Avanzados, Cinvestav Unidad-Saltillo Robotics and Advanced Manufacturing Program, Ramos Arizpe, Coahuila, Mexico; J.-Y. Kim, Georgia Institute of Technology, GWW School of Mechanical Engineering, Atlanta, GA 30303

Synthetic Aperture Focusing for Through-Transmission Microwave Nondestructive Imaging Applications
---**M. T. Ghasr** and R. Zoughi, Missouri University of Science and Technology (MO S&T), ECE Department, Applied Microwave Nondestructive Testing Laboratory (amntl), Rolla, MO 65409-0040

Small Printed Ultra-Wideband Antenna for Near-Field Imaging
---**I. Elshafiey**, A. Fattah, A. Sheta, M. A. Alkanhal, and Z. Al-Hekail, King Saud University, Department of Electrical Engineering, Advanced Technologies Research Center (ATRC), Riyadh, Saudi Arabia; A. AlOrainy, King Abdulaziz City for Science and Technology, Electronics Research Institute, Riyadh, Saudi Arabia

Dedicated Filter for Defects Clustering in Radiographic Images
---**R. Sikora**, K. Swiadek, and T. Chady, Szczecin University of Technology, Department of Electrical Engineering, Szczecin, Poland

Ultrasonic and Radiographic Imaging of Niobium Target Capsules for Radioisotope Production
---H. Bach, **T. N. Claytor**, J. F. Hunter, F. M. Nortier, D. M. Smith, Los Alamos National Laboratory, MS C914, Los Alamos, NM 87544; J. W. Lenz, John W. Lenz & Associates, 412 Muskinum Road, Waxahachie, TX 75165; C. Moddrell and P. A. Smith, P. A. Smith Concepts & Designs, 1475 Central Avenue, Suite 250, Los Alamos, NM 87544

Visualization of Ultrasonic Waves Scattered from Rear Defects by Using a Laser-Based Imaging Technique
---**J. Takatsubo**, B. Wang, H. Miyauchi, H. Tsuda, N. Toyama, and K. Urabe, National Institute of Advanced Industrial Science and Technology, Research Institute of Instrumentation Frontier, Tsukuba, Ibaraki, Japan

High Resolution Transforms
---A. W. F. Volker and **J. G. P. Bloom**, TNO Science and Industry, P. O. Box 155, 2600 AD Delft, The Netherlands

Applications of Detrended-Fluctuation Analysis to Gearbox Fault Diagnosis
---**E. P. Moura**, A. P. Vieira, Universidde Federal do Ceará, Departamento de Engenharia Metalúrgica e de Materials, Fortaleza, CE, Brazil; M. A. S. Irmã, Universidade Federal do Vale do São Francisco, Colegiado de Engenharia Mecânica, Juazeiro, BA, Brazil; A. A. Silva, Universidade Federal de Campina Grande, Departamento de Engenharia Mecânica, Campina Grande, PB, Brazil

Experimental Study of the Repeatability and Accuracy of the Impact Excitation of Vibration Technique for Prismatic Steel Samples
---L. I. Raggio, **J. I. Etcheverry**, and N. Bonadeo, TenarisSiderca R&D, Applied Physics Department, Campana, Buenos Aires, Argentina

3:10 PM ***Break***

A University Course on the Physical Principles of Ultrasound Nondestructive Evaluation

---**Vladimir Genis**, Drexel University, Goodwin College of Professional Studies, One Drexel Plaza, 3001 Market Street, Suite 100, Philadelphia, PA 19104

---The ultrasound nondestructive evaluation (NDE) of materials course has been offered to Applied Engineering Technology (AET) students at Drexel University for past two years. The main objective of this three-credit (thirty-hour) course is to introduce students to physical principles of ultrasound measurements and to demonstrate the basic principles of ultrasound nondestructive evaluation of materials by combining hands-on laboratory experience with lectures. This course is required for AET students enrolled in all program's concentrations: electrical, mechanical, and industrial engineering technology. The goal of this paper is to present in details the first part of the course, which introduces students to principles of ultrasound measurements and helps understand the NDE procedures and techniques. The work in the laboratory enhances the fundamentals taught in the classroom sessions. During the laboratory procedures, the students learn the engineering and physical principles behind the measurements of sound velocity in water and other materials, attenuation of ultrasound waves at different frequencies, and directivity patterns of circular transducers with various resonant frequencies.

High-Frequency Ultrasound of Armor-Grade Alumina Ceramics

---**Stephen Bottiglieri** and Richard A. Haber, Rutgers University, Materials Science and Engineering, Piscataway, NJ 08854

---Several series of high density armor-grade alumina was tested using high frequency ultrasound in order to determine any differences between multiple manufacturers and production lots. C-scans were performed at 15, 75, and 125MHz in order to form attenuation coefficient and elastic property maps. Quantitative analysis enabled the separation of these samples into various categories based on their overall performance and homogeneity. The data acquired corroborated destructive testing performed by the individual manufacturers, thereby confirming the use of ultrasound as a diagnostic tool for determining the quality and performance of alumina in armor applications.

Ultrasound Method of Multi-Layer Material Thickness Measurement

---Yuri V. Kuts, Vladimir S. Yeremenko, and Elena V. Monchenko, National Aviation University, Kyiv 03058, Ukraine; **Anatoliy G. Protasov**, National Technical University of Ukraine "KPI", Nondestructive Testing, Department, Kyiv 03056, Ukraine

---This paper is devoted to the ultrasound method of the thickness measurement which is based on the measurement of signal phase characteristics (SPC) and definition of the superposition moment for two impulses - a direct and reflected from boundary. This method is effective for multi-layer composites testing. In this case delay between reflected from different layers impulses is less then a direct impulse duration. The main point of proposed method is analysis of SPC and definition of its distortion moment. In order to determine SPC it is used the Gilbert transformation. When it is used the radio-frequency pulse with a harmonic carrier wave, a phase characteristic of the undistorted signal will be linear function of time in the range of impulse duration. At time superposition of a direct and reflected from different layers impulses the signal phase characteristic will change within ± ½π . The detection of this change and definition of its time allow to evaluate the delay of ultrasound signal spreading in a testing object. The change can be found as a difference between SPC of direct and SPC of accumulated signals which are produced by an ultrasonic sensor.

Feasibility on Generation Mechanism of Ultrasonic Shear Wave for the Detection of Stacking Orientation Defect in CFRP Composite Laminates

---**Kwang-Hee Im**, Woosuk University, Department of Automotive Eng., 490, Hujung-ri, Samrae-up, Wanju-kun, Chonbuk, 565-701, Korea; Hak-Joon Kim and Sung-Jin Song, Sungkyunkwan University, School of Mechanical Engineering, Kyonggi-do, 440-746, Korea; David K. Hsu, Iowa State University, Center for NDE, Ames, IA 50011; Kil-Sung Lee and In-Young Yang, BK21 Education Center of Mould Technology for Advanced Materials & Parts, Chosun University, 375 Seosuk-dong, Dong-gu, Kwangju 501-759, Korea; Je-Woong, Chosun University, Park Department of Naval Architecture and Ocean Engineering, Gwangju 501-759, Korea

---Composite materials are attractive for a wide range of applications due to the advantages associated with their very large strength-to-weight and stiffness-to-weight ratios. Increasingly, high performance engineering structures are being built with critical structural components made from composite materials. In particular, the importance of carbon-fiber reinforced plastics (CFRP) has been generally recognized in both space and civil aircraft industries, and CFRP composite laminates are widely used. It is very important to detect fiber orientation error in composite laminates because the layup of a CFRP composite laminates affects the properties of the laminate, including stiffness, strength and thermal behavior. An NDE technique for stacking orientation determination would be very beneficial because of layup orientation influence to the laminate stiffness. Usually, it is found that ultrasonic shear wave is pretty sensitive to fiber direction of CFRP composite laminates. A jig is developed for generating a shear wave. A pyramid with an isosceles triangle with two 45o was made of aluminum to generate shear waves using two longitudinal transducers based on ultrasonic-polarized mechanism. Also, the signal splitter was connected to the pulser jack on the pulser/receiver and to the longitudinal transducers. An investigation of shear wave ultrasonic technique was carried out in order to detect stacking orientation error for quasi-isotropy composite laminates. The design and use of a shear wave transducers would greatly aid in alleviating the couplant problem. Also, earlier a ply-by-ply vector decomposition model was developed for composite laminates and was utilized for comparison. Therefore, it is found that the experimentally shear wave variation of specially designed jig was consistent with simulated results and shear wave ultrasonic measurement might be very useful to detect the defects in CFRP composites.

Mechanical Hysteresis as NDE Tool for Evaluating Composite Honeycomb Damage
---**Cory D. Foreman**, Vinay Dayal, Daniel J. Barnard, and David K. Hsu, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011-3042

---The force-displacement response of an undamaged composite honeycomb sandwich is linear and shows no hysteresis. With internal damage, the load and unload cycles are nonlinear and form a hysteresis loop with a reduced average slope. The enclosed area is an indication of the energy dissipation due to internal friction or damage severity. Good correlation was observed between hysteresis loop area and impact energy causing the damages in mechanical testing data. In order for the mechanical hysteresis to be used as an NDE tool, the acquisition of the force-displacement data must be done with one-sided access and at a fast rate. In this work, we demonstrated that the hysteresis loop can be deduced from the voltage-versus-time data of a tap test using an accelerometer of known mass. The displacement was obtained by integrating the acceleration twice and the force was deduced from the acceleration. The method was verified on different honeycomb structures and the loop area was used for making scan images of composite damages.--This work was supported in part by NSF I/U CRC for NDE at Iowa State University and in part by FAA under contract #DTFA03-98-00008, delivery order 0038, technical monitor Paul Swindell.

Ultrasonic Nonlinear Characterization of the Stainless Steel Wire Reinforced Aluminum Composite
---Chung Seok Kim, Penn State University, Engineering Science and Mechanics, PA 16802; Tae Sung Park, Seoul National University of Technology, Department of Mechanical Engineering, Seoul, Korea; Dae Hyun Kim, Seoul National University of Technology, Department of Mechanical Engineering, Seoul, Korea; Ik Keun Park, Seoul National University of Technology, Department of Mechanical Engineering, Seoul, Korea

---The ultrasonic nonlinearity technique for nearly closed cracks was demonstrated for hot pressing of stainless steel 304 short wire reinforced aluminum composite of internal gap. Aluminum based composites are considerable attention as potentials in the aerospace industry and the automotive industry due to their high specific strength and low thermal expansion coefficient. The aluminum composite was made by hot pressing technique at the temperature of 600°C under pressure of 50kg/cm2 and subsequent aging at 500°C. The normalized ultrasonic nonlinearity (β/β0) increased after 4 hr. aging due to the increase of clapping effects of micro voids, which generate the second harmonic, while the longer aging of 8 hr. and 10 hr. showed decrease of ultrasonic nonlinearity indicating that no clapping occurred because of coalescence of coarsened porosity. This suggests potentials to detect the nearly closed cracks comparable to incident compressive wave amplitude.

Eddy Current Assessment of Engineered Components Containing Nanofibers

---**Ray Ko**, Wally Hoppe, and Jenny Pierce, University of Dayton Research Institute, Structural Integrity Division, 300 College Park, Dayton, OH 45469-0120

---New and exotic materials and components are being engineered for specific physical properties through the use of nanotechnologies such as the inclusion of carbon nanofibers. Carbon nanofibers 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 fibers 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 between two separated electrodes. Eddy current methods can provide a more localized measure of conductivity on the surface of a component. In this study, engineered components containing nanofibers 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 non-contact eddy current evaluation of engineered components containing nanofibers will be presented.

Experimental Determination of the Electric Conductivity and Magnetic Permeability of Different Steels and Its Application to Steel Identification in a Pipe Mill

---Gustavo A. Sánchez, **Javier I. Etcheverry**, and Nicolás Bonadeo, TenarisSiderca R&D, Campana, Pcia. Buenos Aires, Argentina

---Eddy currents based equipments can detect differences in electrical conductivity or magnetic permeability of steel samples allowing their proper identification. The starting point of the analysis is the development of a technique to measure the electrical conductivity and the magnetic permeability of steel samples that uses the frequency dependence of the complex electrical impedance measured using a four point contact technique. This allows characterizing the expected coil impedance at low excitation currents. At higher excitation currents the nonlinear/hysteretic behavior of the steel cannot be disregarded. We present preliminary measurements of hysteresis curves together with a numerical analysis of their influence on the anharmonicity of the coil output.

Characterization of the Level of Plastic Deformation in Cold-Rolled Ti–6Al–4V Samples by Thermoelectric Power Measurements

---**H. Carreon**, A. Medina, and A. Ruiz, Universidad Michoacana, Instituto de Investigaciones Metalúrgicas, Morelia, Michoacan, Mexico

---This paper presents experimental data that illustrates the intrinsic sensitivity of the thermoelectric contact technique based on the Seebeck effect, in order to detect the presence of anisotropy due to plastic deformation produced by the manufacturing process of cold working at different degrees of reduction in thickness, namely 40, 60 and 80% in Ti–6Al–4V. The results describe the behavior of the thermoelectric power (TEP) coefficient with respect to the anisotropy and microstructure in a highly textured material that presents both morphological and crystallographic texture. Ultrasonic measurements of shear wave velocity were also conducted in order to obtain a direct correlation between the presence of a significant anisotropy in the cold-rolled Ti–6Al–4V samples and the TEP measurements, before and after heat treatment (annealing). TEP measurements offer a means to assess the evolution of the level of plastic deformation, which allows for a better correlation between texture-induced anisotropy and the material's microstructural and properties.

Effects of Crack Morphology and Closure on Ultrasonic Response

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

---When implementing an inspection, the required sensitivity is often specified as that required to detect a flaw of size sufficient to initiate failure under the design load. This specification assumes knowledge of the strength of the signal generated by the critically sized flaw. Common practice determines and verifies the critical flaw signal strength through a combination of model predictions and test standard experiments, using an artificially machined reflector of size equivalent to that of the critically sized flaw. An important aspect of this practice that needs improved understanding is the variability of signal strength observed in naturally occurring flaws, due to the effects of crack closure and flaw morphology. This poster reports on ongoing work to examine the variability resulting from effects of crack closure and morphology. Work is examining the response of fatigue cracks grown under cyclic loading using an in-situ measurement configuration in which cracks are electronically scanned using a 10 MHz phased array while crack loading is varied. Data showing signal amplitude variability as a function of applied load are being compiled. Precise crack morphology is being measured on selected samples using a combination of high frequency ultrasonic microscopy and X-Ray CT on optimally sectioned samples. The measured morphologies are being used in predictive models of ultrasonic crack scattering to quantify differences between signals generated by idealized reference reflectors, upon which inspection criteria are based, and the signals observed in actual flaws.---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.

