Abstracts

Review of Progress in Quantitative NDE
Marriott San Diego Mission Valley
San Diego, California
July 18 – 23, 2010

Organized by:
Center for Nondestructive Evaluation
Iowa State University

In cooperation with:
Air Force Research Laboratory
American Society for Nondestructive Testing
Ames Laboratory U.S. Department of Energy
Army Research Laboratory
Federal Aviation Administration
National Aeronautics and Space Administration LaRC
National Science Foundation
Industry/University Cooperative Research Centers

The Center for Nondestructive Evaluation is a member of the ISU Institute for Physical Research and Technology.
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<td><strong>KEY:</strong> All technical sessions will be in the Rio Vista Ballroom Salons A-C - Salons A-C E - Salon E D - Salon D F-H - Salons F-H DE - Salons DE</td>
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**Conference check-in and registration**
Rio Vista Ballroom Foyer

**Welcome Reception**
Marriott Poolside
7:00 p.m.

**ONDE Conference Dinner**
Rio Vista Pavilion
Social Reception 6:00 p.m.
Meal at 6:45 p.m.

**Plenary 1 Lessons Learned from the I-35 Bridge Collapse**
(C. French) D-E

**Plenary 2 Emerging Tools for SHM/Prognosis**
(Lynch and M. A. Zikry) D-E

3. UT Modeling - A-C
4. Electromagnetic Inverse Problems - D
5. Process Control & SHM - E
6. New Sensors, Techniques, & Systems - F-H

7. Flaw Sizing Techniques - A-C
8. NDE of Armor & Armor Systems - D
9. Structural Health Monitoring II - E
10. NDE for Civil Structures - F-H

11. Student Poster Competition & Other Posters: Ultrasonic Applications, Sensors, Techniques, & Systems Cabrillo Salons 1 & 2

12. Terahertz NDE - A-C
13. Benchmark Validation NDE - D
14. Welds & Bonds - E
15. POD & NDE Reliability - F-H

16. UT Phased Arrays I - A-C
17. NDE for Microstructure - D
18. Thermography & Thermosonics I - E
19. Probability of Detection - F-H

20. UT Phased Arrays II - A-C
21. NDE for Microstructure - D
22. Material Properties & Microstructure - E
23. Signal Processing - F-H

25. Guided Waves I - A-C
26. X-Ray NDE - D
27. Composites & Composite Structures - E
28. NDE in Civil Engineering - F-H


30. Guided Waves II - A-C
31. NDE for Concrete - D
32. Nonlinear UT Measurements - E
33. Electromagnetic Modeling & Defect Sizing - F-H

34. Laser Ultrasounds - A-C
35. Material Properties Measurements - D
36. Probes, Sensors, & Instruments - E
37. New Techniques & Systems - F-H

8:00 am 9:00 10:00 11:00 12:00 pm 1:00 2:00 3:00 4:00 5:00 6:00 7:00 8:00 9:00
Plenary Session 1 – Lessons Learned from the I-35 Bridge Collapse ................................................................. 1
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Session 6 – New Sensors, Techniques, and Systems ... 22
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.

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<th>Time</th>
<th>Session 3 UT Modeling Salons A-C</th>
<th>Session 4 EM Inverse Problems Salon D</th>
<th>Session 5 Process Control &amp; SHM I Salon E</th>
<th>Session 6 New Sensors, Techniques, &amp; Systems Salons F-H</th>
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Plenary Sessions 1 and 2
Monday, July 19, 2010

PLENARY SESSION 1
LESSONS LEARNED FROM THE I-35 BRIDGE COLLAPSE
R. Bruce Thompson, Chairperson
Rio Vista Ballroom
Salons D and E

9:00 AM Opening Remarks

---C. French, University of Minneapolis, Institute of Technology, Department of Civil Engineering, Minneapolis, MN 55455-0220

10:10 AM Break

PLENARY SESSION 2
EMERGING TOOLS FOR SHM/PROGNOSIS
Dale E. Chimenti, Chairperson
Rio Vista Ballroom
Salons D and E

10:30 AM Multi-Scale Approaches to Monitoring and Assessing the Structural Integrity of Bridges Using Next-Generation Sensor Technologies
---J. Lynch, University of Michigan, Department of Civil and Environmental Engineering, Department of Electrical Engineering and Computer Science, 2380 G. G. Brown Building, Ann Arbor, MI 48109-2125

11:20 AM Microstructural Material Mechanisms and Global Behavior
---M. A. Zikry, North Carolina State University, Department of Mechanical and Aerospace Engineering, 2412 Broughton Hall, 2601 Stinson Drive, Campus Box 7910, Raleigh, NC 27695-7910

12:10 PM Lunch

Please Note: The bolded authors throughout this program indicate the presenting author.
I-35W Collapse, Rebuild, and Structural Health Monitoring: Including Challenges Associated with Structural Health Monitoring of Bridge Systems

---Catherine French, Institute of Technology, Department of Civil Engineering, University of Minneapolis, MN 55455-0220

---During evening rush hour traffic on August 1, 2007, the major interstate highway bridge carrying I-35W over the Mississippi River in Minneapolis catastrophically failed, tragically taking the lives of thirteen people and injuring many more. The steel truss bridge, constructed in 1967, was undergoing deck reconstruction during the collapse, and was estimated to carry more than 140,000 vehicles daily. This tragedy generated great interest in employment of structural health monitoring systems. The I-35W St. Anthony Falls Bridge, a post-tensioned concrete box bridge constructed to replace the collapsed steel truss bridge, contains over 500 instruments to monitor the structural behavior. Numerical models of the bridge are being developed and calibrated to the collected data obtained from truck load tests and thermal effects. The data obtained over the first few years of monitoring are being correlated with the calibrated models and used to develop the baseline bridge behavior. This information is being used to develop a system to monitor and interpret the long-term behavior of the bridge. This presentation describes the instrumentation, preliminary results from the data and model calibration, the plan for developing long-term monitoring capabilities, and the challenges associated with structural health monitoring of bridge systems. In addition, opportunities and directions for future research required to fully realize the objectives of structural health monitoring will be described.
Multi-Scale Approaches to Monitoring and Assessing the Structural Integrity of Bridges Using Next-Generation Sensor Technologies

---Jerome Lynch, University of Michigan, Department of Civil and Environmental Engineering, Department of Electrical Engineering and Computer Science, 2380 G. G. Brown Building, Ann Arbor, MI 48109-2125

---The long-term deterioration of large-scale infrastructure systems is a critical national problem that if left unchecked, could lead to catastrophic structural failures similar in magnitude to the collapse of the I-35W Bridge (Minneapolis 2007). Structural health monitoring (SHM) systems have been proposed for automated detection and quantification of structural degradation in an affordable and real-time manner. Fortunately, the past decade has witnessed the emergence of many new sensing and information technologies that have the potential to radically transform current SHM system design paradigms. This presentation provides a detailed overview of an emerging set of sensor technologies under development at the University of Michigan within the National Institute of Standards and Technology (NIST) Technology Innovation Program. The overall system architecture spans multiple length scales with data collected from sensors deployed at the local and global scales of a structure. Furthermore, a cyberinfrastructure system is proposed to aggregate raw and processed data from multiple bridges at the regional scale. At the local scale, self-sensing materials are capable of directly detecting the onset of structural damage. For example, self-sensing cement-based composites and carbon nanotube coating systems are being developed for use in the construction of future bridge systems. Data from self-sensing materials, as well as from more traditional sensors, are collected using ultra low-power wireless sensors powered by a variety of power harvesting devices fabricated using microelectromechanical systems (MEMS). In the system design, data collected by wireless sensors is seamlessly streamed across the internet and ingested into a regional database system upon which finite element models can be autonomously updated and life-cycle analyses conducted. Sensor and analytical data stored in the system database can also be fed into a decision making toolbox that would assist infrastructure owners in their decision making processes. The project makes use of short- and long-span testbed bridges, including the New Carquinez Suspension Bridge in California, for full-scale validation of the monitoring system.
Microstructural Material Mechanisms and Global Behavior

---M. A. Zikry, North Carolina State University, Department of Mechanical and Aerospace Engineering, 2412 Broughton Hall, 2601 Stinson Drive – Campus Box 7910, Raleigh, NC 27695-7910

---In this talk, I will discuss how microstructural behavior at scales ranging from the nano to the micro can have dominant effects on global structural and material failure. Modeling predictions related to dynamic failure in crystalline materials, nanoindentation, and RF MEMS will be used to demonstrate how failure can be identified and possibly controlled at different physical scales.
Session 3
1:30 PM  New Plat-Form Capabilities for the Integration of Models and Connexion of Codes in the CIVA Framework  
---P. Calmon, S. Leberre, and S. Mahaut, CEA LIST, Gif sur Yvette, France

1:50 PM  Ultrasonic Transducer Models for the Generation of Surface Waves and Plate Waves with Angle Beam Transducers  
---L. W. Schmerr, Jr., Iowa State University, Center for NDE and the Department of Aerospace Engineering, Ames, IA 50011; A. Sedov, Lakehead University, Department of Mechanical Engineering, Thunder Bay P7B 5E1, Canada

2:10 PM  Wave Propagation in Elastic Media with Heterogeneous Quadratic Nonlinearity  
---G. Tang¹ and J. Qu², Northwestern University, ¹Department of Mechanical Engineering, ²Department of Civil and Environmental Engineering, Evanston, IL 60208; L. J. Jacobs, Georgia Institute of Technology, School of Civil and Environmental Engineering, Atlanta, GA 30332-0360

2:30 PM  3-D Image-Based Simulation for Ultrasonic Wave Propagation in Heterogeneous and Anisotropic Materials  
---K. Nakahata, Ehime University, Department of Civil and Environmental Engineering, Ehime, Japan; F. Schubert and B. Koehler, Fraunhofer Institute for Nondestructive Testing, Dresden Branch (IZFP-D), Dresden, Germany

2:50 PM  Efficient Finite Element Model of Elastodynamic Scattering from Near Surface and Surface-Breaking Defects  
---A. Velichko and P. D. Wilcox, University of Bristol, Department of Mechanical Engineering, University Walk, Queens Building, Bristol, United Kingdom

3:10 PM  Break

3:30 PM  Generic Time-Domain Hybrid Models for Ultrasonic NDE  
---P. Rajagopal and M. J. S. Lowe, Imperial College, Mechanical Engineering, London, United Kingdom; E. Skelton, Imperial College, Mathematics, London, United Kingdom; R. Craster, Mathematical and Statistical Sciences, University of Alberta, Edmonton, Canada; J. Russell, Rolls-Royce plc, Derby, United Kingdom

3:50 PM  A Model of Ultrasonic Testing for Cracks Near a Non-Planar Surface  
---J. Westlund and A. Bostrom, Department of Applied Mechanics, Chalmers University of Technology, SE-412 96 Gothenburg, Sweden

4:10 PM  Evaluation on Imperfect Interface with Fundamental Frequency Nonlinearity  
---J. Jiao, Beijing University of Technology, Department of Mechanical Engineering, Beijing, 100124, China

4:30 PM  A Numerical Model for Magnetostrictive Electromagnetic Acoustic Transducers  
---R. Ribichini, F. Cegla, and P. Cawley, Imperial College, Mechanical Engineering, London, United Kingdom; P. B. Nagy, University of Cincinnati, Aerospace Engineering & Engineering Mechanics, Cincinnati, OH 45221

4:50 PM  Simulation of Ultrasonic Inspection Involving Multiple Skips and Realistic Defects  
---S. Chatillon, N. Leymarie, G. Rougeron, and S. Mahaut, CEA, LIST, F-91191, Gif-sur-Yvette, France
New Platform Capabilities for the Integration of Models and Connexion of Codes in the CIVA Framework
---Pierre Calmon, Stephane Leberre, and Steve Mahaut, CEA LIST, Gif sur Yvette, France

---Since several years the CIVA software has evolved towards becoming a NDT platform which allows the connexion or integration of models and codes developed by groups collaborating with CEA. The major interest of this platform approach is the mutualization of common NDT-oriented software tools existing in CIVA such as CAD link, GUI system and so on. This makes easier both the development and the utilization by end-users of new modules. Linked to this approach a network of academic partners has been created aiming at proposing new models or methods to the platform. In this context efforts have been put at CEA in order to provide efficient means for connexion, coupling or integration of codes or algorithms in CIVA. The encountered situations are very different: improvement or enrichment of existing modules, new modelling functionalities (modeling or data processing), connexion of "huge" codes such as FEM based simulation codes. This variety has motivated the development of several technical solutions. In this communication we give an overview of these new platform capabilities. We present some examples of codes integration realized in the framework of various collaborations which illustrate the interest of the approach. These examples cover different techniques (Ultrasonics, Eddy Current) and applications.

Ultrasonic Transducer Models for the Generation of Surface Waves and Plate Waves with Angle Beam Transducers
---Lester W. Schmerr Jr., Center for NDE and the Department of Aerospace Engineering, Iowa State University, Ames, IA 50011; Alexander Sedov, Department of Mechanical Engineering, Lakehead University

---In ultrasonic inspections with surface waves and plate waves, angle beam wedge transducers are commonly used to generate the interrogating waves. However, to date there are no effective models of such transducers similar to those that have been developed for bulk wave angle beam transducers. Instead, most model studies often rely on the approach of Viktorov (I.A. Viktorov, Rayleigh and Lamb Waves, Plenum Press, New York, N.Y., 1967) where the wedge geometry is replaced by a specified stress distribution on a stress-free surface. As Viktorov points out this procedure is inadequate because: 1) it does not take into account the waves as they are actually generated in the transducer wedge, 2) the simple stress distributions used are not representative of the actual stresses present, and 3) the model ignores the attenuation of the waves as they are generated under the wedge. In addition to using these simplifying assumptions many studies also only consider 2-D models. Here, we will present a fully 3-D model of an angle beam transducer that generates surface or plate waves that addresses all of the inadequacies mentioned. The model uses a combination of high frequency asymptotics and Greens functions for surface and plate waves.—This work was supported for L.W. Schmerr by the NSF Industry/University Cooperative Research program. A. Sedov wishes to acknowledge support by the Natural Sciences and Engineering Research Council of Canada.
Wave Propagation in Elastic Media with Heterogeneous Quadratic Nonlinearity
---Guangxin Tang and Jianmin Qu*, Northwestern University, Department of Mechanical Engineering, *Department of Civil and Environmental Engineering, Evanston, IL 60208; Laurence J. Jacobs, Georgia Institute of Technology, School of Civil and Environmental Engineering, Atlanta, GA 60208

---This paper studies the one-dimensional wave propagation in an elastic medium with spatially non-uniform quadratic nonlinearity. Two problems are solved analytically. One is for a time-harmonic wave propagating in a half-space where the displacement is prescribed on the surface of the half-space. It is found that spatial non-uniformity of the material nonlinearity causes backscattering of the second order harmonic, which when combined with the forward propagating waves generates a standing wave in steady-state wave motion. The second problem solved is the reflection from and transmission through a layer of finite thickness embedded in an otherwise linearly elastic medium of infinite extent, where it is assumed that the layer has a spatially non-uniform quadratic nonlinearity. The results show that the transmission coefficient for the second order harmonic is proportional to the spatial average of the nonlinearity across the thickness of the layer, independent of the spatial distribution of the nonlinearity. On the other hand, the coefficient of reflection is proportional to a weighted average of the nonlinearity across the layer thickness. The weight function in this weighted average is related to the propagating phase, thus making the coefficient of reflection dependent on the spatial distribution of the nonlinearity. Finally, the paper concludes with some discussions on the case when the nonlinearity distribution is a stochastic function.