Inspection of Internal Defects in Cold-Rolled Steel Sheets Using Lamb Wave

---**Sang-Woo Choi**, Goohwa Kim, and Jinsu Bae, POSCO, Instrumentation & Control Research Group, Pohang, Gyeongbuk, Korea

---Steel product parts such as automotive panel, appliance case and can are made of steel sheet by pressing. Burst of product and tool broken can be happen at pressing process because of internal defects in cold-rolled sheet. Ultrasonic test using Lamb wave was proposed to detect these internal defects at on-line process. In this study, Lamb wave was applied to inspect natrual internal defects in the cold-rolled steel sheets in the laboratory. Injecting air into molten steel in the slab mold introduced oxidized inclusion defects with various sizes naturally during continuous casting process and these real defects were stretched in rolling direction in rolling process. Lamb wave was introduced to inspect defects in width direction which is normal to the defect direction. Artificial defects with different depth and width were inspected to evaluate sensitivity of Lamb wave and to select better mode of Lamb wave. Inspected natural internal defects were evaluated to show their shape and to find exact location with other techniques such as magnetic particle test and X-ray CT. There is correlation between MT indication length and Lamb wave signal level. All of real defects were located near the subsurface according to the X-ray CT results.

Characterization of Fatigue Damage in A36 Steel With Nonlinear Rayleigh Waves

---**Suzanne E. Duncan** and Laurence J. Jacobs, Georgia Institute of Technology, School of Civil and Environmental Engineering, Atlanta, GA 30332-0355; Jin-Yeon Kim and Jianmin Qu, Georgia Institute of Technology, G. W. Woodruff School of Mechanical Engineering, Atlanta, GA 30332

---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 which has been used to describe changes in micro structure 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.

Ultrasonic Testing for the Evaluation on the Decarburization of SA 106 Carbon Steel

---**Ho Sang Shin** and Myung Ho Song, Materials Engineering Department, Korea Institute of Nclear Safety, Daejeon, Korea; Hak-Joon Kim and Sung-Jin Song, School of Mechanical Engineering, Sungkyunkwan University, Suwon, Kyunggi-do, Korea; Sung Sik Kang, Reactor Engineering Research Department, Korea Institute of Nclear Safety, Daejeon, Korea; Joong Keun Park, Department of Materials Science and Engineering, Korea Advanced Institute of Science and Technology, Daejeon, Korea

---Decarburized layer which can be one of major causes of material degradation was found in some feeder pipes in pressurized heavy water reactor. The existence of decarburized layer can be identified by either using optical observation of the microstructure of the materials or measuring the micro-hardness. However, a method that can measure decarburized layers nondestructively is needed. Thus, in this study, we will apply ultrasonic methods to characterize the decarburized layers, since ultrasonic methods can measure change of grain size and/or hardness using attenuation and sound velocity. For that purpose, we fabricated decarburized SA 106 carbon steel specimens with different chromium contents and decarburizing time. And then, optical microscope analysis and hardness testing will be performed to clarify the change in microstructure due to decarburization heat treatment of SA 106 carbon steel with different chromium contents. From the measured results, we will investigate relations between decarburized layer and ultrasonic parameters (attenuation and sound velocity). In this presentation, optical measurements of decarburized layers and variation of ultrasonic parameter of the decarburized specimens will be discussed. Also, relation between ultrasonic parameters and decarburizing time will be presented.

Application of Laser-Generated Ultrasound for Evaluation of Wall-Thinning in Carbon Steel Elbow

---**Do-Youn Kim**, Joon-Hyun Lee, Dae-Hoon Lee, and Young-Joon Ha, Pusan National University, Graduate School of Mechanical Engineering, Jangjeon-dong, Gumjeong-gu, Busan

---The objective of this research is to estimate location and size using laser ultrasound guided wave for wall thinning evaluation of elbow. Wall thinning of carbon steel pipe is one of the most serious problems in Nuclear Power Plant especially wall thinning of carbon steel elbow caused by FAC (Flow-Accelerated Corrosion). Therefore non-destructive inspection method of elbow is essential for safe operation of nuclear power plants. Specimens used in this study were carbon steel elbows as the main elements of real nuclear power plants, and shape of wall thinning was an oval with 120mm-width, 80mm-length and 5mm-depth. The L(0,1) and L(0,2) modes variation of ultrasound guided wave from the response obtained by the laser generation/air-coupled detection ultrasonic hybrid system represent characteristics of the defect. The trends of these characteristics and signal processing used to estimate the size and location of wall thinning.

Non-Contact Magnetostrictive Lamb-EMAT Designs and Applications for Health Monitoring of Piping

---**Ik-Keun Park**, Seoul National University of Technology, Department of Mechanical Engineering; Tae Sung Park and Yong-Kwon Kim, Seoul National University of Technology, Graduate School of Energy and Environment; Young-June Kang, Chonbuk National University, Department of Mechanical Design Engineering, Korea

---Ultrasonic guided waves are widely being studied and successfully applied to various non-destructive tests with the advantage of a long range inspection. A magnetostrictive Lamb EMAT transducer is a non-contact transducer which can transmit the ultrasonic guided waves into specimens without couplant. Therefore, it is possible to detect flaws without interruption using the EMAT transducer. And it can easily generate guided waves which are desired in each specific problem by altering the design of coil and magnet. In this study, the Ultrasonic guided waves, which are generated by EMAT, have been applied to estimate the thickness-reduction. The defects of the thickness-reduction are simulated as a hidden-corrosion-area in thin steel plates. Especially, interesting features of the dispersive behavior in selected wave modes are used to detect the thickness-reduction. Experimental results show that the observation of mode-cut-off allows us to monitor the reduction-level. In addition, the reduction-level can be quantified by the measurement of the group velocity of the wave which passes though the thinning area. Consequently, it turns out that change of group velocity and mode-cut-off can be used as a parameter for the evaluation of the thickness-reduction.

Application of Impulse Resonant Acoustic Spectroscopy (IRAS) for Crack Detection in Pipes

---**Alexander Sutin**, Stevens Institute of Technology, Hoboken, NJ 07901; Yulian Kin, Purdue University, Calumet, IN; Shayne Drivdahl and Christopher Drenth, Boart Longyear Company, Salt Lake City, UT

---Acoustic methods of crack detection are based on crack influence to acoustic wave propagation. One of the most powerful methods of acoustic NDE, Impulse Resonance Acoustic Spectroscopy, is based on impact excitation of tested parts and measurements of frequencies of free vibrations and their decay (Q factor). The presence of cracks decreases resonance frequencies and Q factor. In many cases, cracks also can lead to splitting of resonance frequencies. We developed software for fast processing of IRAS measurement results (resonance frequencies and Q factors) from the recorded signal of free vibration. Vibrations can be measured by microphone or laser vibrometer. The developed technique was applied to test tooling used by Boart Longyear for environmental drilling. Twenty eight steel pipes were tested at Purdue Calumet Fracture Mechanics Laboratory. Nine of the 28 tested pipes had measurable frequency shift and low Q factor. Existence of cracks in some of these pipes was validated by dye penetration method. We believe that IRAS method and developed software can be recommended for pipe inspections in the field. Support of Boart Longyear Company is greatly appreciated.

Evaluation of Leak Signal of High Temperature and Pressure Pipeline Using AE Sensor and Accelerometer Sensors

---**Jin-Hyun Kim**, Joon-Hyun Lee, Bong-Min Song, and Young-Hoon Kim, Pusan National University, Research Institute of Mechanical Technology, Graduate School of Mechanical Engineering, 30 JangJeon-Dong, GeumJeong-Gu, Busan, 609-703, Korea

---Currently in most Nuclear power plants, the acoustic leak monitoring system using acoustic emission sensor is mainly employed to detect leakage of high temperature and pressure pipeline. Since this kind of system only monitors the existence of leak using the Root Mean Square(RMS) value of raw signal from AE sensor, the difficulty arises when the characteristics of leak need to be evaluated such as shape and size of the leakage. In this study, dual monitoring system using AE and Accelerometer sensors was introduced in order to solve the problem above. AE sensor would receive surface wave which propagates along pipeline structure meanwhile accelerometer sensor would receive low frequency vibration signal generated by the leakage. The Levenberg-Marquardt of Artificial Neural Network training algorithm was also applied due to rapid training rate and gave the reliable classification performance. The input parameters of this artificial Neural Network were extracted from signal received by changing experimental condition as : (1) fluid pressure inside pipe, (2) the shape of the leak area, (3) the size of leak area.

Surface Defects on GA Steel Sheets and Detection

---**Jinsu Bae**, Goohwa Kim, and Sang-woo Choi, POSCO, Instrumentation & Control Research Group, Pohang, Gyeongbuk, Korea

---The GA(Galvannealed) strips are strategic steel products used for the exterior of cars and other high value-added manufacturing fields. Steel companies recently focused on delivering high quality products which have no surface or internal defects along the full length of the strip. It is necessary to inspect defects of steel sheets while being produced. The objective of this study is to estimate the characteristics of surface defects of GA strip and to get the relationship between surface defects and the results of ultrasonic inspection. The shapes and ingredients of such defects are found using optical microscope and SEM and surface defects have high correlation with the results of lamb wave inspection. We analyzed the process for defects to be formed in the steel production line.

Formation of Stress Corrosion Cracks in Austenitic Stainless Steel and Their Evaluation Using Subharmonic Phased Array for Crack Evaluation (SPACE)

---**Hiroaki Endo**, Kosuke Sasaki, Setsu Yamamoto, Yoshikazu Ohara, and Kazushi Yamanaka, Tohoku University, Department of Materials Processing, Sendai-City, Miyagi, Japan; Tsuyoshi Mihara, University of Toyama, Department of Mechanical and Intellectual Systems Engineering, Toyama-City, Toyama, Japan

---When large-amplitude ultrasound is transmitted to closed cracks which cause underestimate of crack depths, subharmonic wave with half-frequency of input signal is generated, so this wave is expected to be useful for detecting and evaluating closed cracks. However, the measurement of closed crack depth has never been achieved. In this situation, we developed the subharmonic phased array for crack evaluation (SPACE), and demonstrated accurate sizing of closed fatigue crack depth. In this study, we formed stress corrosion cracks (SCCs) by applying bending stress in MgCl2 solution after extending fatigue cracks in sensitized austenitic stainless steel SUS304 specimens, imaged it with the SPACE. Next we compared crack depths optically observed after slicing SCC specimen with measured crack depths in fundamental and subharmonic images. As a result, subharmonic images gave less underestimate of crack depths than fundamental images did. Therefore we verified accurately sizing not only of fatigue cracks but also of SCCs. Additionally subharmonic images gave crack depths deeper than optically-measured crack depths. This suggests that subharmonic images could measure the optically-unobservable crack depths. In our future work, in order to enhance the signal-to-noise ratio and lateral resolution, we will use LiNbO3 (LN) array transmitter to focus the beam.

Application of Ultrasonic Rayleigh Surface Waves to Characterize Asphaltic Concrete

---**Chi-Won In**, Jin-Yeon Kim, Laurence Jacobs, and Kimberly Kurtis, Georgia Institute of Technology, Civil and Environmental Engineering, Atlanta, GA 30332-0355

---This study develops a real time segregation monitoring system of asphalt concrete by inspecting a two layered asphaltic concrete beam with bottom segregation. Segregation occurs when coarse aggregate materials are localized in some areas and fine aggregate in others. A wedge excitation technique (generation) and an air coupled transducer (receiver) is implemented to measure Rayleigh surface waves in an asphaltic concrete beam with bottom segregation. Two ultrasonic parameters, the phase velocity and attenuation coefficient, are measured in this asphaltic concrete beam with bottom segregation and are compared to the results measured in an asphaltic concrete beam without segregation. Next, a numerical simulation is performed on an asphaltic concrete beam to validate the experimentally measured results; an effective medium is developed with two different layers. The experimental and numerical simulation results demonstrate the potential of using ultrasonic Rayleigh surface waves to characterize localized segregation in asphaltic concrete in real time.

Influence of Surface Properties on the Detection and Quantification of Voids in Concrete Structures

---Christiane Maierhofer, Mathias Röllig, and **Marc Kreutzbruck**, Federal Institute for Materials Research and Testing (BAM), Department VIII Non-Destructive Testing, Berlin, Germany; Ralf Arndt, Federal Highway Administration, Turner Fairbank Highway Research Center, Georgetown Pike, VA

---Impulse-thermography is an active method for quantitative investigations of the near surface region of various structures. It has recently been applied and optimized to applications in civil engineering. By using an external heat source, parts of the structure under investigation are heated up and the transient heat flux is observed by recording the temperature change at the surface as a function of time. This method is very well suited for the detection of voids and honeycombing in concrete up to concrete covers of 10 cm. Also safety relevant defects like delaminations, voids in tendon ducts and cracks in concrete can be recognized. For quantitative analysis of data recorded on the building site, the problems are manifold. Here, the influence of the following surface properties on the detection and characterization of voids and honeycombing simulated by polystyrene cubes and cubes prepared of porous concrete will be studied: mechanical treatment of concrete surface; contamination with vaseline, used as coupling agent for ultrasonic testing; white wall paint; untreated surface. Various amounts of heat and two different defect depths are considered and data were analyzed in time as well as in frequency domain.

Thickness Determination of a Plate with Varying Thickness Using an Artificial Neural Network for Frequency-Time Representation of Lamb Waves

---Chidentree Treesatayapun and **Arturo Baltazar**, Centro de Investigación, y Estudios Avanzados, Cinvestav Unidad-Saltillo Robotics and Advanced Manufacturing Program, Ramos Arizpe, Coahuila, Mexico; Jin-Yeon, Kim, Georgia Institute of Technology, GWW School of Mechanical Engineering, Atlanta, GA 30332-0355

---Thickness estimation of a varying-thickness media is carried out using an algorithm acting as an artificial neural network for time-frequency representation (TFR) of Lamb waves. Dispersion curves are reconstructed using a self adjustable network multi-input fuzzy rules emulated network (MIFREN). The uncertainty in the frequency-time determination is compared with typical spectrogram techniques. The novel proposed algorithm is computationally less complex than others used in the past. Experimental results were obtained exciting Lamb waves with narrow band transducers on an aluminum plate with varying thickness and then compared with numerical estimations.