3-D Image-Based Simulation for Ultrasonic Wave Propagation in Heterogeneous and Anisotropic Materials
---Kazuyuki Nakahata, Ehime University, Dept. of Civil and Environmental Engineering, Ehime, Japan; Frank Schubert and Bernd Koehler, Fraunhofer Institute for Nondestructive Testing, Dresden Branch (IZFP-D), Dresden, Germany

---Time domain simulation tools for ultrasonic wave propagation in materials with a complex outer surface or various inclusions are developed by combining the finite integration technique (FIT) and the finite element method (FEM) with an image-based modeling approach. The FIT is a grid-based spatial discretization method that works in conjunction with a leapfrog time marching scheme. On the other hand, the FEM adopts a voxel-shaped spatial element and the calculation is updated by an explicit scheme without solving system equations. In our simulation, geometries of targets are determined by digital images such as X-ray pictures or CAD data, and the processed voxel data are directly fed into the wave simulation by the image-based FIT and FEM. The accuracy of the two methods is checked by comparison with the boundary element method (BEM). Here some simulations for acoustic and elastodynamic problems are demonstrated.
Efficient Finite Element Model of Elastodynamic Scattering From Near Surface and Surface-Breaking Defects

---Alexander Velichko and Paul D. Wilcox, University of Bristol, Dept. of Mechanical Engineering, University Walk, Queens Building, Bristol, United Kingdom

---Detection and characterization of near surface and surface breaking defects is still a major challenge for non-destructive evaluation. The information about defects can be obtained using ultrasonic arrays and special processing techniques for defect localization and characterization can be applied. However, in order to correctly interpret array data the interaction of elastic waves with defects has to be well understood and, therefore, mathematical modeling of the scattering process is required. It is convenient to characterize the scattered wave field by a far-field scattering coefficient matrix, the scattering matrix. The scattering matrix can be calculated more or less straightforwardly in the framework of the semi-analytical approaches or boundary element methods which deal rigorously with the infinite extent of the host medium. However, volume discretization methods such as FEM or FD must truncate discretization at some point by introducing, for example, absorbing boundaries, and generally only relatively small volumes can be discretized because the model size becomes unrealistically large otherwise. In the current paper, an efficient Finite Element procedure is presented for predicting the complete scattering behavior of an arbitrary-shaped scatterer which is located near free surface in an otherwise homogeneous isotropic half-space. Example results for 2D and 3D wave scattering are presented.

Generic Time-Domain Hybrid Models for Ultrasonic NDE

---Prabhu Rajagopal and Michael J.S. Lowe, Imperial College, Mechanical Engineering, London, United Kingdom; Elizabeth Skelton, Imperial College, Mathematics, London, United Kingdom; Richard Craster, Mathematical and Statistical Sciences, University of Alberta, Edmonton, Canada; Jonathan Russell, Rolls-Royce plc, Derby, United Kingdom

---Simulation tools to visualize the entire process of ultrasonic NDE involving wave generation, propagation, scattering and reception have long been desirable. However, with increasing complexity of features to be inspected and consequently of transduction, usage of a single method to model the whole process is becoming challenging. Hybrid models that can seamlessly combine different solution procedures are becoming attractive in this context. The authors discussed the merits of a generic procedure to implement such hybrid models using commercial packages during last year’s QNDE conference. These considerations resulted in the creation of a generic hybrid interface that could link any two solution procedures or platforms for modeling 2D ultrasound. First results from a single-frequency implementation of this interface within a prototype hybrid model linking Finite Element (FE) model domains were also presented. Here we report progress in this work, applying it to problems of interest to practical inspection. We first outline an extension of the prototype hybrid interface to work in the time-domain, as this is valuable for visualization of the inspection situation. We then present results from FE-FE hybrid models of the scattering of bulk longitudinal (P) and shear (SV) waves from simple defects. Different source-defect domain and configuration types are considered to highlight the versatility of the method. Finally, competing factors affecting the accuracy of the results are revealed using convergence and validation studies.
A Model of Ultrasonic Testing for Cracks Near a Non-Planar Surface
---Jonathan Westlund and Anders Bostrom, Department of Applied Mechanics, Chalmers University of Technology, SE-412 96 Gothenburg, Sweden

---Based on the methodology of the 2D models presented at QNDE 2008 and QNDE 2009, this paper presents an extension to 3D of a model of ultrasonic testing for cracks near a non-planar back surface. The elastic wave scattering in a thick-walled component by an interior rectangular crack located near a back surface of arbitrary geometry is considered. The 3D wave scattering problem is solved using a hybrid boundary integral equation method (BIEM): a displacement boundary element method (BEM) for the back surface displacements is combined with an analytical technique for the hypersingular traction integral equation for the crack-opening displacements. The action of ultrasonic transducers in transmission and reception is taken into account in the model, and a few numerical examples illustrating the influence of the back surface geometry are given.

Evaluation on Imperfect Interface With Fundamental Frequency Nonlinearity
---Jingpin Jiao, Beijing University of Technology, Department of Mechanical Engineering, Beijing, 100124, China

---The interaction of ultrasonic waves with interfaces formed by two rough surfaces in contact has been the subject of numerous investigations. When ultrasonic wave is incident to interfaces, repetition of collisions are generated between the two surfaces, which results in contact acoustic nonlinearity (CAN). Most of the present methods consider only part of the nonlinear signature, in general, that is due to higher-order harmonics or sidebands, excluding therefore the contribution observable at the fundamental frequency. As a result, in particular when dealing with early/small damage, these methods need very accurate measurements to be performed in a controlled environment. In this paper, a fundamental frequency nonlinear method is proposed which exploits the nonlinear contribution to the fundamental frequency component of the detected signal. The fundamental frequency nonlinear method which includes phase nonlinear indicator and attenuation nonlinear indicator is applied to evaluate contact nonlinearity. The interfaces nonlinearity between two aluminium block surfaces on the quasistatic compression load and nonlinear features are studied. The relationships between nonlinear features and interface roughness are also discussed. The results showed that the fundamental frequency nonlinear method have potential in extracting nonlinear features. From the nonlinear features, it can see that phase and attenuation contribution of the fundamental frequency signal is obvious than harmonic contribution of higher frequency signal.
A Numerical Model for Magnetostrictive Electromagnetic Acoustic Transducers
---Remo Ribichini, Frederic Cegla, and Peter Cawley, Imperial College, Mechanical Engineering, London, United Kingdom; Peter B. Nagy, University of Cincinnati, Aerospace Engineering & Engineering Mechanics, Cincinnati, OH 45221

---Piezoelectric transducers are widely employed for Nondestructive Evaluation; however they usually require the use of a couplant fluid between the sensor and the test object. This sets a limitation whenever inspections on high temperature or moving objects have to be performed. Electromagnetic Acoustic Transducers (EMATs) do not need the sensor to physically touch the test object and can be an attractive alternative to piezoelectric probes in a number of applications. In order to optimize the design of EMATs for specific applications, a Finite Element model has been developed. The model includes the main transduction mechanisms; the physics of magnetostriction is modelled and its effects are analyzed in detail. The FE model was validated against experiments for a simple EMAT configuration. The wave amplitude dependence on significant parameters, such as the static bias field, the driving current amplitude and the excitation frequency was successfully predicted. An absolute validation, with no arbitrary adjustable parameter, was achieved, the discrepancy between predicted wave amplitudes and measured values being lower than 20%. The study also shows how magnetostrictive transduction is significantly affected by the magnetic permeability and the consequences of this effect for EMAT sensitivity are discussed.

Simulation of Ultrasonic Inspection Involving Multiple Skips and Realistic Defects
---Sylvain Chatillon, Nicolas Leymarie, Gilles Rougeron, and Steve Mahaut, CEA, LIST, F- 91191, Gif-sur-Yvette, France

---For several years, simulation tools aiming at predicting results of ultrasonic inspection have been developed and integrated into the CIVA simulation platform software at CEA-LIST. Those models have recently been extended in order to take account of more complex phenomena, as multiple skips (over backwall, surface, lateral walls of components), mode conversion arising in internal medium of heterogeneous parts, and interaction between branches of ramified flaws. In addition to canonical (planar and cylindrical parts), parametric (nozzles) and 2D CAD components (complex profile and translation or revolution extrusion) already dealt with, those skills are now also available for 3D CAD components. Dedicated tools have also been developed in order to help for interpretation, settings and time saving of the computation: advanced ray tracing for displaying different echo modes (one or several skips, mode conversions, possibility to display only rays coming back to the receiving probes, selection of specific echoes), selection of specific zones over a 3D component to define echogenic areas. These developments are illustrated through several industrial applications.
SESSION 4
ELECTROMAGNETIC INVERSE PROBLEMS
Jeremy S. Knopp and John Bowler, Co-Chairpersons
Salon D

1:30 PM Qualitative Methods in the Use of Electromagnetic Waves to Image Anisotropic Media
---F. Cakoni, D. Colton, and P. Monk, Department of Mathematical Sciences, University of Delaware, Newark, DE 19716

2:30 PM Shape Identification of Pipe-Wall Thinning Using Electromagnetic Acoustic Transducers
---F. Kojima, Kobe University, Organization of Advanced Science and Technology, Kobe, Japan; T.-D. Nguyen and H. Yamaguchi, Kobe University, Graduate School of Engineering, Japan

2:50 PM Importance of Accurate Impedance Measurements in Defect and Property Imaging
---Y. Sheiretov and N. Goldfine, JENTEK Sensors, Inc., 110-1 Clematic Avenue, Waltham, MA 02453-7013

3:10 PM Break

3:30 PM Electromagnetic Interrogation and the Doppler Shift Using the Method of Mappings
---H. T. Banks, S. Hu, and W. C. Thompson, Center for Research in Scientific Computation, North Carolina State University, Raleigh, NC 27695-8212

3:50 PM Solution of Inverse Problem Using Time Reversal Techniques
---S. Reyes-Rodriguez, C. Bardel, N. Lei, L. Udpa, and S. S. Udpa, Michigan State University, NDE Laboratory, Department of Electrical and Computer Engineering, East Lansing, MI 48824

4:10 PM Uncertainty Propagation in Eddy Current NDE Inverse Problems
---J. C. Aldrin, Computational Tools, Gurnee, IL 60031; J. S. Knopp and M. P. Blodgett, U.S. Air Force Research Laboratory, Wright-Patterson AFB, OH 45433; H. A. Sabbagh, Victor Technologies LLC, Bloomington, IN 47407

4:30 PM Inversion of Eddy Current Crack Data in the Thin Skin Regime
---J. R. Bowler, Iowa State University, Center for NDE and Department of Electrical and Computer Engineering, Ames, IA 50011

4:50 PM Simulation of Eddy Current Inspection Including Magnetic Field Sensor Such as a Giant Magneto-Resistance Over Planar Stratified Media Components with Embedded Flaws
---D. Prémel, J.-M. Decitre, B. Marchand, and G. Pichenot, CEA, LIST, F-91191, Gif-sur-Yvette, France
Qualitative Methods in the Use of Electromagnetic Waves to Image Anisotropic Media

---Fioralba Cakoni, David Colton, and Peter Monk, Department of Mathematical Sciences, University of Delaware, Newark, DE 19716

---Anisotropic materials play a special role in the use of electromagnetic waves in the imaging of dielectrics. This is due to the fact that the permittivity tensor is not uniquely determined from the scattered field even if multi-frequency data is available. In particular, it has been shown that only the support of the inhomogeneous media can be uniquely determined from the measured scattering data. Although the permittivity tensor of the subject being investigated cannot be uniquely determined, there remains the possibility of estimating certain qualities of physical interest, in particular the eigenvalues of the permittivity tensor. In this talk we will review recent mathematical developments showing how this is possible provided both the amplitude and phase of multistatic data is available. In particular, we will discuss the linear sampling method to determine the support of the unknown anisotropic target and then, making use of a new set of eigenvalues associated with scattering from dielectrics, will provide estimates on the material properties of the anisotropic media.

Shape Identification of Pipe-Wall Thinning Using Electromagnetic Acoustic Transducer

---Fumio Kojima, Kobe University, Organization of Advanced Science and Technology, Kobe, Japan; Thanh-Duong Nguyen and Hiroshi Yamaguchi, Kobe University, Graduate School of Engineering, Japan

---Electromagnetic acoustic transducer (EMAT) is an innovative inspection technique that is already benefiting many industries. Although it is well known that EMAT is less sensitive compared with the conventional ultrasonic testing, this has great advantages on remote inspection of the plants. In this report, we propose a sizing methodology of pipe wall thinning using data acquisition by EMAT. First, a mathematical model of nondestructive test is given by eddy current systems and a linear elastic system. Corrosion shape of pipe wall thinning is then characterized by a piecewise linear function in two spatial dimensions. Secondly, a parameter estimation problem is discussed within the theoretical framework of the nonlinear least square error analysis using method of mapping. Thirdly, using principle components analysis (POD), the proposed method deploys a reduced order model in order to save the computational cost of the forward analysis. Then, an approach of signal processing based on peak values at back-wall echo and POD method applied to extracted feature of test signals are introduced. Finally, an inverse analysis is performed for recovering corrosion shape of pipe wall. Experimental results with high accuracy on both simulation and synthetic measurement data demonstrate the capability and effectiveness of the proposed method.
Importance of Accurate Impedance Measurements in Defect and Property Imaging
---Yanko Sheiretov and Neil Goldfine, JENTEK Sensors, Inc., 110-1 Clematis Avenue, Waltham, MA 02453-7013

---In this presentation we discuss several interesting phenomena that demonstrate the critical importance of accurate impedance measurement instrumentation including both magnitude and phase (or real and imaginary parts). It is common that conventional eddy current instrumentation, especially for support of arrays with many sensing elements, do not provide accurate phase measurements. In this presentation we discuss a few simple case studies that demonstrate behaviors that could confuse conventional methods and require accurate phase and magnitude measurements. These include (1) images of buried defects – illustrating that the magnetic diffusion time can introduce phase delays that can either obscure defect responses or make them appear counterintuitive by appearing to increase effective conductivity, (2) conditions where moving an eddy current sensor closer to a component can actually increase the signal magnitude for even nonmagnetic materials, and (3) the double-valued nature of the eddy current response for coating thickness measurements when the coating thickness is on the order of the skin depth. The goal of this paper is to highlight the value of accurate modeling and instrumentation for solving simple problems in eddy current sensing.