Synthetic Aperture Focusing for Through-Transmission Microwave Nondestructive Imaging Applications

---**Mohammad T. Ghasr** and Reza Zoughi, Missouri University of Science and Technology (MO S&T), ECE Department, Applied Microwave Nondestructive Testing Laboratory (amntl), Rolla, MO 65409-0040

---Synthetic aperture focusing techniques (SAFT) provides for many advantages in microwave imaging such as having robust and efficient algorithm. Currently the monostatic configuration is mostly used due to its simplicity in SAFT processing algorithm. However, in some nondestructive imaging applications it is advantageous to perform the measurement in a bistatic configuration. Furthermore, when access to both sides of the sample under test is readily available, a bistatic through -transmission configuration may help in reducing unwanted reflections and thus enhancing the obtained images. The bistatic configuration offers some degrees of freedom in term of probe design and target illumination strategies. On the other hand, the increased freedom comes on the expense of increased complexity in synthetic aperture processing algorithms. Swept frequency version of this method is potentially capable of producing 3D (volumetric) images of embedded flaws. Recently, the bistatic SAFT have received attention from the earth and oceanic observatory scientists for its many advantages. This paper will demonstrate the utility of bistatic SAFT for microwave nondestructive testing applications using scanned 1D and 2D synthetic arrays.

Small Printed Ultra-Wideband Antenna for Near-Field Imaging

---**Ibrahim Elshafiey**, Abdel Fattah A. Sheta, Majeed A. Alkanhal, and Zeyad Al-Hekail, King Saud University, Department of Electrical Engineering, Advanced Technologies Research Center (ATRC), Riyadh, Saudi Arabia; Abdullah AlOrainy, King Abdulaziz City for Science and Technology, Electronics Research Institute, Riyadh, Saudi Arabia

---Ultra-wideband (UWB) antennas have been suggested recently for use in near field imaging systems. A small printed antenna is introduced in this paper with reduced ground-plane effect to achieve UWB characteristics, and thus allows reconfiguration of the inspection system to various operation sub-bands. Design and optimization of antenna characteristics including matching and bandwidth are performed using FDTD computational modeling. Simulation is performed of the antenna in free space as well as in the proximity to multilayer configuration simulating composite material structures. Antenna performance is also studied in the vicinity of biological tissues. Experimental validation of antenna characteristics is studied using liquid samples to allow evaluation of field values inside the material. The system implements a six-degree-of-freedom robot to control the scanning of the object with the measurement sensor. Results of this research should help enhance applications of UWB imaging as a nondestructive tool for material characterization.

Dedicated Filter for Defects Clustering in Radiographic Images

---**Ryszard Sikora**, Kamil Swiadek, and Tomasz Chady, Szczecin University of Technology, Department of Electrical Engineering, Szczecin, Poland

---Defects clustering is very important issue in defect recognition and identification phase during radiographic image analysis. In many cases groups of defects such as linear or clustered porosity are more important than single flaws. Dedicated lookup table based filter is used for calculation of distances between objects in the specified range. Maximum range might be specified by user or can be automatically obtained in accordance to each defect size and EU/ISO norms. The result matrix contains distances (in pixels or millimeters) and shows relations between all objects at the input image. Input image should be preprocessed and all objects should have unique indexes. To optimize calculations of distances, input image is previously scanned to obtain boundary coordinates of each object. Next within this specified range distance mask is used for each defect's pixel. This algorithm was tested with both true and simulated radiograms containing typical welds and castings flaws, which should be considered as clusters.

Ultrasonic and Radiographic Imaging of Niobium Target Capsules for Radioisotope Production

---Hong Bach, **Thomas N. Claytor**, James F. Hunter, Francois M. Nortier, Donna M. Smith, Los Alamos National Laboratory, MS C914, Los Alamos, NM 87544; John W. Lenz, John W. Lenz & Associates, 412 Muskingum Road, Waxahachie, TX 751653; Chuck Moddrell and Paul A. Smith, P. A. Smith Concepts & Designs, 1475 Central Ave, Suite 250, Los Alamos, NM 87544

---In proton-irradiated radioisotope production, the target capsules are exposed to intense radiation, thermally induced stress, and chemicals for extended periods. The structural integrity of the target capsules is of crucial importance for containing the accelerator-produced radioisotopes. The capsule material needs to be as light and transparent to the proton beams as possible, and preferably does not become significantly activated under proton irradiation. In addition, the material for the capsule needs to be as defect-free as possible. For many materials, these conditions are difficult to meet. It is also not known if the isotope producing target material wets the capsule that encapsulates it and if it does, to what degree. We show that local areas of wetting occur between the gallium starting material and the niobium capsule. We use ultrasonic images from various lots of niobium capsule material to assess the integrity of the capsules. Digital radiography is also used to detect any voids in the isotope producing target material that will tend to cause local heating in the capsules. These results illustrate the utility of non destructive testing in detecting defects that may result in mechanical failures of the capsules during proton-irradiated radioisotope production.

Visualization of Ultrasonic Waves Scattered from Rear Defects by Using a Laser-Based Imaging Technique

---**J. Takatsubo**, B. Wang, H. Miyauchi, H. Tsuda, N. Toyama, and K. Urabe, National Institute of Advanced Industrial Science and Technology, Research Institute of Instrumentation Frontier, Tsukuba, Ibaraki, Japan

---We proposed a method for visualizing wave propagation in ultrasonic fields. This method generates thermal-excitation ultrasonic waves on a specimen through pulsed laser scanning and detects the propagating signals via a reception transducer mounted on a fixed point. Dynamic images of ultrasonic waves propagated from a fixed point are created using the reciprocity principle of wave propagation. This method has the excellent feature that enables a visible and quick flaw inspection for actual objects. However, since this method visualizes all waves propagating on an object, it is disadvantageous in that defect echoes are often hidden in the forward traveling wave. In this research, we developed a data processing method for image enhancement of defect echoes. In the ultrasonic tests with aluminum plates or pipes with rear defects, we could visualize the defect echoes as they scatter in a radial manner, like water rings, on the surface of the specimen, which proved the validity of this data processing method. These results demonstrated the usefulness of the laser-based ultrasonic visualization technique in flaw inspection.

High Resolution Transforms

---Arno W. F. Volker and **Joost G.P. Bloom**, TNO Science and Industry, P. O. Box 155, 2600 AD Delft, The Netherlands

---The introduction of phased arrays opens-up a range of new possibilities for ultrasonic inspections. Arrays come in various shapes ranging from linear arrays for weld inspection to circular arrays emitting guided waves for permanent monitoring applications. For this kind of applications, the data is best displayed as angle versus time to locate the position a defects. However, the data is normally measured as function of a certain spatial coordinate and time. A transformation is then applied to convert data from the spatial domain into the angle domain. The simplest example is a spatial Fourier transform. Unfortunately the resolution obtained by this kind of transforms is determined by the size of the array compared to the wavelength. The longer the array is compared to the wavelength, the higher is the resolution. The reason for this is the increased phase rotation along the aperture. A new iterative approach is proposed to overcome the shortcomings of the traditional plane wave decomposition. This is a so-called high resolution transform. The new approach yields at least a five times higher resolution and can deal easily with irregular sampling or missing data. The approach will be illustrated on numerically modeled.

Applications of Detrended-Fluctuation Analysis to Gearbox Fault Diagnosis
---**Elineudo P. Moura**, André P. Vieira, Universidade Federal do Ceará, Departamento de Engenharia Metalúrgica e de Materiais, Fortaleza, CE, Brazil; Marcos A. S. Irmão, Universidade Federal do Vale do São Francisco, Colegiado de Engenharia Mecânica, Juazeiro, BA, Brazil; Antonio A. Silva, Universidade Federal de Campina Grande, Departamento de Engenharia Mecânica, Campina Grande, PB, Brazil

---Aiming at fault diagnosis, we study vibration signals obtained from gearboxes under various conditions. We consider normal gearboxes, gearboxes containing scratched gears, and gearboxes containing toothless gears, both unloaded and under load, with several rotation frequencies. By applying detrended-fluctuation analysis (DFA), a mathematical tool introduced to study fractal properties of time series, we are able to distinguish the signals with respect to their working conditions. For each signal, DFA involves performing a linear fit to the data inside intervals of a certain size, and evaluating the corresponding fluctuations detrended by the local fit. Repeating this procedure for many interval sizes yields a curve of the average fluctuation as a function of size. From the curves, we define vectors whose components correspond to the average fluctuation associated with suitably chosen interval sizes. We finally apply principal component analysis to the set of all vectors, obtaining very good clustering of the transformed vectors according to the different working conditions, with a performance comparable to that obtained from Fourier analysis, especially for gears working under load.

Experimental Study of the Repeatability and Accuracy of the Impact Excitation of Vibration Technique for Prismatic Steel Samples
---Leandro Iglesias Raggio, **Javier I. Etcheverry**, and Nicolás Bonadeo, TenarisSiderca R&D, Applied Physics Department, Campana, Buenos Aires, Argentina

---Measurement of the lowest resonance frequencies for several steel parallelepipeds of different aspect ratios allows analyzing the repeatability of the technique, as well as the influence of the sample geometry on the obtained elastic moduli and wave speeds. This work shows that standard expressions for the elastic moduli as functions of the sample dimensions and measured resonance frequencies limit the accuracy to about 1-2% unless the sample dimensions are chosen in an appropriate way. If more accurate numerical results based on the solution of the 3D linear elasticity equations are used to compute the elastic moduli, these inaccuracies are eliminated.

Session 30

SESSION 30
STRUCTURAL HEALTH MONITORING II
S. Krishnaswamy, Chairperson
Meeting Room F

3:30 PM **Dynamically Reconfigurable Piezoelectric Sensors for Ultrasonic Nonlinearity Measurements**
---**G. R. Kirikera**, B. Regez, O. Balogun, A. Zinck, and S. Krishnaswamy, Northwestern University, Center for Quality Engineering and Failure Prevention, Evanston, IL 60208

3:50 PM **Structural Health Monitoring of Stiffened Plates Using Guided Ultrasonic Waves**
---**P. Fromme**, University College London, Department of Mechanical Engineering, London, United Kingdom

4:10 PM **Effects of Liquid Loading and Degradation of Adhesive Joints on Subtraction Techniques for Structural Health Monitoring**
---**T. Cicero**, P. Cawley, M. J. S. Lowe, and F. Simonetti, Imperial College, Mechanical Engineering, London, United Kingdom

4:30 PM **Continuous Structural Health Monitoring Guided Wave PPM System Using Steel Pipes as Communication Channel for Flood Detection in Steel Offshore Oilrigs**
---**R. Mijarez** and F. Martinez, Gerencia de Control e Instrumentación, Instituto de Inestigaciones Eléctricas, CP 62490, Cuernavaca, Morelos, Mexico; P. Gaydecki, The University of Manchester, School of Electrical and Electronic Engineering, P. O. Box 88, Manchester M60 1QD, United Kingdom

4:50 PM **A Millimeter Wave Sensor for Far-Field Standoff Vibrometry**
---S. Bakhtiari, N. Gopalsami, T. W. Elmer, and A. C. Raptis, Argonne National Laboratory, Nuclear Engineering Division, Argonne, IL 60439-4825

Dynamically Reconfigurable Piezoelectric Sensors for Ultrasonic Nonlinearity Measurements

---**Goutham R. Kirikera**, Bradley Regez, Oluwaseyi Balogun, Aurora Zinck and Sridhar Krishnaswamy, Northwestern University, Center for Quality Engineering and Failure Prevention, Evanston, IL 60208

---Ultrasonic interaction with damage in a material can lead to nonlinear ultrasonic harmonic generation. For ultrasonic nonlinearity measurements, ultrasound at one frequency is injected into a specimen at one location, and the fundamental and second harmonic signals are received at another. The receive sensors therefore need to have a large dynamic range. To facilitate this, we propose to modify standard interdigital transducers by coupling the two sets of electrodes in a sum and difference configuration externally. It can be shown that the summed signal eliminates the fundamental and all odd harmonics, and the difference signal eliminates all even harmonics. Dynamic external reconfiguration of the electronics can therefore enable the same sensor to precisely measure either the fundamental or the second harmonic signal without running into problems of amplifier saturation that would be encountered with broadband receivers. In this work, we demonstrate such sensors for use in ultrasonic nonlinearity based structural health monitoring systems.

Structural Health Monitoring of Stiffened Plates Using Guided Ultrasonic Waves

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

---Structural health monitoring using permanently attached, distributed sensors for guided ultrasonic waves offers an efficient methodology for the long-term monitoring of large technical structures. The measurement concept has been demonstrated for plate structures and shown to be able to localize defects under laboratory conditions. For the application to real technical structures it needs to be shown that the methodology works equally well in the presence of structural features. Structural features, e.g. stiffeners, have been identified as safety-critical areas for the development of fatigue and corrosion damage. Problems employing this structural health monitoring concept can occur due to the presence of additional changes in the signal reflected at undamaged parts of the structure. Laboratory experiments are presented for a large steel plate structure with a welded stiffener and crack-like defects (notch). The influence of the signal processing parameters and transducer placement on the damage localization accuracy is discussed. Results are compared to Finite Element simulations to investigate the influence of signal variation and noise.

Effects of Liquid Loading and Degradation of Adhesive Joints on Subtraction Techniques for Structural Health Monitoring

---**Tindaro Cicero**, Peter Cawley, Michael J. S. Lowe and Francesco Simonetti, Imperial College, Mechanical Engineering, London, United Kingdom

---Ultrasonic guided waves offer the possibility of inspecting large areas from a small number of sensor positions. However, inspection of complex structures is difficult as the reflections from different features overlap. Identifying changes in measured signals over time is crucial for the development of a successful guided wave inspection system, in order to enable damage to be detected. Subtraction techniques appear to be a promising approach for Structural Health Monitoring (SHM) since they can identify changes in the measured signal by comparison of the recorded time trace with the available baselines for the undamaged structure. Subtraction performance can be negatively affected by several factors. For instance, temperature changes modify the mechanical properties of the material and therefore the velocity of propagation of the guided waves. This can result in a significant time shift between the current signal and the baseline, and therefore in poor results in the subtraction. Although the effects of temperature changes have been investigated and various compensation techniques have been proposed, less attention has been devoted to the effects of other issues of interest for SHM, such as liquid loading, painting and natural ageing of adhesive bond layers. In this work, the effects of liquid loading and variation of properties of adhesive bonds will be compared with the detrimental effects caused by temperature changes. Our aim is to establish whether temperature compensation techniques are able to cope also with the changes caused by liquid loading or changes in the mechanical properties of adhesive bonds.

Continuous Structural Health Monitoring Guided Wave PPM System Using Steel Pipes as Communication Channel for Flood Detection in Steel Offshore Oilrigs

---**R. Mijarez** and F. Martinez, Gerencia de Control e Instrumentación, Instituto de Investigaciones Eléctricas, CP 62490, Cuernavaca, Morelos, Mexico; P. Gaydecki, The University of Manchester, School of Electrical and Electronic Engineering, P.O. Box 88, Manchester M60 1QD, United Kingdom

---The detection of water inside hollow cross-beam members in offshore oilrigs is an underwater NDT technique, which is normally performed by divers and 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. The authors have developed a system that employs a single piezoelectric transducer that can be permanently attached to the inner wall of every sub-sea structure and which is powered by a normally inert seawater battery. Upon activation, the sensor transmits ultrasonic 21–42 kHz chirp or tone encoded pulses, to a monitoring receiver system at deck level for decoding and identifying flooded members. This work presents a continuous pulse position modulation (PPM) system, which transmits 40 kHz PPM ultrasonic guided waves pulses, through hollow steel tubes in air. The system employs two smart modulators that are composed of a PZT element, electronics and batteries. The demodulator instrumentation is made of a PZT ultrasound transducer, a DSP board and a microcontroller based module, which performs automatic PPM detection of guided wave energy packets. Experiments carried out in a tubular steel heliport structure and the base of a deck of an oilrig under construction, have successfully distinguished automatically guided wave encoded information.