 Electromagnetic Interrogation and the Doppler Shift Using the Method of Mappings
---H.T. Banks, Shuhua Hu, and W. Clayton Thompson, Center for Research in Scientific Computation, North Carolina State University, Raleigh, NC 27695-8212

---We consider inverse problems involving the electromagnetic detection of hidden moving or oscillating conductive targets. The resulting mathematical problem involves computation of a Doppler shift for an electromagnetic wave reflecting from a moving interface. This entails solving Maxwell's equations on a domain changing in time. We employ the method of mappings to transform the problem to one of computing solutions of a Maxwell system with time dependent coefficients on a fixed reference domain. Thus we obtain a problem that is eminently tractable with finite element or finite difference time domain methods. Accuracy of numerical solutions is illustrated with computations for a number of different velocities for the moving interface.
Solution of Inverse Problem Using Time Reversal Techniques
---S. Reyes-Rodriguez, C. Bardel, N. Lei, L. Udpa, and S. S.Udpa, NDE Laboratory, Department of Electrical and Computer Engineering, Michigan State University, East Lansing, MI 48824

---Time reversal experiments in acoustics have shown significant potential for the detection and imaging of flaws in materials. This paper presents a feasibility study of imaging defects in dielectric materials using principles of time reversal applied to microwave NDE data. The principle is demonstrated using a two-dimensional finite difference time domain model for simulating the propagation of forward and time reversed wave fields. With an excitation source chosen to be a modulated Gaussian pulse of 2 GHz center frequency, the scattered electric field is recorded on a linear array of receivers; time reversed and propagated backwards using the model to highlight the scatterer/defect. The key advantage of the approach is that it provides a model-based inversion method that is not iterative. Simulation and experimental results validating the approach will be presented.

Uncertainty Propagation in Eddy Current NDE Inverse Problems
---John C. Aldrin, Computational Tools, Gurnee, IL 60031; Jeremy S. Knopp and Mark P. Blodgett, U.S. Air Force Research Laboratory, Wright-Patterson AFB, OH 45433; Harold A. Sabbagh, Victor Technologies, LLC, Bloomington, IN 47407

---Although eddy current models can accurately simulate many realistic NDE scenarios, limited progress has been made to implement model-based inverse methods partly due to the wide range of varying conditions under test. To study this problem, it is necessary to treat the input model parameters as random variables rather than deterministic quantities. This paper presents a non-intrusive method, the probabilistic collocation method (PCM), to efficiently propagate the distributions of input parameters in eddy current numerical models to the NDE measurement response. Simulations are appropriately selected by collocation points determined by the roots of orthogonal polynomials. A case study for eddy current NDE is presented for the problem of characterizing material loss in a multi-layer structure with varying liftoff and material conditions. The performance and sensitivity of the uncertainty propagation method using PCM was evaluated under varying settings and compared to conventional methods such as Monte Carlo simulation and Cramer Rao lower bound. A multilevel approach was also considered to simultaneously address input parameter variability and the uniqueness of the model-based inversion result. Both experimental and simulated case studies are presented to demonstrate the method. Lastly, an important observation concerning the calibration of experimental measurements with simulated impedance calculations is discussed.
Inversion of Eddy Current Crack Data in the Thin Skin Regime
---John R. Bowler, Center for NDE and Department of Electrical and Computer Engineering, Iowa State University, Ames IA 50011

---Crack detection using eddy current methods is commonly carried out at relative high frequencies at which the skin depth is small compared with the crack depth. For example, inspection of bolt holes in the aluminum aircraft structures is performed at frequencies such that the skin depth is of the order of 100 μm, yet most of the cracks detected are at usually much deeper than this. At high frequencies, it is possible to use a model of eddy current-crack interaction based on a thin skin approximation. It turns out that if the skin depth is less than about one third of the crack depth, a well developed thin skin theory can be reasonably accurate, simple, and computationally efficient for solving the forward problem. Given these attributes, the model seems to be a candidate for use in dealing with the corresponding inverse problem. Based on a strategy of minimizing a cost function which quantifies the difference between model predictions and probe measurements, a gradient method has been used to determine the optimum crack shape from the probe signals. The key requirement is to evaluate the gradient of the cost function with respect to the measurements. Then a standard decent algorithm can be used to find the flaw shape for which predictions and measurements are in optimal agreement. We have validated the forward model by comparison with experiment. Then computed shapes of notches that have been determine from coil impedance data starting with an initial estimate and proceeding iterative to find the best shape consistent with the measurements.---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.

Simulation of Eddy Current Inspection Including Magnetic Field Sensor Such as a Giant Magneto-Resistance Over Planar Stratified Media Components with Embedded Flaws
---Denis Prémel, Jean-Marc Decitre, Benoît Marchand and Grégoire Pichenot, CEA, LIST, F-91191 Gif-sur-Yvette, France

---The ECT inspection of a conductive component consists in detecting the perturbation of the induced currents due to a flaw. Among new detectors, Giant Magneto-Resistance (GMR) or Giant Magnetic Impedance sensors, which are sensitive to the magnetic field above the surface of the component, have shown growing interest due to their high performances with respect to classical bobbin coils. In this communication, we present a numerical model based on the volume integral approach which allows computing the components of the perturbed magnetic field due to a given notch embedded in a planar stratified media. Though the inducer may be chosen arbitrary in a list of potential exciting coils, rectangular coils or current foils are very useful for generating a uniform current flow orientated perpendicularly to the length of the flaw. This paper presents firstly some numerical results considering two kinds of distinct numerical models, and then some experimental results will be presented for different kinds of practical applications. This numerical model results in new computation facilities which have been translated into new functionalities in the last version of the CIVA software.
Session 5
Monday, July 19, 2010

SESSION 5
PROCESS CONTROL AND STRUCTURAL HEALTH MONITORING I
Tony Sinclair, Chairperson
Salon E

1:30 PM  The Threshold Choice in Image Processing
---R. M. Almeida and J. M. A. Rebello, Federal University of Rio de Janeiro, Department of Metallurgical and Materials Engineering, COPPE/UFRJ, P. O. Box 68505, CEP 21941-972, Rio de Janeiro, Brazil

1:50 PM  Development of Ultrasonic Guided Wave Based Inspection Methodology for Hexcan Sheath and Seal Weld of a Fast Breeder Reactor Fuel Subassembly
---A. Kumar, K. V. Rajkumar, G. K. Sharma, G. S. Kumar, C. B. Rao, and T. Jayakumar, Non-destructive Evaluation Division, Indira Gandhi Centre for Atomic Research, Kalpakkam, 603 102, Tamil Nadu, India

2:10 PM  Ultrasonic Measurement of Erosion/Corrosion Rates in Industrial Piping Systems
---A. N. Sinclair and V. Safavi, University of Toronto, Department of Mechanical and Industrial Engineering, Toronto, Ontario, Canada; F. Honarvar, K. N. Toosi University of Technology, Faculty of Mechanical Engineering, Tehran, Iran

2:30 PM  Using a Quantitative Laser Ultrasound Visualization System to Detect the Interaction of Wedge Waves with a Defect on Wedge Tip
---I.-H. Liu and C.-H. Yang, Institute of Manufacturing Technology, National Taipei University of Technology, Taipei, R.O.C., Taiwan

2:50 PM  Monitor Product Performance, not Quality Via Process Compensated Resonant Testing (PCRT)

3:10 PM  Break

3:30 PM  Development of Ultrasonic Surface Wave Sensors for Structural Health Monitoring of Composite Wind Turbine Blades
---C. J. Druffner, Mound Laser & Photonics Center, Miamisburg, OH 45342; V. Nalladega and J.-K. Na, University of Dayton Research Institute, Dayton, OH 45469

3:50 PM  Contact Defect Detection in Plates Using Guided Wave and Vibro-Acoustic Modulation Techniques
---J. Jiao, G. Song, C. He, and B. Wu, Beijing University of Technology, Department of Mechanical Engineering, Beijing, 100124, China; B. W. Drinkwater, S. A. Neild, and P. D. Wilcox, University of Bristol, Department of Mechanical Engineering, Bristol, BS8 1TR, United Kingdom

4:10 PM  Continuous Surveillance Technique for Flow Accelerated Corrosion of Pipe Wall Using Electromagnetic Acoustic Transducer
---F. Kojima, Kobe University, Organization of Advanced Science and Technology, Kobe, Japan; D. Kosaka, Kobe University, Graduate School of Engineering; K. Umetani, Kobe University, Graduate School of System Informatics, Japan

4:30 PM  Initial Field Test Assessment of a Dynamically-Reconfigurable Health Monitor
---R. Austin and C. Coughlin, Texas Research Institute, NDE Group, Austin, TX 78733; L. Braden, National Institute for Aviation Research, Full-Scale Structural Testing Lab, Wichita, KS; D. Forsyth to present this work
The Threshold Choice in Image Processing
---Romulo M. Almeida and João M. A. Rebello,
Federal University of Rio de Janeiro,
Department of Metallurgical and Materials
Engineering, COPPE/UFRJ, P.O. Box 68505,
CEP 21941-972, Rio de Janeiro, Brazil

---It is well known that interpretation of film weld
radiographs is a rather difficult and complex
task, even when conducted by experienced and
well qualified inspectors. Difficulties arise due to
several factors for example: weld radiographic
images are in general too dark, have high noise,
exhibit low contrast, and the background gray
level is not uniform over the whole image area
due to thickness variations of the weld bead.
Moreover, the weld surface is frequently rough
and rippled, what can be seen as gray level
variation on the radiograph, being sometimes
mistaken as defective areas. For these reasons,
detection and sizing of small weld defects may
become difficult if not uncertain. That is why
image processing of weld radiographs has
currently become widely employed and
necessary to provide inspectors with a more
reliable diagnostics. A very common way of
image improvement is by contrast enhancement
and noise reduction. This can be accomplished
by several ways; for instance, applying threshold
techniques, which consist in suppressing data
from the image where the gray pixel level is
below a previously set value. Adoption of a too
high value of threshold implies in a risk of
suppressing relevant features from the image.
As a consequence, thresholding techniques are
being extensively studied by several authors
and, therefore, require further studies. The
present work proposes a simple procedure to
evaluate the efficiency of a given image
processing technique applied to weld
radiographs. Specifically, special attention is
given to the problem of how to evaluate whether
or not a threshold value was suitably set in order
to preserve relevant image features. In short, a
quantitative comparison is made between the
images of welds revealing defects before and
after processing. Six weld radiographs of rather
different image quality were chosen to be
analyzed using this proposed procedure.

Development of Ultrasonic Guided Wave
Based Inspection Methodology for Hexcan
Sheath and Seal Weld of a Fast Breeder
Reactor Fuel Subassembly
---Anish Kumar, Kesavan Vadivelu Rajkumar, Govind
Kumar Sharma, Gnanamuthu Suresh Kumar,
Chelamchala Babu Rao, and Tammana Jayakumar,
Non Destructive Evaluation Division, Indira Gandhi
Centre for Atomic Research, Kalpakkam, 603 102,
Tamil Nadu, India

---Fuel subassembly of Prototype Fast Breeder
Reactor (PFBR) at Kalpakkam, consists of a
hexagonal wrapper tube (hexcan) which
contains fuel pins. These 3600 mm long
hexcans are made up of 3.2 mm thick cold
worked stainless steel. The fuel subassembly
comprises of seal welds, which join the 3.2 mm
thick hexcan sheath to the thick head and foot
sections. Structural integrity of the hexcan
sheath as well as seal welds are very critical, as
any failure of these during operation may result
in separation of fuel pins from the bundles and
consequent difficulties in discharging of fuel
subassembly from the reactor core and/or failure
of fuel pins leading to contamination of the
coolant with fuel and radioactive fission
products. Hence, stringent quality control of
hexcan sheath and seal welds is important. The
conventional angle beam inspection has
inherent limitations for inspection of hexcan.
Further, the hexcan seal welds warranted
development of a new inspection method at
fabrication stage due to its complex geometry,
which would not allow reliable radiography
testing. An ultrasonic guided wave based
methodology has been developed for inspection
of the hexcan sheath and the seal welds. Using
immersion guided wave based inspection
method, both ID and OD defects of the order of
6 mm (L) x 200 μ (W) x 100 μ (D) (reference
defect) could be detected in the hexcan sheath.
The developed methodology is fast requiring
only one axial line scan using two transducers
for detection of any axial defect in one face of
the hexcan sheath. Similarly, transverse line
scans at 30 mm spacing are only required for
complete coverage of the hexcan sheath for
detection of transverse defects. The contact
guided wave based inspection methodology has
been employed on a hexcan seal weld having
natural defects. The size of the defects, as
determined using the ultrasonic methodology
developed, is found to be in close agreement
with those obtained using the destructive in-situ
metallography.
Ultrasonic Measurement of Erosion/Corrosion Rates in Industrial Piping Systems
---Anthony N. Sinclair and Vahid Safavi, University of Toronto, Department of Mechanical and Industrial Engineering, Toronto, Ontario, Canada; Farhang Honarvar, K. N. Toosi University of Technology, Faculty of Mechanical Engineering, Tehran, Iran

---Industrial piping systems that carry aggressive corrosion or erosion agents may suffer from a gradual wall thickness reduction that eventually threatens pipe integrity. Thinning rates could be estimated from the very small change in wall thickness values measured by conventional ultrasound over a time span of at least a few months. However, measurements performed over a shorter time spans would yield no useful information - minor signal distortions originating from grain noise and ultrasonic equipment imperfections prevent a meaningful estimate of the minuscule reduction in echo travel time. A signal processing scheme has been developed that enables the echo signals from the pipe wall to be separated from the noise, using a Model Based Estimation technique. This was implemented in a laboratory experimental program, featuring accelerated erosion/corrosion on the inner wall of a test pipe. The result was a reduction in the uncertainty in the wall thinning rate by a factor of 4. This improvement enables a more rapid response by system operators to a change in plant conditions that could pose a pipe integrity problem; it also enables a rapid evaluation of the effectiveness of new corrosion inhibiting agents under plant operating conditions.