A Millimeter Wave Sensor for Far-Field Standoff Vibrometry

---Sasan Bakhtiari, **Nachappa Gopalsami**, Thomas W. Elmer, and Apostolos C. Raptis, Argonne National Laboratory, Nuclear Engineering Division, Argonne, IL 60439-4825

---Current state-of-the-art in remote vibrometry is based predominantly on optical technology. Although these systems allow measurement of displacement with high degree of precision, they suffer from known limitations of optics including sensitivity to atmospheric conditions and surface scattering. We have developed a millimeter wave (MMW) counterpart of an optical vibrometer for the detection of acoustic signatures from common man-made structures and at far-field standoff distances. This compact W-band system employs solid-state active and passive components. The comparative studies carried out to date have demonstrated the advantages of the MMW sensor over commercial laser vibrometers with regard to detection range, ease of alignment, and reduced sensitivity to surface condition of the target. Although the system was intended initially for national security applications, it is expected that this technology will be useful for a wide range of applications including structural health monitoring, nondestructive examination of dielectric materials, and for biomedical sensing.

Session 31

SESSION 31
ULTRASONIC PHASED ARRAYS II
V. Lupien, Chairperson
Meeting Room D

3:30 PM **Ultrasonic Phased Array Inspection of Flaws on Weld Fusion Faces Using Full Matrix Capture**
---**R. Long** and P. Cawley, Imperial College, 682 Mechanical Engineering, Exhibition Road, London SW7 2AZ, United Kingdom

3:50 PM **The Wavenumber Algorithm – Fast Fourier-Domain Imaging Using Full Matrix Capture**
---**A. J. Hunter**, B. W. Drinkwater, and P. D. Wilcox, University of Bristol, Department of Mechanical Engineering, Queens Building, University Walk, Bristol, BS8 1TRa, United Kingdom

4:10 PM **Simulation of Advanced UT Phased Array Techniques with Matrix Probes and Dynamic Settings for Complex Component Inspections**
---**S. Chatillon**, S. Mahaut, and Ph. Dubois, CEA-LIST, Centre de Saclay, 91191 Gif-sur-Yvette, France

4:30 PM **Phased Array-Based SAFT for Defect Sizing on Power Plant Components**
---G. Brekow, D. Brackrock, R. Boehm, and **M. Kreutzbruck**, Federal Institute for Materials Research and Testing, Nondestructive Testing Department, 12205 Berlin, Germany

4:50 PM **Imaging of Simple Defects in Austenitic Steel Welds Using a Simulated Ultrasonic Array**
---**G. Connolly**, M. J. S. Lowe, and A. Temple, Imperial College, Mechanical Engineering, London, United Kingdom; S. Rokhlin, The Ohio State University, Edison Joining Technology Center, Columbus, OH 43085

5:10 PM **The Use of Scattering Coefficient Matrix to Predict and Optimize Multi-Modes Array Inspection with the TFM**
---**J. Zhang**, B. W. Drinkwater, and P. D. Wilcox, University of Bristol, Department of Mechanical Engineering, Bristol, BS8 1TR, United Kingdom

Ultrasonic Phased Array Inspection of Flaws on Weld Fusion Faces Using Full Matrix Capture

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

---Work is being conducted to develop phased array techniques for the ultrasonic inspection of welds in reactor pipe lines. Of interest is the inspection for flaws that might lie on the upper and lower fusion faces. Ideally this uses waves reflected and mode converted at the inner surface of the pipe, but most commercial phased array controllers do not currently provide for this. Our solution was to use Full Matrix Capture (FMC) and process the data ourselves. This paper introduces the FMC principle, describes the signal processing algorithms and illustrates how the processed data was presented; the advantages of FMC over conventional phased array data capture are then discussed. In addition, a comparison is made between the results obtained when using single depth focusing and focusing at each point in the image. The inspections were also modeled using the CEA CIVA software which was compared to experimental results.

The Wavenumber Algorithm – Fast Fourier-Domain Imaging Using Full Matrix Capture

---**Alan J. Hunter**, Bruce W. Drinkwater, and Paul D. Wilcox, University of Bristol, Department of Mechanical Engineering, Queens Building, University Walk, Bristol, BS8 1TR, United Kingdom

---Ultrasonic imaging using full matrix capture, e.g., via the total focusing method (TFM), has been shown to increase angular inspection coverage and improve sensitivity to small defects in non-destructive evaluation (NDE). In this paper, we develop a Fourier-domain approach to full matrix imaging based on the wavenumber algorithm used in synthetic aperture radar and sonar. The extension to the wavenumber algorithm for full matrix data is described and the performance of the new algorithm compared to the TFM, which we use as a representative benchmark for the time-domain algorithms. The wavenumber algorithm provides a mathematically rigorous solution to the inverse problem for the assumed forward wave propagation model, whereas the TFM employs heuristic delay-and-sum beamforming. Consequently, the wavenumber algorithm has an improved point-spread function and provides better imagery. However, the major advantage of the wavenumber algorithm is its superior computational performance. For large arrays and images, the wavenumber algorithm is several orders of magnitude faster than the TFM. On the other hand, the key advantage of the TFM is its flexibility. The wavenumber algorithm requires a regularly sampled linear array, while the TFM can handle arbitrary imaging geometries. The TFM and the wavenumber algorithm are compared using simulated and experimental data.

Simulation of Advanced UT Phased Array Techniques with Matrix Probes and Dynamic Settings for Complex Component Inspections

---**S. Chatillon**, S. Mahaut, and Ph. Dubois, CEA-LIST, Centre de Saclay, 91191 Gif-sur-Yvette, France

---UT Phased arrays are now widely used in various industrial fields thanks to their inherent versatility compared to inspections carried out with standard probes. In addition to the adaptability to various inspection configurations – beam focusing and deflecting through arbitrary interfaces using modeled delay laws- , the ever increasing number of channels in industrial acquisition systems and optimized 2D probes (matrix, sectorial patterns) allow designing new applications using the combination of electronic commutation (use of successive groups at transmission and reception scanned over the aperture of the array), multiple shots and multiple receptions (application of dynamic depth focusing laws). This paper presents new tools dedicated to matrix settings in terms of trajectories, multiple delay laws settings which have been recently gathered in the CIVA platform software. Those skills are illustrated with experimental and simulated configurations for complex inspection cases.

Phased Array-Based SAFT for Defect Sizing on Power Plant Components

---Gerhard Brekow, Daniel Brackrock, Rainer Boehm, and **Marc Kreutzbruck**, Federal Institute for Materials Research and Testing, Nondestructive Testing Department, 12205 Berlin, Germany

---Quantitative NDE methods play a key role when it comes to inspect components, which requires high operational safety. UT-SAFT is one of the well-known reconstruction tools, which provides information about the defect size. In this work we studied the use of phased array technique in combination with the SAFT algorithm to inspect power plant components. As a first example we inspected a real-sized mock-up model representing a part of a reactor pressure vessel with a 180 mm-thick ferritic base material followed by a 6 mm-thick austenitic cladding layer. The phased array probe was coupled at the outer ferritic surface. We detected and sized artificial cracks within the cladding with a depth ranging from 4 mm to 10 mm. Secondly, we investigated a mock-up model resembling a nozzle including a thermo sleeve inlet and a maximum wall thickness of about 37 mm. Artificially inserted notches with a depth of 3 mm could be detected and sized, where the thermo sleeve is welded at the inside of the nozzle. We also report on accompanying model calculations adapting our experimental parameters and describing the required inspection conditions for an appropriate use of SAFT.

Imaging of Simple Defects in Austenitic Steel Welds Using a Simulated Ultrasonic Array

---**George Connolly**, Michael J. S. Lowe, and Andrew Temple, Imperial College, Mechanical Engineering, London, United Kingdom; Stanislav Rokhlin, The Ohio State University, Edison Joining Technology Center, Columbus OH 43085

---Austenitic steel is the main material used in the piping and the construction of pressure vessels in nuclear power plants due to its high fracture toughness and resistance to corrosion. Ultrasonic inspection of this material is difficult due to the formation of anisotropic grains, resulting in an inhomogeneous structure whose texture is unknown. These grains are similar in dimension to the applied ultrasonic wavelength, causing scattering and severe beam-steering. The use of ultrasonic phased arrays has increased within recent years since they can perform multiple types of inspection without the need for physical reconfiguration, and they allow the rapid production of images of the structure through post-processing of received signals. These arrays offer great potential to the NDT industry since they enable inspections of higher quality to be performed over shorter times. This paper will outline the principles of elastic wave propagation through inhomogeneous anisotropic media and the generation of images of point or simple planar defects within the weld. Simulated images of defects, within a previously developed model of the weld, produced from various inspection types and wave modes will also be shown. Future needs and studies will be discussed.

The Use of Scattering Coefficient Matrix to Predict and Optimize Multi-Modes Array Inspection with the TFM

---Jie Zhang, Bruce W. Drinkwater, and Paul D. Wilcox, University of Bristol, Department of Mechanical Engineering, Bristol, BS8 1TR, United Kingdom

---The scattering coefficient matrix describes the far field amplitude of scattered signals from a scatterer as a function of incident and scattering angles. It can be predicted from FE model. By combining the predicted scattering coefficient matrix with a ray tracing model to predict the full matrix of array data, an efficient forward model of the complete array inspection process is presented. Shear wave and wave mode conversions are considered in the model. The TFM images for various wave mode combination cases from a weld sample are predicted and measured. Results show that by selecting the optimum array mode combination a good image for a given defect in the weld sample can be produced using an array. This technique can also be used for optimizing the array inspection configuration.

Session 32

SESSION 32
NDE FOR ENGINEERED MATERIALS
J. Smith, Chairperson
Meeting Room G

3:30 PM **Evaluation of Oven-Cured, Solid Carbon/Epoxy Composites with Various Porosity Levels**
---**M. A. Stone**, Cirrus Design, 4515 Taylor Circle, Duluth, MN 55811

3:50 PM **Ultrasonic Imaging for Assessment of Impact Damage in Composite Plates**
---A. Kumar, G. K. Sharma, **T. Jayakumar**, and B. Raj, Indira Gandhi Center for Atomic Research, Nondestructive Evaluation Division, Kalpakkam, Tamil Nadu, India; S. Ahmed and S. Vijayarangan, PSG College of Techology, Coimbatore, Tamil Nadu, India

4:10 PM **Characterization of 2D Lattice Structures Using Laser Ultrasonics**
---P. Samala, **J. A. Smith**, and Z. Shi, Corning Incorporated, Advanced Engineering, Corning, NY 14831

4:30 PM **Modeling of Ultrasonic Testing of Woven Fabric Laminates: A Microstructure Approach**
---**J. Hegemann**, B. van den Broucke, and A. Peiffer, EADS Innovation Works, Structures Engineering, Production & Mechatronics, Munich, Bavaria, Germany; H. Baier, Technical University of Munich, Institute for Lightweight Structures, Garching, Bavaria, Germany

4:50 PM **Size and Depth Determination of Defects in Plastic Materials, Especially in CFRP, by Means of Shearography**
---**G. Hendorfer**, Upper Austrian University of Applied Sciences, Wels, Austria; C. Reiter and G. Mayr, FH OÃ Forschungs & Entwicklungs GmbH, Wels, Austria

Evaluation of Oven-Cured, Solid Carbon/Epoxy Composites with Various Porosity Levels

---**Molly A. Stone**, Cirrus Design, 4515 Taylor Circle, Duluth, MN 55811

---Cirrus has developed a strong core competency fabricating composite components using oven cure vacuum bag technology. Initially, only glass/epoxy composites were used for aircraft primary and secondary structure. Visual inspection methods utilizing back-lighting, visual standards, and supporting test combined to form a mature and reliable inspection program. As Cirrus began incorporating carbon/epoxy composites, ultrasonic methods were selected as a proven technology for inspection of thick composite sections. When using a vacuum bag oven-cure process, porosity levels must be carefully managed and the effects of porosity must be well understood. Excessive porosity will negatively affect material performance as well as reduce the effectiveness of the NDT method. This paper will present material characterization results from carbon/epoxy composite panels produced with various levels of porosity. Panels were inspected using two different ultrasonic methods, Pulse Echo Glass Reflector Plate, and Pulse Echo Phased Array. After inspection, panels were destructively tested to correlate static mechanical and physical properties to ultrasonic absorption coefficients. The goal of this work is to characterize material behavior to allow use of ultrasonic inspection in a manufacturing environment on vacuum bag oven-cured parts where porosity may be a factor.

Ultrasonic Imaging for Assessment of Impact Damage in Composite Plates

---Anish Kumar, Govind Kumar Sharma, **Tammana Jayakumar**, and Baldev Raj, Indira Gandhi Center for Atomic Research, Non Destructive Evaluation Division, Kalpakkam, Tamil Nadu, India; Sabeel Ahmed and S. Vijayarangan, PSG College of Technology, Coimbatore, Tamil Nadu, India

---Ultrasonic imaging has been carried out on four different grades of composite plates (10 layers of jutes and 1 to 3 layers of glass on either sides of the jute layers) in order to estimate the extent of damage consequent to impact tests. The specimens of each type of composite plates were subjected to 4 different energies of impacts i.e. 5, 10, 15 and 20 J. The extent of damage in the composite plates was estimated from the C-scan image, based on the loss of ultrasonic backwall echo. For similar impact energy, the extent of damage was found to be minimum in the composites with 2 layers of glass on either side of the jute layers. The ultrasonic B-scan imaging and C-scan imaging corresponding to different times of flight intervals provided the detailed information about the damage mechanisms in different types of specimens. From the ultrasonic B-scan images, it is clearly visualized that fiber breakage was the predominant mode of damage in jute laminates, whereas delamination was the major damage mode in hybrid laminates.