Using a Quantitative Laser Ultrasound Visualization System to Detect the Interaction of Wedge Waves With a Defect on Wedge Tip
---I-Hung Liu and Che-Hua Yang, Institute of Manufacturing Technology, National Taipei University of Technology, Taipei, R.O.C, Taiwan

---Antisymmetric flexural (ASF) modes are wedge waves with their particle motion antisymmetric about the mid-plane bi-sectioning and energy tightly confined near the wedge tip. Machine tool blades exhibit typical wedge-shaped tips where defects are very likely to exist and call for nondestructive characterization. In order to investigate the interaction behaviors of ASF mode propagating along a damaged wedge tip, a quantitative laser ultrasound visualization system (QLUVS) which employs a pulsed laser to scan over the interested area then detected with a piezoelectric transducer is applied. With the aid of reciprocal theorem, dynamic behaviors of ASF modes encountering a defect can be reconstructed. In this research, the QLUVS is used to evaluate several crack-depth-dependent quantities of the ASF modes, including reflection coefficient (R), transmission coefficient (T) and the scattering intensity. With the QLUVS behaviors of ASF modes interacting with a wedge-tip-crack are characterized in a quantitative way. More complex behaviors for higher-order ASF interacting with cracks are under investigation.
Monitor Product Performance Not Quality via Process Compensated Resonant Testing (PCRT)
---Surendra Singh, Eric Yen, Daniel Cabrera, and Larry Whalen, Honeywell Aerospace, Materials and Process Engineering, Phoenix, AZ 85034; Leanne Jauriqui and Eric Biedermann, Vibrant Corporation, Albuquerque, NM 87109-4408; David Piotrowski, Delta Air Lines, Delta Tech Ops, Atlanta, GA; David Heck, Boeing, Boeing Phantom Works, Berkeley, MO 63134

---For the last several years, Honeywell in collaboration with Vibrant, Delta Tech Op, and Boeing has used Process Compensated Resonant Testing (PCRT) to successfully study structural integrity and functional performance over wide range of components. Results from JT8D 1st stage turbine blades and ceramic balls for defense and space programs were reported in earlier meetings. Recently uses of PCRT have expanded to a wide range of parts in aerospace, automotive, and power generation industries. The application emphasis of PCRT is shifting from quality inspection during manufacturing to monitoring structural integrity of in-service hardware. In this paper, we present results for several on-going projects where PCRT is used to study the empirical correlation between manufacturing induced anomalies and structural deficiency (and functional performance) in ceramic balls, ceramic seal runners, turbine blades, molded carbon disks, aircraft wheels, and fasteners. The results show that PCRT can be successfully used to sort acceptable parts from parts containing defects, including materials with structural deficiency, dimensional variations, and service induced defects such as micro-structural changes, cracks, inter-granular attack (IGA), and excessive wear, etc. Our long term goals include correlating failure modes with PCRT response and estimating the remaining useful life of the parts.

Development of Ultrasonic Surface Wave Sensors for Structural Health Monitoring of Composite Wind Turbine Blades
---Carl J. Druffner, Mound Laser & Photonics Center, Miamisburg, OH 45342; Vijay Nalladega and Jeong-Kwan Na, University of Dayton Research Institute, Dayton, OH 45469

---To increase the power generating capacity of a windmill, composite turbine blade manufacturers have been increasing the size of blades. Current utility-scale windmills are equipped with moving blades ranging from 40 m (130 ft) to 90 m (300 ft) in diameter. The increased turbine size brings greater structural and safety demands. Recent blade recalls and field failures reinforce the market need for structural health monitoring (SHM) capability that can address the problems of manufacturing inspection and real time monitoring of the conditions of critical components. As a first step towards developing a reliable SHM system, an ultrasonic surface wave sensor technology based on the interdigitization transduction (IDT) is utilized, that can ultimately be used to detect defects in the wind turbine blades. The current work covers the design, fabrication, and characterization of the IDT sensors with a frequency range of 250 kHz to 1 MHz. The sensor characterization includes ultrasonic properties such as beam spread and energy dissipation in an anisotropic medium along with the operational sensing window size.
Contact Defect Detection in Plates Using Guided Wave and Vibro-Acoustic Modulation Techniques
---Jingpin Jiao, Guorong Song, Cunfu He, and Bin Wu, Beijing University of Technology, Department of Mechanical Engineering, Beijing, 100124, China; B. W. Drinkwater, S. A. Neild, and P. D. Wilcox, University of Bristol, Department of Mechanical Engineering, Bristol, BS8 1TR, United Kingdom

---There is growing interest in the nonlinear acoustic effects in solids due to promising applications of these effects for nondestructive testing and characterization of materials and structures. An important advantage of the nonlinear acoustic methods is to discriminate between integrity reducing flaws and other inhomogeneities. Contact-type defects such as cracks, disbonds, delaminations, etc. lead to an anomalously high level of nonlinearity. In this paper, a nonlinear acoustic technique for detection of contact defects in plates was developed associating guided waves with vibro-modulation techniques. The low frequency vibration varies the interface area within the contact defect; therefore the amplitude and phase of high frequency guided waves reflected from the contact defect will be modulated. Due to the exiting of contact defects, there was obvious low frequency component in the time-frequency distribution of modulated guided wave series. The nonlinear responses at frequency of vibration were extracted out and used for defect imaging. It was shown that the nonlinear guided wave imaging method based on vibration modulation can effectively characterize and locate the contact defects.

Continuous Surveillance Technique for Flow Accelerated Corrosion of Pipe Wall Using Electromagnetic Acoustic Transducer
---Fumio Kojima, Kobe University, Organization of Advanced Science and Technology, Kobe, Japan; Daigo Kosaka, Kobe University, Graduate School of Engineering; Kosuke Umetani, Kobe University, Graduate School of System Informatics, Japan

---Over the years, flow accelerated corrosion (FAC) causes wall thinning of carbon steel piping exposed to flowing water or wet steam. Ultrasonic testing (UT) allows the accurate measurements of the pipe wall thickness measurement from the surface of the materials. Since the inspection by UT is performed during a unit outage with insulation removed from the piping area, the inspection cost is increasing at the aged plants. Therefore continuous surveillance during the operation is much more important than the periodical inspection by UT. In this report, we propose a on-line monitoring technique using electromagnetic acoustic transducer (EMAT). The advantage of our method is that measurements can be remotely implemented and that various kinds of testing signal can be automatically reproduced by electrical circuits without human experts. In the series of laboratory experiments, carbon steel pipes (68or2B-SS400) were used and each sample was fabricated to simulate FAC (10% and 50% notch samples). Electromagnetic acoustic resonance method (EMAR) is successfully tested for pipe wall thickness measurements. The validity and the feasibility of our method are also demonstrated through the practical test at the real plant.
Initial Field Test Assessment of a Dynamically-Reconfigurable Health Monitor
---Russell Austin and Chris Coughlin, Texas Research Institute, NDE Group, Austin, TX 78733; Larry Braden, National Institute for Aviation Research, Full-Scale Structural Testing Lab, Wichita, KS

NOTE: D. Forsyth to present this work

---TRI's Large Area Health Monitoring Processor (LAHMP) is a ruggedized hardware and software solution designed for nondestructive testing and condition-based maintenance. Originally designed to support two-channel acoustic emission and four-channel acousto-ultrasonics modes, the platform has since been revamped to allow for a more modular, dynamic approach to operation. By abstracting out the concepts of sensor data acquisition, storage, and analysis, the new LAHMP platform can be configured to change its mode of operation on demand. This paper describes a recent field deployment of this SHM system for monitoring a full scale component fatigue test. This paper also outlines the initial results of these efforts.
Session 6
SESSION 6
NEW SENSORS, TECHNIQUES, AND SYSTEMS
Arthur G. Every, Chairperson
Salons F-H

Monday, July 19, 2010

1:30 PM  Piezoelectric Behavior of Sputtered Aluminium Nitride Thin Film for High Frequency Ultrasonic Sensors

1:50 PM  Laser Generated Ultrasound Using a Ring Source
---S. Dixon, T. Harrison, B. Dutton, Y. Fan, and P. A. Petcher, University of Warwick, Department of Physics, Coventry, United Kingdom