Characterization of 2D Lattice Structures Using Laser Ultrasonics

---Praveen Samala, **James A. Smith**, and Zhiqiang Shi, Corning Incorporated, Advanced Engineering, Corning, NY 14831

---As requirements for structural performance increases with time, engineered structures and materials are becoming much more complex. Lattice structural elements are a prime example of high performance structural elements that maintains structural rigidity, resistance to vibration, and functionality while keep weight down. Unfortunately, the lattice network makes characterizing the structure for material and structural defects very challenging. With the increasing demand for lattice structures there has been an ever increasing need for an efficient non-destructive technique. Amongst the more successful techniques are ultrasonic and acoustic testing. The focus of this paper is to understand the ultrasonic wave propagation through 2D lattice structures for characterization purposes. Understanding the response of ultrasonic waves to lattice structures will help to optimize the design of ultrasonic/acoustic testing techniques as well as outline the boundaries of applicability for ultrasonic testing. By exploiting the natural wave guiding tendency of periodic cells with in the lattice structure, there may be an opportunity to simplify the propagation characteristics of the sound and hence simplify the interpretation of the resulting signals. Two lattice geometries will be investigated. The paper will address these fundamental questions: can lattice structures be excited to behave like wave guides and can waveguide properties be used to effectively characterize the lattice structure.

Modeling of Ultrasonic Testing of Woven Fabric Laminates: A Microstructure Approach

---**Julia Hegemann**, Björn van den Broucke, and Alexander Peiffer, EADS Innovation Works, Structures Engineering, Production & Mechatronics, Munich, Bavaria, Germany; H. Baier, Technical University of Munich, Institute for Lightweight Structures, Garching, Bavaria, Germany

---Ultrasonic Testing is an established non-destructive testing method, however for complex material new challenges appear. In aeronautic industry CFRP with a high level of inner inhomogeneity is used. New construction methods of these materials lead to problems that cannot be monitored satisfactorily yet. Therefore a consolidated knowledge of the materials and of the interactions during testing is necessary. Modeling is a promising tool to improve the understanding of physical backgrounds and to reduce testing costs. In this work UT of three-dimensional models of woven fabrics on microstructure level is simulated for the first time. Model generation and simulation performance are done separately. The inner geometry of laminates made of woven fabrics is modeled using the software WiseTex developed by the Catholic University of Leuven. In these models the wave propagation is numerically calculated using the Elastodynamic Finite Integration Technique implemented with C++. The calculations are performed for anisotropic heterogeneous media. The resolution of the investigated inner structure is in the range of micrometers. The possibility of introducing defects in the structure is shown. The influence of the interfaces between carbon fiber rovings, matrix and defects on the wave propagation is investigated. Comparisons of the results with experimental data are presented.

Size and Depth Determination of Defects in Plastic Materials, Especially in CFRP, by Means of Shearography

---**Günther Hendorfer**, Upper Austrian University of Applied Sciences, Wels, Austria; Christoph Reiter, Günther Mayr, FH OÃ Forschungs & Entwicklungs GmbH, Wels, Austria

---Interferometric methods are known to be very sensitive, allowing metrology with resolutions better than the wavelength of the light used for illumination. On the other hand, those methods are susceptible to environmental and mechanical noise, usually. We use Shearography, a version of Speckle interferometry, which, in contrast, is a robust method, resistant to noise and vibrations and compatible to industrial applications. We survey vibration- as well as thermally-induced Shearography in order to detect defects in plastic materials, especially in carbon fibers reinforced plastics. We show that by analyzing out-of-plane-deformations, it is possible to evaluate those data quantitatively, enabling the determination of the size as well as the depth of defects. The method of depth determination is based on a gray-scale evaluation with respect to the deformations induced. It has been applied for defects localized in depths up to 10 mm, so far. The method of size determination is based on modelling the dependence of the apparent defect size as a function of the amount of shearing. Simulations of the out-of-plane-deformations for specific defects in different materials have been performed as well. It is shown that the simulations' results agree well with the experimental data. An estimation of the errors of size- and depth-results is given for comparison to other methods.

Session 33

SESSION 33
VISUALIZATION TECHNIQUES
B. Kohler, Chairperson
Meeting Room E

3:30 PM **Electrodynamic Approach for Visualization of Sound Propagation in Solids**
---U. Voelz, K. Matthies, H. Mrasek, and **M. Kreutzbruck**, Federal Institute for Materials Research and Testing, Nondestructive Testing Department, 12205 Berlin, Germany

3:50 PM **Tube Support Plate Blockage Evaluation with Televisual Inspection and Eddy Current Analysis**
---**L. Chatellier**, M. Stindel, J-M. Devinck, F. Chavigny, and O. de Bouvier, EDF Generation, Nuclear Engineering Division, Ceidre, 2 rue Ampere, F-93206 Saint Denis Cedex 01, France

4:10 PM **Analysis of Guided Wave Propagation by Visualizing In-Plane and Out-of-Plane Modes**
---N. S. B. Muhammad, **T. Hayashi**, M. Murase, and S. Kamiya, Nagoya Institute of Technology, Faculty of Engineering, Gokiso Showa Nagoya, Japan

4:30 PM **Tomographic Imaging Based on Scanning Acoustic Microscopy**
---**B. Koehler**, F. Schubert, and M. Barth, Fraunhofer IZFP, Dresden Branch, Dresden, Germany

4:50 PM **Air-Coupled Ultrasonic Tomographic Imaging for Solids**
---**K. S. Hall** and J. S. Popovics, The University of Illinois, Civil & Environmental Engineering, 205 N. Mathews St., MC-250, Urbana, IL 61801

Electrodynamic Approach for Visualization of Sound Propagation in Solids

---Uwe Voelz, Klaus Matthies, Heinz Mrasek, and **Marc Kreutzbruck**, Federal Institute for Materials Research and Testing, Nondestructive Testing Department, 12205 Berlin, Germany

---The visualization of sound propagation in solids is vital for transducer adaption and better understanding of complex test samples. In this work we present an electrodynamic technique detecting the grazing sound beam with a 10mm-sized electrodynamic probe. The particle displacement along the sample's cross-section was then measured as a function of time. Adapting the electrodynamic probe and its coil alignment allows for measuring the displacement components in all three dimensions. Thus horizontal and vertical particle displacement with respect to the surface can be detected. A SNR of higher than 26 dB could be achieved within ferromagnetic and high conductive chrome steel when using a transversal wave generated by an angled beam transducer. When dealing with nonconductive materials such as PMMA we obtained a reduced SNR of 12 dB. We report on measurements of the sound field in complex weld joints. One example shows a narrow gap weld joining a nickel alloy with a chrome steel. The weld of the 80 mm-thick component shows a distinct anisotropic texture. The system enables us to visualize the wave propagation within the weld and indicates the reflection scenario and the energy losses due to both the anisotropic structure and material defects.

Tube Support Plate Blockage Evaluation with Televisual Inspection and Eddy Current Analysis

---**Laurence Chatellier**, Marc Stindel, Jean-Michel Devinck, François Chavigny, and Odile de Bouvier, EDF Generation, Nuclear Engineering Division, Ceidre, 2 rue Ampere, F-93206 SAINT DENIS CEDEX 01, France

---In some steam generators with broached tube support plates (TSPs), water-holes (flow path of secondary water) were observed to be clogged. This phenomenon can cause U-bend instability as happened in the French nuclear units on Cruas in 2005 and 2006. The challenge is to estimate the average blockage level for each TSP in order to conduct the safety studies based on thermal-hydraulic models. This estimation is also necessary to plan maintenance operation (chemical cleaning) and follow the phenomenon after cleaning. This paper presents the technique used by EDF so as to estimate TSP blockage on model 51B and Bi French Steam Generator. The method relies on the association of visual inspection of the upper TSP and eddy current signal analysis. Signal processing of the visual inspection data allows to evaluate accurately the blockage rate on the upper TSP. Eddy current indicator results from laboratories studies and real data analysis. This indicator is calibrated with visual inspection data and then enables to estimate the blockage of other TSP for which televisual inspection is not possible owing to difficult access. Combined use of both techniques allows to estimate the state of blockage for the whole steam generator.

Analysis of Guided Wave Propagation by Visualizing In-Plane and Out-of-Plane Modes
---Nor Salim Bin Muhammad, **Takahiro Hayashi**, Morimasa Murase, and Shoji Kamiya, Nagoya Institute of Technology, Faculty of Engineering, Gokiso Showa Nagoya, Japan

---In guided wave inspection for a pipe, axisymmetric modes and low order non-axisymmetric modes are measured. However, we experienced that these modes cannot be detected depending on the shape, size and depth of a defect. Therefore, we have done the experimental study of guided wave visualization using a Laser doppler vibrometer controlled by a robot arm, in which, reflected waves from a oblique defect on a pipe propagated spirally around the pipe. In this study, measured signals at a large number of points on the pipe surface were separated into in-plane and out-of-plane vibrations and detailed modal analysis was conducted using the visualization results.

Tomographic Imaging Based on Scanning Acoustic Microscopy
---**Bernd Koehler**, Frank Schubert, and Martin Barth, Fraunhofer IZFP, Dresden Branch, Dresden, Germany

---In the majority of cases the term “tomography” is associated with computed x-ray tomography. However several other physical interactions have also the ability to provide information from the inside of objects. Already the usual scanning acoustic microscopy (SAM) gives volume information for opaque materials. But for most defect types in a homogeneous material the SAM C- and B-Scans alone give no correct volume image. Algorithms processing data from different scan positions with each other improve the situation significantly. But only with a combination of a number of additional measures satisfactory results are obtained. After describing the basic principles of SAM tomography an example of application is given and the results are compared to x-ray tomography (CT) of the same object.

Air-Coupled Ultrasonic Tomographic Imaging for Solids

---**Kerry S. Hall** and John S. Popovics, The University of Illinois, Civil & Environmental Engineering, 205 N. Mathews St., MC-250, Urbana, IL 61801

---Ultrasonic tomography is a powerful tool for identifying defects within an object or structure. This method can be applied on structures where x-ray tomography is impractical due to size, low contrast, or safety concerns. By taking many ultrasonic pulse velocity (UPV) readings through the object, an image of the internal velocity variations can be constructed. One of the largest drawbacks in ultrasonic tomography is the time consuming requirement of transducer coupling at many locations. Variability in coupling pressure can also result in variation in data collection. Air-coupled UPV can eliminate these problems and allow for more automated and rapid collection of larger amounts of data. With continued development air-coupled ultrasonic tomography could provide for fast and accurate evaluation of unseen defects in massive structures, such as reinforced concrete bridge piers. This research aims to integrate recent developments in air-coupled ultrasonic measurements with the current tomography technology. Using measurements from capacitive ultrasonic transducers and advanced signal processing methods, high and low velocity inclusions in a solid object are imaged. Issues related to the application to massive concrete structures are discussed.

FRIDAY

FRIDAY, JULY 25, 2008

	Session 34 POD and Reliability *Meeting Room G*	**Session 35 Techniques and Systems** *Meeting Room D*	**Session 36 Detectors, Transducers, and Probes** *Meeting Room E*	**Session 37 Techniques for Defect Characterization** *Meeting Room F*
8:30 AM				
8:50				
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10:10	COFFEE BREAK			
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Session 34

SESSION 34

POD AND RELIABILITY

P. Johnston, Chairperson
Meeting Room G

8:30 AM **Application of Model-Assisted POD Using A Transfer Function Approach**
---**C. A. Harding**, G. R. Hugo, and S. J. Bowles, Defence Science and Technology Organization, Fisherman's Bend, Victoria, Australia

8:50 AM **POD Generator Project: Development of Numerical Modeling Tools for Quantitative Assessment of the Performance of Nondestructive Inspection Techniques**
---A. Mast, A. Volker, J. Bloom, **U. Stelwagen**, A. Krom, A. Mohamoud, and G. van Gils, TNO Science and Industry, Flow Control & Instrumentation, Delft, The Netherlands

9:10 AM **Capability Assessment of POD Based on Composite NDE Methods**
---**Y. Guo**, Wayne State University, Industrial and Manufacturing Engineering Department, Detroit, MI 48201; F. Ruhge, Siemens Power Generation, NDE Technologies, Orlando, FL 32826

9:30 AM **Comparison of Detection Capability for Acoustic Thermography, Vision Inspection and Fluorescent Penetrant Inspection on Gas Turbine Components**
---**Y. Guo**, Wayne State University, Industrial and Manufacturing Engineering Department, Detroit, MI; F. R. Ruhge, Siemens Power Generation, NDE Technologies, Orland, FL 32826

9:50 AM **Addressing the Limit of Detectability of Residual Oxide Discontinuities in Friction Stir Butt Welds of Aluminum Using Phased Array Ultrasound**
---**P. H. Johnston**, NASA Langley Research Center, Nondestructive Evaluation Sciences Branch, Hampton, VA 23605

10:10 AM ***Break***

10:30 AM **Effect of Crack Closure on Ultrasonic Detection of Fatigue Cracks at Fastener Holes**
---S. J. Bowles, **C. A. Harding**, and G. R. Hugo, Defense Science and Technology Organization, Fisherman's Bend, Victoria, Australia

10:50 AM **Ultrasonic Examination of an Austenitic Weld: Illustration of the Disturbances of the Ultrasonic Beam**
---**B. Chassignole**, O. Dupond, L. Doudet, EDF R&D, Materials and Mechanics of Components Branch, 77818 Moret sur Loing, France; N. Etchegaray, EDF, CEIDRE, Saint Denis, France

11:10 AM **Uncertainty Analysis of Ultrasonic Methods for Measuring Burning Rate of Solid Propellants**
---**T. Kang**, H.-J. Kim, S.-J. Song, and S.-F. Ko, Sungkyunkwan University, School of Mechanical Engineering, Suwon, Korea; I.-C. Kim, J.-C. Yoo, Jung-Yong, and J. Core, Technology Development, Agency for Defense Development, Daejeon, Korea

11:30 AM **Application of POD to Complex Industrial Problems: New Approaches**
---**K. Takahashi**[1], M. Pavlovic[1], M. Bertovic[1], U. Ewert[1], C. Mueller[1], and U. Ronneteg[2], [1]Federal Institute for Materials Research and Testing (BAM), Unter den Eichen 87, 12205 Berlin, Germany; [2]Canister Laboratory, Swedish Nuclear Fuel and Waste Management Co. (SKB), Box 925, SE-572 29 Oskarshamn, Sweden

11:50 AM ***Adjourn***

Application of Model-Assisted POD Using a Transfer Function Approach

---**Cayt A Harding**, Geoff R Hugo, and Susan J. Bowles, Defense Science and Technology Organization, Fisherman's Bend, Victoria, Australia

---The reliability of nondestructive inspections is usually quantified as probability of detection (POD) as a function of defect size, which is traditionally measured empirically using a POD trial in which inspections are performed under field conditions on a set of specimens containing representative defects. These trials are very expensive and it is frequently impractical to generate truly representative defects within representative structure. Consequently, relatively few inspections have their POD measured via POD trials and, even then, it is common for artificial defects such as electric-discharge machined notches to be substituted for real defects such as fatigue cracks. Model-assisted probability of detection (MAPOD) offers scope to reduce the cost of POD trials, whilst providing better fidelity assessments of the POD by simultaneously accounting for both representative defects and representative structural geometry. This paper will report the application of MAPOD to validate the reliability of an automated ultrasonic inspection for crack detection at fastener holes in an aircraft lower wing skin. The model takes into account the effects of structural geometry, the natural variability in fatigue cracks and human factors in the inspection process. The model includes a quantification of the significant difference in ultrasonic response for fatigue cracks compared with electric-discharge machined notches.

POD Generator Project: Development of Numerical Modeling Tools for Quantitative Assessment of the Performance of Nondestructive Inspection Techniques

---Arjan Mast, Arno Volker, Joost Bloom, **Uilke Stelwagen**, Alfons Krom, Ali Mohamoud, and Gerard van Gils, TNO Science and Industry, Flow Control & Instrumentation, Delft, The Netherlands

---Risk based inspection strategies rely on detailed knowledge of the performance of inspection techniques. It is well known that every inspection technique has limitations in terms of reliability and effectiveness. Moreover, these are influenced by many factors. E .g. it depends on operator skills, inspection procedure, defect and object geometry as well as technique specific material conditions and properties. The objective of the "POD generator" project is to develop a numerical modeling approach to assess inspection effectiveness for a specific technique and situation flexibly and reliably yet at acceptable costs. Besides the models to simulate various degradation mechanisms, numerical models have been developed and validated for accurately simulating the physics of inspection techniques. Also the human factor is taken into account. These numerical models are then used to generate quantitative probability of detection (POD) curves. This will be illustrated for ultrasonic pulse-echo inspection of corrosion.

Capability Assessment of POD Based on Composite NDE Methods

---**Yan Guo**, Wayne State University, Industrial and Manufacturing Engineering Department, Detroit, MI, 48201; Forrest Ruhge, Siemens Power Generation, NDE Technologies, Orlando, FL 32826

---In nondestructive evaluation studies, the probability of detection (POD) curve is an important performance metric for a nondestructive evaluation (NDE) system. One of the NDE capability assessments is based on the flaws detected and the flaws missed. To verify missed flaws, artificial defects, destructive analysis and fine volumetric method are often used in most laboratory demonstrations. However, this practice is too expensive and impractical to use in the field environment. In this study, a new truncated logistic regression method, combining alternative nondestructive inspections and a simulation model can derive a good estimation of POD and perform good NDE capability analysis. The result of this approach is compared and verified with that from the destructive analysis.

Comparison of Detection Capability for Acoustic Thermography, Vision Inspection and Fluorescent Penetrant Inspection on Gas Turbine Components

---Yan Guo, Wayne State University, Industrial and Manufacturing Engineering Department, Detroit, MI; **Forrest R. Ruhge** Siemens Power Generation, NDE Technologies, Orlando, FL 32826

---The innovative NDE inspection system Acoustic Thermography is developed with Sonic IR technology. Since the probability of detection is sensitive to the flaw characteristics, the fabricated flaws could not simulated the nature flaws with accuracy. The study is focus on gas turbine blades with service induced fatigue cracks. The detection capability of this innovative NDE inspection system is compared with two traditional NDE methods: Visual Inspection and Fluorescent Penetrant Inspection. POD curves for each technique were generated and compared.

Addressing the Limit of Detectability of Residual Oxide Discontinuities in Friction Stir Butt Welds of Aluminum Using Phased Array Ultrasound

---**Patrick H. Johnston**, NASA Langley Research Center, Nondestructive Evaluation Sciences Branch, Hampton, VA 23605

---Residual oxide discontinuity (ROD) can occur in a friction stir weld (FSW) when the surface oxide layer is inadequately removed from one or both aluminum surfaces to be welded. If the oxide is not sufficiently broken up by the friction stir process, residual areas of weakened fusion can occur in the finished weld. Efforts have been made at a number of labs to nondestructively detect ROD using ultrasound, with mixed results reported. The present activity seeks to estimate an upper bound of detectability for a layer of oxide embedded in aluminum. The optimal geometry for ultrasonic detection would be a uniform planar layer oriented for normal incidence of the waves. The ultrasonic reflection coefficient from a planar layer of pure aluminum oxide embedded in aluminum was calculated for varying thicknesses of oxide, and compared with the reflection coefficient from a planar aluminum-water interface. Experimentally, the reflection from a planar aluminum-water interface and the amplitude of the adjacent grain scattering were measured. Using the planar interface reflection as a reference, the measured grain noise serves as a lower bound of detectability, while the modeled reflection from the oxide layer serves as a theoretical upper bound.

Effect of Crack Closure on Ultrasonic Detection of Fatigue Cracks at Fastener Holes

---Susan J. Bowles, **Cayt A. Harding**, and Geoff R. Hugo, Defense Science and Technology Organization, Fisherman's Bend, Victoria, Australia

---Crack closure due to localized residual compressive stress has often been thought to reduce the ultrasonic response from fatigue cracks. This paper will present a quantitative study of the effects of crack closure on ultrasonic detection of fatigue cracks at fastener holes in an aircraft lower wing skin. In this study, laboratory fatigue cracks were grown in aluminum alloy specimens using representative spectrum loading. An ultrasonic scanning system mounted on the fatigue test machine enabled the specimens to be scanned under applied tensile or compressive loads. The ultrasonic responses from fatigue cracks, as small as 1 mm radial depth, were characterized using 5 – 15 MHz shear-wave immersion transducers. Trends with applied load were observed and C-scans were used to map the opening of the fatigue cracks as a function of applied tensile load. The cracks were measured using ultrasonics and a good correlation against sizes measured from fractography was found. The significant differences observed between the ultrasonic response from fatigue cracks and electric-discharge machined notches will be discussed.

Ultrasonic Examination of an Austenitic Weld: Illustration of the Disturbances of the Ultrasonic Beam

---**Bertrand Chassignole**, Olivier Dupond, Loic Doudet EDF R&D, Materials and Mechanics of Components Branch, 77818 Moret sur Loing, France; Nicolas Etchegaray, EDF, CEIDRE, Saint Denis, France

---The ultrasonic examination of the primary coolant piping of Pressurized Water Reactors (PWR) is an important challenge for the nuclear industry. Numerous studies were undertaken by EDF R&D for a few years to improve the NDT process on these applications and to help to their qualification. More particularly, a great deal was made on the examination of the austenitic stainless steel welds. Indeed, the anisotropic, heterogeneous and coarse granular structures of these welds lead to important disturbances of the ultrasonic propagation. This paper presents a synthesis of the experimental and numerical studies which allowed to highlight the different disturbances. We give some examples of beam deviation, division or scattering for different industrial applications. We will pay more attention on spurious echoes which may appear when a plane defect is located in an austenitic weld. The experimental approach is based on tests on mock-ups containing artificial defects. The results for different types of probes are presented. On the other hand, a numerical approach with the finite element code ATHENA, developed by EDF, allows to explain the origin of the disturbances. We show the interest of this tool to carry out a close analysis of the ultrasonic mode conversions in the complex structure of the weld which produce the spurious echoes.

Uncertainty Analysis of Ultrasonic Methods for Measuring Burning Rate of Solid Propellants

---**To Kang**, Hak-Joon Kim, Sung-Jin Song, and Sun-Feel Ko, Sungkyunkwan University, School of Mechanical Engineering, Suwon, Korea; In-Chul Kim, Ji-Chang Yoo, Jung-Yong, and Jung Core, Technology Development, Agency for Defense Development, Daejeon, Korea

---The ultrasonic burning rate measurements of solid propellants has been used for many years instead of strand burner method. While strand burner method measures a burning rate per a constant pressure, ultrasonic method can be measured burning rates of solid propellants with wide range of pressure in a single test. In the ultrasonic method, burning rates of solid propellants is measured by measuring instantaneous thickness as function of pressure and time using time-of-flight(TOF) of reflected ultrasonic signal from the burning surface. Thus, to verify reliability of ultrasonic methods for measuring burning rates of solid propellants, uncertainties of the measured burning rates by ultrasonic method need to evaluate with variation of pressure, TOF and initial thickness. In this study, we will evaluate uncertainties of ultrasonic methods of measuring burning rates of various types of solid propellants with three different methods for measuring TOF of the reflected signals: zero-crossing, cross-correlation and moving gate developed in this study. Furthermore, comparison of uncertainties of ultrasonic burning rate measurements using the three different TOF measurement methods will be presented.

Application Of POD To Complex Industrial Problems: New Approaches

---**Kazunori Takahashi**[1], Mato Pavlovic[1], Marija Bertovic[1], Uwe Ewert[1], Christina Mueller[1], and Ulf Ronneteg[2], [1]Federal Institute for Materials Research and Testing (BAM), Unter den Eichen 87, 12205 Berlin, Germany; [2]Canister Laboratory, Swedish Nuclear Fuel and Waste Management Co. (SKB), Box 925, SE-572 29 Oskarshamn, Sweden

---Nondestructive testing (NDT) by means of phased array (PA) ultrasonic inspection has been applied in order to ensure the integrity of canisters, which encapsulate spent nuclear fuels for permanent storage. The NDT system is evaluated in terms of probability of detection (POD) to check and/or prove whether possible critical defects are able to be detected. The POD analysis using a common method, â versus a, has been studied to be modified to the PA ultrasonic inspections using two approaches; expansions of a and â. As the first approach, new a has been proposed to include influences of several parameters on the POD (e.g. depth, size, sound fields created by a PA probe), in contrast to one parameter in the conventional analysis. The idea of the second approach is to use sophisticated signal response interpretations than the highest amplitude, which is employed as â in the conventional analysis to include more information on reflectors. From another aspect, it is known that total performance of NDT is influenced by human factors. The study on the human factors will be carried out to investigate where they exist, how much influence they have and how can be reduced.

Session 35

SESSION 35
TECHNIQUES AND SYSTEMS
P. Nagy, Chairperson
Meeting Room D

8:30 AM **Wave Reflections in Semi-Infinitely Long Cylinders with Attached Solid of Revolution**
---N. Yin and **H. Bai**, Lakehead University, Mechanical Engineering, 955 Oliver Road, Ontario, Thunder Bay, P7B 5E1, Canada

8:50 AM **Forensic Examination Using a Nondestructive Evaluation Method for Surface Metrology**
---**D. J. Eisenmann**, Iowa State Univeristy, Center for NDE, Ames, IA 50011; L. Scott Chumbley, Iowa State University, Materials Science Engineering Department, Ames, IA 50011

9:10 AM **Detection of Laminations in Multilayered Clad Products Using Guided Wave EMATs**
---**H. Gao**, S. Ali, J. Monks, and B. Lopez, Innerspec Technologies, Inc., Research and Development, Lynchburg, VA 24501

9:30 AM **Potential Drop Mapping for Corrosion Monitoring**
---**G. Sposito** and P. Cawley, Imperial College, Mechanical Engineering, London, United Kingdom; P. B. Nagy, University of Cincinnati, Aerospace Engineering and Engineering Mechanics, Cincinnati, OH 45221-0070

9:50 AM **Constant Group Velocity Ultrasonic Guided Wave Inspection for Corrrosion and Erosion Monitoring in Pipes**
---G. Instanes, A. Pedersen, and M. Toppe, ClampOn AS, Laksevaag, Bergen, Norway; **P. B. Nagy**, University of Cincinnati, Department of Aerospace Engineering, Cincinnati, OH 45221-0070

10:10 AM ***Break***

10:30 AM **A Switching Technique for Measuring High Ultrasonic Attenuation**
---C.-W. In, **J.-Y. Kim**, and L. J. Jacobs, Georgia Institute Tech., Civil and Environmental Engineering, Atlanta, GA 30332-0355

10:50 AM **Nondestructive Testing of Overhead Transmission Lines – Numerical and Experimental Investigation**
---S. Kulkarni and **S. Hurlebaus**, Texas A&M University, Zachry Department of Civil Engineering, College Station, TX 77843-3136

11:10 AM **Resonant Frequency Shifts of a Fluid Filled Cavity Caused by a Bubble**
---**H. Zhang**, X. Wang, D. Chen, and C. Che, Institute of Acoustics, Chinese Academy of Sciences, The State Key Laboratory of Acoustics, Beijing 100080, China

11:30 AM ***Adjourn***

Wave Reflections in Semi-Infinitely Long Cylinders with Attached Solid of Revolution

---Nairui Yin and **Hao Bai**, Lakehead University, Mechanical Engineering, 955 Oliver Road, Ontario, Thunder Bay, P7B 5E1, Canada

---A numerical procedure is developed for the study of end reflections in a semi-infinitely long isotropic circular cylinder attached with piezoelectric patch. A hybrid method is employed in the study. It combines the finite element formulation in the piezoelectric patch with a wave function expansion representation in the isotropic cylinder. Reflections due to monochromatic incoming axisymmetric (m = 0) and flexural (m = 1) waves are studied and numerical examples are presented. The end resonance is observed through the numerical examples. For an oscillating end voltage that is out-of-phase with the incoming wave, it is possible to extract electrical energy from it, i.e., energy harvesting. Examples of such applied oscillating voltage with a particular radial distribution are given. Furthermore, the effect of the thickness of the piezoelectric patch on the end resonance as well as the harvested energy is studied through the numerical examples.

Forensic Examination Using a Nondestructive Evaluation Method for Surface Metrology

---**David J. Eisenmann**, Iowa State University, Center for NDE, Ames, IA 50011; L. Scott Chumbley, Iowa State University, Materials Science Engineering Department, Ames, IA 50011

---The objective of this paper is to describe the use of a new technique of optical profilometry. This new technique of surface metrology has been used in a nondestructive, non-contact fashion for the comparison of two metallic surfaces, one hard and one soft. When brought in contact with one another the harder material will impress it's surface roughness onto the softer. It is assumed that the resulting set of impressions acts in a manner similar to a photographic negative. If properly inverted and reversed, measurements from the softer material should be identical to the harder indenting object with regard to surface texture and roughness. This assumption is inherent in the area of forensics, where bullets, cartridge cases, and tool marked surfaces from crime scenes are compared to similar marks made under controlled conditions in the forensic laboratory. This paper will examine the methodology used to compare two surfaces for similarities and dissimilarities, and comment on the applicability of this technique to other studies.---This work supported by the National Institute of Justice, Ames Laboratory and the Department of Energy .

Detection of Laminations in Multilayered Clad Products Using Guided Wave EMATs

---**Huidong Gao**, Syed Ali, Jeff Monks, and Borja Lopez, Innerspec Technologies, Inc., Research and Development, Lynchburg, VA 24501

---In metallurgy, cladding refers to the bonding together of dissimilar metals, normally achieved by extruding two or more metals through a die or pressing sheets together under high pressure. Inspection of bond quality especially identification of lamination defects has long been a desire for these clad products. This paper presents a guided wave technique using electromagnetic acoustic transducer (EMAT) technology that permits 100% inspection of the strip using a single set of sensors. EMATs also provide consistency and ease of integration for high-speed, automated inspections. The paper shows the analysis performed for a three-layer, brass/copper/brass product including a comprehensive examination of phase and group velocities, excitability dispersion curves for optimum wave mode selection, and FEM models to analyze wave propagation and responses from different defect sizes. The analytical calculations are compared with lab and production data to demonstrate the effectiveness of this technique, and its suitability for real-life industrial environments. This technique can also be applied to multilayered adhesive bond products and other composite structures.

Potential Drop Mapping for Corrosion Monitoring

---**Giuseppe Sposito** and Peter Cawley, Imperial College, Mechanical Engineering, London, United Kingdom; Peter B. Nagy, University of Cincinnati, Aerospace Engineering and Engineering Mechanics, Cincinnati, OH 45221-0070

---Commercial systems are available which employ Potential Drop techniques to monitor corrosion/erosion occurring on the inner surface of pipes, pressure vessels etc. An array of electrodes on the external surface is used to inject currents and measure voltages at multiple locations on the area to be inspected; the data are then combined to produce maps of corrosion/erosion in that area, thus giving information on the position and size of defects. The aim of the present study is to determine how accurately the maximum depth of a defect, which is often the key parameter in the assessment of structural integrity, can be estimated as a function of factors such as the shape and size of the defect itself and the geometry of the electrode array. Numerical simulations with a simple Finite Element (FE) model were run to compare the performance of the probe geometry most commonly used in commercial systems (a matrix of equispaced electrodes) with that of an alternative arrangement in which the injecting and measuring electrodes are adjacent to each other; the advantages and disadvantages of each configuration are discussed. Based on the indications of the FE model, an array probe exploiting the adjacent configuration was then built. Tests were conducted on a stainless steel plate with machined defects, injecting much smaller currents than those needed in commercially available systems. The results of these experiments were used to validate those of the numerical simulations.

Constant Group Velocity Ultrasonic Guided Wave Inspection for Corrosion and Erosion Monitoring in Pipes

---Geir Instanes, Audun Pedersen, and Mads Toppe, ClampOn AS, Laksevaag, Bergen, Norway; **Peter B. Nagy**, University of Cincinnati, Department of Aerospace Engineering, Cincinnati, OH 45221-0070

---The so-called Constant Group Velocity (CGV) ultrasonic guided wave inspection technique relies on the fundamental flexural mode to measure the average wall thickness over the inspection path. The inspection frequency is chosen so that the group velocity of this mode is essentially constant throughout the wall thickness range of interest. In the vicinity of the CGV point, the phase velocity of the fundamental flexural mode is highly dispersive and changes in a more or less linear way with varying wall thickness of the pipe. We based our inversion procedure on the so-called true phase angle of the received pulse, which is a measure of the difference between the phase and group slownesses. Although this approach is somewhat less sensitive than the often used transverse resonance methods, it smoothly integrates the wall thickness over the whole propagation length, therefore it is very robust and can tolerate large and highly uneven thickness variations from point to point. This method also eliminates very effectively velocity variations caused by changing temperature and fluid loading. In the vicinity of the CGV point, these spurious variations do not influence significantly the measured true phase angle. The presented results show that the CGV method is capable of monitoring the average wall thickness over the inspection length with an accuracy of 1%. The CGV guided wave method was validated in both laboratory and field tests.

A Switching Technique for Measuring High Ultrasonic Attenuation

---C.-W. In, **J.-Y. Kim**, and L. J. Jacobs, Georgia Institute of Technology, Civil and Environmental Eng., Atlanta, GA 30332-0355

---The ultrasonic attenuation coefficient is one of the fundamental acoustic parameters of a material. This phenomenological parameter contains information on a material's microstructure such as grain structure, dislocations, meso-scale inhomogeneity, etc, and thus can often be related to the damage that evolves from the microstructural change during fatigue or creep. For this reason, an accurate measurement of the attenuation coefficient of a material is important. The conventional technique for measuring the attenuation coefficient uses the first and second reflection signals from the opposite wall, which travel twice and four times the sample thickness. In many cases, the attenuation of material is significantly high or the sample is thick enough that the second reflection signal is either undetectable or too weak. This is especially true with an in-situ monitoring in which the object cannot be cut into a thin laboratory sample. In this study, a new simple switching technique is developed to measure high ultrasonic attenuation coefficient in an absolute sense. In this technique, through transmitted and first reflected signals are measured in both initial and switched configurations. The attenuation coefficient is obtained by multiplying two transfer functions defined in these two configurations. The capability of the technique is demonstrated with several plastic and cement-based materials.

Nondestructive Testing of Overhead Transmission Lines – Numerical and Experimental Investigation

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

---Overhead transmission lines are periodically inspected using both on-ground and helicopter-aided visual inspection. Factors including sun glare, cloud cover, close proximity to power lines, and the rapidly changing visual circumstances make airborne inspection of power lines a particularly hazardous task. In this study, a finite element model of an overhead transmission line is developed to compute the response due to a pulse force. The response is required to calculate the theoretical dispersion curves using a time frequency analysis. Then, the dispersion curves are calculated for the case where the overhead transmission line is under tension using the acoustoelastic effect. The interaction of ultrasonic waves with cracks, crack size, crack location, and crack orientation is also considered. The numerical results are then verified with experimental test using a high-fidelity, non-contact, and broadband laser detection technique. The methodology developed in this study can be further extended to a continuous monitoring system and be applied to other cable monitoring applications, such as bridge cable monitoring, which would otherwise put human inspectors at risk.

Resonant Frequency Shifts of a Fluid Filled Cavity Caused by a Bubble

---**Hailan Zhang**, Xiuming Wang, Dehua Chen, and Chengxuan Che, Institute of Acoustics, Chinese Academy of Sciences, The State Key Laboratory of Acoustics, Beijing 100080, China

---Acoustic resonant frequencies of an oil filled cavity are perturbed if a solid sample is included in the cavity. The frequency shifts are related with the material and geometry of the included solid sample. Based on this principle, an acoustic resonant method was proposed to estimate acoustic wave velocities and attenuation of the perturbation sample by measuring the resonant frequencies as well as the resonant amplitudes of the cavity in which the solid sample is included. Although the resonant frequencies are measured accurately, it was found that the frequencies are shifted if there are air bubbles in the cavity. Even if there is a tiny bubble in the oil filled cavity, it generates a large frequency shift, resulting in the measurement failure. The theoretical analysis and numerical simulation show that the resonant frequency shifts are caused by the coupling vibration of an air bubble with the oil in the cavity. It is found that the bubble with the diameter as small as one percent of the size of the cavity reduces the resonant frequency significantly. This study shows that the measurement must be carefully prepared to prevent any air bubbles from entering the cavity.

Session 36

SESSION 36

DETECTORS, TRANSDUCERS, AND PROBES

M. Hirao, Chairperson
Meeting Room E

8:30 AM **Low Scatter, High Kilovolt, A-Si Flat Panel X-Ray Detector**
---P. D. Smith, **T. N. Claytor**, P. C. Berry, and C. R. Hills, Los Alamos National Laboratory, MS C914, Los Alamos, NM 87545; S. C. Keating, D. H. Phillips, and S. Setoodeh, IMTEC, 110 Eastgate Drive, Los Alamos, NM 87544

8:50 AM **Ultrasonic Measurements of Bore Temperature in Large Caliber Guns**
---**D. E. Yuhas**, M. J. Mutton, J. R. Remiasz, and C. L. Vorres, Industrial Measurement Systems, Inc., Aurora, IL 60502

9:10 AM **Contact Elevated Temperature Transducer**
---**D. A. Parks** and B. R. Tittmann, Penn State University, Engineering Science and Mechanics, University Park, PA 16802

9:30 AM **Sol-Gel Deposited Thick Film Bismuth Titanate Transducer Achieves Operation Up To 550°C**
---**C. T. Searfass**, B. R. Tittmann, D. K. Agrawal, Pennsylvania State University, Department of Engineering Science and Mechanics, University Park, PA 16802

9:50 AM **Quantitative Young's Modulus Microscopy by Isolated Langasite Oscillator: A Contact Mechanics Study**
---**H. Ogi**, T. Inoue, H. Nagai, and M. Hirao, Osaka University, Graduate School of Engineering Science, Osaka, Japan

10:10 AM ***Break***

10:30 AM **Mode Conversions of a Torsional Guided Wave in a Piping Mockup from a Magnetostrictive Strip Transducer**
---**Y. Cheong** and S. Kim, Nuclear Materials Research Division, Korea Atomic Energy Research Institute, Yusong, P. O. Box 105, Daejon, 305-600, Korea

10:50 AM **Variation of Eddy Current Probe Impedance Due to Borehole Cracks**
---**J. R. Bowler**[1] and T. Theodoulidis[2], [1]Department of Electrical and Computer Engineering and The Center for NDE, Iowa State University, Ames, IA 50011; [2]Department of Engineering and Management of Energy Resources, West Macedonia University, Kozani, Greece

11:10 AM **Hand-Held NDE System Using High-Tc SQUID**
---**D. He** and M. Tachiki, Superconducting Materials Center, National Institute for Materials Science, 1-2-1 Sengen Tsukuba Ibaraki 305-0047, Japan; H. Itozaki, Osaka University, Graduate School of Science Engineering, 1-3 Machikaneyama, Toyonaka, Osaka 560-8531, Japan

11:30 AM ***Adjourn***

Low Scatter, High Kilovolt, A-Si Flat Panel X-Ray Detector

---Peter D. Smith, **Thomas N. Claytor**, Phillip C. Berry, and Charles R. Hills, Los Alamos National Laboratory, MS C914, Los Alamos, NM 87545; Scott C. Keating, David H. Phillips, and Shariar Setoodeh, IMTEC, 110 Eastgate Drive, Los Alamos, NM 87544

---We have been using amorphous silicon (a-Si) flat panel detectors in high energy (> 400kV) cone beam computed tomography (CT) applications for a number of years. We have found that these detectors have a significant amount of internal scatter that degrades the accuracy of attenuation images. The scatter errors cause cupping and streaking artifacts that are practically indistinguishable from beam hardening artifacts. Residual artifacts remain after beam hardening correction and over correction increases noise in CT reconstructions. Due to the limitations of the current detectors, we decided to design a detector specifically for high energies that has significantly reduced scatter. Our new design reduces scatter, makes attenuation measurements more accurate, improves the ability to make corrections for beam hardening, and increases signal to noise ratio in DR images and CT reconstructions. Preliminary results showing the dramatic reduction in self scatter from the panel will be presented as well as the effect of this improvement on CT images.

Ultrasonic Measurements of Bore Temperature in Large Caliber Guns

---**Donald E. Yuhas**, Mark J. Mutton, Jack R. Remiasz, and Carol L. Vorres, Industrial Measurement Systems, Inc., Aurora, IL 60502

---The Navy has a need to measure temperatures at critical areas on the inner bore surfaces of large guns in order to insure appropriate action is taken in case of a misfire. Inappropriate actions could result in the loss of life and the disabling of a naval warship. In this report we describe the development of an ultrasonic-based sensor capable of measuring internal bore temperature. Using high precision, rapid, ultrasonic time-of-flight measurement techniques to analyze echoes from the rifled region, high fidelity transient temperature profiles can be measured. For some propellants, we find that within 20 milliseconds of firing the average temperature in the rifled region can exceed 600°F, but cools rapidly to under 150°F after 2 seconds. These internal bore temperatures are measured using probes mounted on the exterior surface more than 60 millimeters from the inner surface. In this report we describe a series of laboratory experiments as well as live fire field trials on the 5” MK 45 MOD 4 Gun. Factors that determine the temporal response, stability, temperature localization and precision will be described.

Contact Elevated Temperature Transducer

---**David A. Parks** and Bernhard R. Tittmann, Penn State University, Engineering Science and Mechanics, University Park, PA 16802

---This paper presents data on the use of Aluminum Nitride (AlN) for generating and receiving bulk acoustic waves at temperatures up to 650°C. Because AlN is not ferroelectric it is quite likely that AlN can exceed 650°C were it not for the present lack of a suitable couplant. The resonant frequency of a 0.45 mm thick z-cut AlN plate was found to be 13.4 MHz the measured stiffness was C33D=474GPa. The transducer was backed by a high impedance absorptive medium to obtain bandwidth in the range of 20% over the range of room temperature up to 650°C when coupled to a controlled CTE metal (Kovar). The results were obtained in longitudinal pulse echo mode with a propagation distance of about 50 mm. The reasonable bandwidth and signal to noise ratio was obtained by maximizing the transient response of the transducer. To maximize the transient response a template was used to model the excitation pulse, allowing for a closed form solution for the unloaded and infinitely loaded elements displacement as a function of time. The results were shown to agree with finite element (Wissoft Co.) simulations and were supported by experimental results.

Sol-Gel Deposited Thick Film Bismuth Titanate Transducer Achieves Operation Up to 550^{o}C

---**Cliff T. Searfass**, Bernhard R. Tittmann, and Dinesh K. Agrawal, Pennsylvania State University, Department of Engineering Science and Mechanics, University Park, PA 16802

---Piezoelectric bismuth titanate thick film transducers were deposited onto steel substrates using a sol-gel deposition method. The samples were microwave annealed at a temperature of 850^{o} C for 10 minutes. Samples had d33 values in the range of 10-18 pC/N with signal to noise ratios up to 64 dB on a 1.6 cm thick steel block at room temperature. Longitudinal wave signals were monitored in pulse-echo mode and waveforms were collected in a temperature range from room temperature to above 500^{o} C. The operating frequencies were in the MHz range and the change in the frequency spectrum with temperature was also recorded. The bismuth titanate films have demonstrated their potential capability of ultrasonically monitoring structures at temperatures above 500^{o} C.

Quantitative Young's Modulus Microscopy by Isolated Langasite Oscillator: A Contact Mechanics Study

---**Hirotsugu Ogi**, Takashi Inoue, Hironao Nagai, and Masahiko Hirao, Osaka University, Graduate School of Engineering Science, Osaka, Japan

---We developed a wireless langasite oscillator for measuring quantitatively local Young's modulus of solids through change in its resonance frequency caused by contact with the solid. The electrodeless langasite crystal bar is excited by a line antenna by tone bursts, and its vibrational signals are detected by another antenna to measure the resonance frequency: The piezoelectric effect allows a noncontacting measurement. A constant biasing force results from the oscillator mass, and it is independent of surface roughness. The effect of material anisotropy on the measured stiffness is theoretically discussed for studying the limitation of the quantitative measurement. The microscopy has been applied to polycrystalline copper, and the measured modulus is compared to calculations based on electron-backscatter-diffraction measurements. Also, we applied it to a duplex stainless steel and an embedded silicon-carbide fiber. The results reveal textured regions, defects with high sensitivity, and even stiffness distribution in a single grain.

Mode Conversions of a Torsional Guided Wave in a Piping Mockup from a Magnetostrictive Strip Transducer

---**YongMoo Cheong** and Shin Kim, Nuclear Materials Research Division, Korea Atomic Energy Research Institute, Yusong, P. O. Box 105, Daejon, 305-600, Korea

---The magnetostrictive tranducer has several advantages for practical applications of long-range guided wave inspection, such as a 100-percent volumetric coverage of a long segment of a structure, a reduced inspection time and its cost effectiveness, as well as its' relatively simple structure. One promising feature of the magnetostrictive transducer technique is that the wave patterns are relatively clear and simple compared to the conventional piezoelectric ultrasonic transducer. If we characterize the evolution of the defect signals, it could be a promising tool for a structural health monitoring of pipes for a long period as well as the identification of flaws. In this paper, we fabricated a realistic piping mockup for a long-range inspection. Various artificial defects were fabricated and wave patterns from various ultrasonic reflectors, such as hole, circumferential crack, axial crack, pipe support, and girth weld, are evaluated. We found mode conversions from various reflectors from torsional guided wave T(0,1) mode generated by a magnetostrictive strip transducer. Based on the experimental results, theoretical model for a mode conversion from T(0,1) mode are discussed.

Variation of Eddy Current Probe Impedance Due to Borehole Cracks

---**John R. Bowler**[1] and T. Theodoulidis[2], [1]Department of Electrical and Computer Engineering and the Center for Nondestructive Evaluation, Iowa State University, Ames, IA 50011; [2]Department of Engineering and Management of Energy Resources, West Macedonia University, Kozani, Greece

---We have computed the electromagnetic field at cracks in boreholes, due to an eddy current coil and used the field to determine the variation of coil impedance with position and frequency. The field is found from the numerical solution of a matrix equation that is derived using a boundary element scheme from an integral equation for the crack field. 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 which limits the number of unknowns needed. 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.

Hand-Held NDE System Using High-Tc SQUID

---**Dongfeng He** and M. Tachiki, Superconducting Materials Center, National Institute for Materials Science, 1-2-1 Sengen Tsukuba Ibaraki 305-0047, Japan; H. Itozaki, Graduate School of Science Engineering, Osaka University, 1-3 Machikaneyama, Toyonaka, Osaka 560-8531, Japan

---We developed a hand-held eddy-currrent NDE system using high-Tc SQUID. The SQUID could keep locked when moving in the earth field. To reduce the noise caused by the vibration of the hand or the changing of the lift-off. Dual frequency excitation method was used. For the lower frequency, the penetration depth is small, the surface signal can be detected; for the higher frequency, the penetration depth was big, not only the surface signal, but also the deep defect signal both can be detected. By subtracting the signal of the two frequency and adjusting the subtraction factor, the noise caused by the vibration of hand could be effectively reduced. Artificial hole defect under 6 mm in an aluminum plate could be successfully detected using this hand-held system.

Session 37

SESSION 37

TECHNIQUES FOR DEFECT CHARACTERIZATION

Meeting Room F

C. Pecorari, Chairperson

8:30 AM **Detection Principle of Sizing and Orientation of Defect in Plate Using Ultrasonic Guided Wave**
---**C. Xu**, J. L. Rose, and F. Yan, Pennsylvania State University, Department of Engineering Science and Mechanics, State College, PA 16802; X. Zhao, FBS Inc., 143 Hawbaker Industrial Drive, Suite 102, State College, PA 16802

8:50 AM **A Defect Identifying and Sizing Method with Time Reversal Guided Wave Inspection in Pipes**
---F. Deng, B. Wu, Z. Liu, C. He, College of Mechanical Engineering and Applied Electronic Technology, Beijing University of Technology, Ping Le Yuan 100#, Chaoyang District Beijing 100022, P. R. China

9:10 AM **Automatic Classification of Welding Flaws Using Artificial Intelligence Algorithms**
---**R. Sikora**, T. Chady, and P. Baniukiewicz, Szczecin University of Technology, Department of Electrical Engineering, Szczecin, Poland; B. Piekarczyk, Technic-Control sp.z o.o., Szczecom. Poland

9:30 AM **High-Resolution Ultrasonic Imaging of a Dual-Layer Bond Interface Target**
---**T. N. Claytor,** D. R. Grove, C. R. Hills, P. D. Kleinschmidt, and J. C. Mitchell, Los Alamos National Laboratory, MS C914, Los Alamos, NM 87545; R. K. Torney, Stanford University, Department of Human Biology, Stanford, CA 94305

9:50 AM **Low Pass Effect of Surface Defect Metal Based on Lser Ultrasonics**
---J. Wang, X. Xu, and **X. Liu**, Nanjing University, Key Laboratory of Modern Acoustics of MOE, Institute of Acoustics, Nanjing University, Nanjing, 210093, China

10:10 AM ***Break***

10:30 AM **Finite Element Modeling of Magnetic Flux Leakage Signals from Mechanical Dents Containing Corrosion Pits**
---**V. K. Babbar** and L. Clapham, Queen's University, Department of Physics, Kingston, Ontario, K7L 3N6, Canada

10:50 AM **Automated Defect Classification Using an Artificial Neural Network**
---**T. Chady** and M. Caryk, Szczecin University of Technology, Department of Electrical Engineering, Szczecin, Poland; Bogdan Piekarczyk, Technic-Control Sp. Z o.o., Szczecin, Poland

11:10 AM **Defect Sizing Method Using Ultrasonic Guided Waves in Pipes**
---**Y. Nagashima**, M. Endou, and M. Miki, Hitachi, Ltd., Power & Industrial Systems R&D Laboratory 7-2-1, Omika-cho, Hitachi-shi, Ibaraki-ken 319-1221, Japan

11:30 AM ***Adjourn***

Detection Principle of Sizing and Orientation of Defect in Plate Using Ultrasonic Guided Wave

---**Chunguang Xu**, Joseph L. Rose, and Fei Yan, Pennsylvania State University, Department of Engineering Science and Mechanics, State College, PA 16802; Xiang Zhao, FBS Inc., 143 Hawbaker Industrial Drive, Suite 102, State College, PA 16802

---Capturing defects size and orientation exactly and factually is fundamental to evaluate the integrity, reliability and lifespan of plate-like structures in service. Especially, the sharpness and direction of defects are very critical issues influencing usability of plate-like components. Principles of defects size and orientation determination using ultrasonic guided waves in plates are presented. It is detailed that modeling ultrasonic guided waves propagation and interaction with defect boundaries is explained theoretically, and sharpness and direction model is established. By means of transducer array, control technique, and relationship of multi-sound field a pseudo-3D sound field inside a plate can be established. Two transducer arrays are arranged in parallel. Sound pressure vector expressing one point in pseudo-3D sound field formed by two transducer arrays is described in equation mathematically. Generally, defect contours in plates can be defined as half-ellipsoid which can comprehend almost all sorts of defect shape on the surface and inside solid. Half-ellipsoidal defect parameters can be declared as defect model. Different combinations of the lengths of major axis and minor axis of ellipsoid individually may represent different classifications of defects. Simulations and experiments will prove its correctness.

A Defect Identifying and Sizing Method with Time Reversal Guided Wave Inspection in Pipes

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

---In the pipe inspection by guided waves, a defect serves as a passive wave source which produces a scattered wave field including the reflection mode and many conversion modes. The types and the energy of these modes are determined by the characteristics of the defect. All modes propagate along the pipe at different velocities, which results in complicated detection signals in the time domain. When the time reversal method is used, the energy included in the time reversal intercepting window will concentrate on the location of the defect because of the temporal-spatial focusing effect. When the start point for intercepting is held, the number of the wave packages included in the time reversal signals increases with widening the intercepting window, so, the defect reflection coefficient increases accordingly. The scattered wave field is analyzed by discussing the relation between the width of the intercepting window and the defect reflection coefficient. A defect identifying and sizing method is presented based on such relation curves. In addition, the numerical simulation results are provided to illustrate the validity of this defect identifying and sizing method.

Automatic Classification of Welding Flaws Using Artificial Intelligence Algorithms

---**Ryszard Sikora**, Tomasz Chady, and Piotr Baniukiewicz, Szczecin University of Technology, Department of Electrical Engineering, Szczecin, Poland; Bogdan Piekarczyk, TECHNIC-CONTROL Sp. z o.o., Szczecin, Poland

---Welding is most common way of permanently joining metal parts. The heat applied to joined pieces causes melting and fusing them to form of permanent bond. Welding without proper precautions can be dangerous due to possible occurrence of defects and discontinuities in the weld. These cracks can reduce the strength of the joint and can lead to catastrophic failure. The most popular method of inspection of welds is radiography. The radiograms can be analyzed by qualified operator or by using advanced computerized systems. In this paper the authors propose the automatic analysis system applied to radiographic images of welded joins involves defect identification in the weld and classification of defects that were found. The classification is done in accordance with welding norms. The shape of the crack is described by selected features calculated for flaws extracted from radiograms. The neural networks and fuzzy logic are used to implement linear and nonlinear pattern classifiers. The statistical methods such as PCA, KLT and factor analysis are applied in order to reduce the dimensionality of a multivariable data as well as to find most significant features and remove those mutually dependent. The algorithms are verified on real radiograms of welds obtained from shipbuilding industry.

High-Resolution Ultrasonic Imaging of a Dual-Layer Bond Interface Target

---**Thomas N. Claytor**, Daniel R. Grove, Charles R. Hills, Phillip D. Kleinschmidt, and John C. Mitchell, Los Alamos National Laboratory, MS C914, Los Alamos, NM 87545; Robert K. Torney, Stanford University, Department of Human Biology, Stanford, CA 94305

---Various methods of simulating an unbonded layer have been proposed in the past but have been difficult to implement. Often, flat-bottom holes are used to simulate an unbonded condition but the contrast ratio between holes and a true unbonded region can be quite different. Here we have placed a laser cut unbonded pattern at the interface between two elastically different materials. The differences in amplitude between the unbonded and bonded regions will verify quantitative amplitude differences and the pattern will allow the resolution of various transducers to be evaluated under realistic conditions.

Low Pass Effect of Surface Defect Metal Based on Laser Ultrasonics

---Jingshi Wang, Xiaodong Xu, and **Xiaojun Liu**, Nanjing University, Key Laboratory of Modern Acoustics of MOE, Institute of Acoustics, Nanjing, 210093, CHINA

---The traveling properties of laser-generated surface acoustic wave with broad bandwidth, which propagated on a surface defect sample, have been investigated in theory. The numerical results of theoretical models with different defects indicate that the surface defects worked as low-pass filter for the travelling surface acoustic waves, the cut-off frequencies of low-pass filter is linearly related to the depth of the defect, and decreased against to the increasing depth of the defect. The amplitude of the traveling surface acoustic wave is powerfully attenuated by the width of surface defect. The numerical results provide a theoretical basement for quantitative detection of the surface defects.

Finite Element Modeling of Magnetic Flux Leakage Signals from Mechanical Dents Containing Corrosion Pits

---**Vijay K. Babbar** and Lynann Clapham, Queen's University, Department of Physics, Kingston, Ontario, K7L 3N6, Canada

---Magnetic flux leakage (MFL) technique is the most cost effective method of detecting corrosion pits and mechanical dents in in-service oil and gas pipelines. These defects have been studied separately by using both experimental MFL technique and finite element modelling (FEM). In steel pipelines, dents are the regions of high stresses where corrosion may occur preferentially. So, in a practical scenario, the nature of defects is likely to be complex, making the MFL signal recognition very difficult. The present work employs three-dimensional FEM to investigate MFL signals from a dent geometry modified by the presence of a concentric pit of varying radius and depth. Both radial and axial components of MFL signals are examined at the inside (convex) surface of the dent with pit lying on the outside. The radial MFL signal from the pit is found to have a polarity that is opposite to the inner two peaks of the dent signal. For a certain pit radius, the peaks merge with the inner dent peaks to almost cancel each other, thus making the pattern recognition very difficult. The models also reveal the minimum detectable pit diameter and pit depth in a dent of diameter 56 mm and depth 8 mm.

Automated Defect Classification Using an Artificial Neural Network

---**Tomasz Chady** and Marcin Caryk, Szczecin University of Technology, Department of Electrical Engineering, Szczecin, Poland; Bogdan Piekarczyk, TECHNIC-CONTROL Sp. z o.o., Szczecin, Poland

---The automated defect classification algorithm using an artificial neural network is presented. In order to create the neural network it is necessary to prepare representative database of defects. The database is used as a learning data in neural network training process. Database preparation requires the following steps: image acquisition and pre-processing, image enhancement, defect detection and feature extraction. The real digital radiographs of welded parts of a ship were used for this purpose. The analyzed radiographs contain various defects such as: cracks, porosity, gas pores, elongated cavities, wormholes, slag inclusions, lack of side wall fusion and undercuts. After pre-processing operation, the defect detection process was carried out. The indirect defect detection method was applied. In this method the radiograph background is generated using a filter. Then, the background was subtracted from the original radiograph. Next, the results of background subtraction are thresholded. The adaptive and Sauvola local thresholding were used. Finally, the features for each detected defect were calculated. As a classification algorithm the artificial neural network classifier with multilayer backpropagation structure was utilized. The selected features of flaws were used as input data. The output layer of neural network contains 5 neurons. Each neuron corresponds to one group of defect. All calculations were carried out using C and Matlab environment.

Defect Sizing Method Using Ultrasonic Guided Waves in Pipes

---**Y. Nagashima**, M. Endou, and M. Miki, Hitachi, Ltd., Power & Industrial Systems R & D Laboratory 7-2-1, Omika-cho, Hitachi-shi, Ibaraki-ken 319-1221, Japan

---This paper presents a defect-sizing method using swept-frequency guided wave. In this technique, reflection coefficients of multiple frequencies are measured, and the coefficients were compared with the analysis result that was calculated by integration of reflection waves from divided calculation-regions that had different characteristic acoustical impedances. The reflection coefficient was analyzed for three typical defect shapes (rectangle, triangle and semiellipse). For the rectangle defect, the reflection coefficient indicated maximum value when the axial aperture length of defect was (2n - 1)/4 times of wavelength (n=1, 2..). This result was caused by interference between anti-phase reflection wave from thickness declining position and in-phase reflection wave from thickness increasing position. The reflection coefficients for triangle and semiellipse defect are also changed cyclically depended on frequency, but the coefficients were getting lower for high frequency areas. Therefore, defect shape along pipe-axis can be estimated by measuring relationship between frequency and the reflection coefficients. The effectiveness of the method was identified experimentally using torsional mode guided waves that propagate pipes of which diameters are 60 mm or 114 mm and in which defects (ratio of depth by length = 1:8, 1:16, 1:32) were fabricated. The experimental results were good agreement with analysis results.

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