2:10 PM  Phased Array Transducers for Billet Inspection
---R. A. Roberts¹, J. A. Umbach², J. H. Fried³, and R. B. Thompson¹, ¹Iowa State University, Center for NDE, Ames, IA 50011 ; ²Pratt & Whitney, P. O. Box 109600, West Palm Beach, FL 33410 ; ³Pratt & Whitney, 400 Main Street, East Hartford, CT 06108

2:30 PM  Analysis of a Concentric Coplanar Capacitive Sensor Using a Spectral Domain Approach
---T. Chen, J. R. Bowler, and N. Bowler, Iowa State University, Center for NDE, Ames, IA 50011; J. Song, Iowa State University, Department of Electrical and Computer Engineering, Ames, IA 50011

2:50 PM  Pulsed Eddy Current Inspection of Multi-Layer Aluminum Structures in the Presence of Ferrous Fasteners
---T. W. Krause, P. P. Whalen, V. K. Babbar, and D. R. Desjardins, Royal Military College of Canada, Department of Physics, Kingston, Ontario, Canada

3:10 PM  Break

3:30 PM  Wireless NDE Sensor System for Continuous Monitoring
---G. Dib, T. Khan, and L. Udpa, Michigan State University, Department of Electrical and Computer Engineering, East Lansing, MI 48824; L. Mhamdi, N. Lajnef, and J.-W. Hong, Michigan State University, CEE Department, East Lansing, MI 48824; P. Ramuhalli, Pacific Northwest National Laboratory, Applied Physics and Materials Characterization Sciences, Richland, WA 99352; K. Balasubramaniam, Indian Institute of Technology, Madras, Department of Mechanical Engineering, Chennai, Tamil, India

3:50 PM  Ultrasonic Wave Field Modeling in a Conical Scanning Probe Tip
---A. G. Every, University of the Witwatersrand, School of Physics, WITA 2050, South Africa; I. Wenke and J. Dual, Department of Mechanical and Process Engineering, ETH, CH-8092, Zurich, Switzerland

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

4:30 PM  Development of General X-Ray Scattering Model
---S. Wendt and J. Gray, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011
Piezoelectric Behavior Of Sputtered Aluminium Nitride Thin Film For High Frequency Ultrasonic Sensors
---Thomas Herzog, Susan Walter, Dieter Joneit, and Henning Heuer, Fraunhofer Institute for Non-Destructive Testing, IZFP Dresden Branch; Hagen Bartzsch, Matthias Gittner, and Daniel Gloess, Fraunhofer Institute for Electron Beam and Plasma Technology, FEP Dresden, Germany

---The well known piezoelectric composite materials, like 1-3 composites of PZT are limited to frequencies up to 20 MHz due to technological limitations of the dice and fill technology for composite production. Many new materials and processes require non destructive evaluation in higher resolutions by phased array ultrasonic techniques in a frequency range up to 250 MHz. This paper presents aluminium nitride, a promising material for the use as a piezoelectric sensor material in the considered frequency range, which contains the potential for high frequency phased array application in the future. This work represents the fundamental development of piezoelectric aluminium nitride films with a thickness of up to 10 µm. We have investigated and optimized the deposition process of the aluminium nitride thin film layers regarding their piezoelectric behaviors. Therefore we created a specific test setup and a measuring station to determine the piezoelectric charge constant (d33) and the electro acoustic behavior of the sensor. Single element transducers were deposited on silicon substrates with aluminium electrodes for top and bottom, using different parameters for the magnetron sputter process, like pressure and bias voltage. Afterwards we have carried out acoustical measurements up to 500 MHz in pulse echo mode and have qualified the electrical and electromechanical properties. As a result, we found out, that there are two parameter sets for the sputtering process to obtain an excellent piezoelectric charge constant of about 8.7 pC/N maximum. Additionally a PSpice simulation model was created and the results of simulation and measurements were compared.

Laser Generated Ultrasound Using a Ring Source
---Steve Dixon, Timothy Harrison, Benjamin Dutton, Yichao Fan, and Phillip A. Petcher, University of Warwick, Department of Physics, Coventry, United Kingdom

---A pulsed Nd:YAG laser is focused to a sharp ring on a metal sample in the thermoelastic regime. This is achieved by firstly expanding the collimated laser beam before passing it through a convex lens and an axicon lens. The addition of the extra convex lens provides a significant focusing improvement. On thick samples, this shape of acoustic source generates simultaneously a surface Rayleigh wave and bulk waves. The surface waves generated by the ring source travel outwards from the ring and also inwards to focus at a point in the centre of the ring. Large amplitude Rayleigh waves are thus generated at the centre of the ring. The absolute, out-of-plane displacement caused by the acoustic waves travelling along a sample surface is measured using a Michelson interferometer with a bandwidth of approximately 80 MHz. The experimental results have been correlated with those obtained by numerical modeling to show good agreement and less successfully with finite element modeling. The ring acoustic source has various applications for defect detection and measurement, and material characterization.
Phased Array Transducers for Billet Inspection
---Ronald A. Roberts1, Jeffrey A. Umbach2, Jon H. Friedl3, and R. Bruce Thompson1, 1Iowa State University, Center for NDE, Ames, IA 50011; 2Pratt & Whitney, P. O. Box 109600, West Palm Beach, FL 33410; 3Pratt & Whitney, 400 Main Street, East Hartford, CT 06108
---Rotor-grade titanium is inspected in the billet form prior to forging rotors as a means of finding potential defects as early as possible in the production process. Phased array inspection of billets provides improvement over current practice by being able to apply a focused beam continuously through the depth of a billet with a single 128 element transducer. The design of the transducer allows inspection of billets between 6" and 10" diameter to a sensitivity of #2 FBH or better. Larger or smaller diameters could be accommodated with similar transducer designs. The transducer was designed to function with a commercially available instrument with 64 pulse channels and 128 receive channels. The number of pulse channels allowed the design of the transducer to incorporate a sweep motion of the beam in the circumferential direction to correct for imperfections in billet shape that might refract the beam away from the centerline. When instruments become available with more than 64 pulse channels, a larger sweep angle can be designed into a transducer. The transducer for 6" to 10" billet has been fabricated and was shown to function at full production speed for billet inspection.---This work was funded by Pratt & Whitney and performed at Iowa State University's Center for NDE in cooperation with Pratt & Whitney's Advanced NDE Research group.

Analysis of a Concentric Coplanar Capacitive Sensor Using a Spectral Domain Approach
---Tianming Chen, John R. Bowler, and Nicola Bowler, Iowa State University, Center for NDE, Ames, IA 50011; Jiming Song, Iowa State University, Department of Electrical and Computer Engineering, Ames, IA 50011
---Previously, concentric coplanar capacitive sensors have been developed to quantitatively characterize the permittivity or thickness of one layer in multi-layered dielectrics. Electrostatic Green’s functions due to a point source at the surface of one- to three-layered test-pieces were first derived in the spectral domain, under the Hankel transform. Green’s functions in the spatial domain were then obtained by using the appropriate inverse transform. Utilizing the spatial domain Green’s functions, the sensor surface charge density was calculated using the method of moments and the sensor capacitance was calculated from its surface charge. In the current work, the spectral domain Green’s functions are directly used to derive the integral equation for the sensor surface charge density in the spectral domain, using Parseval’s theorem. Then the integral equation is discretized to form matrix equations using the method of moments, in which each matrix element is calculated using the inverse transform. It is shown that the spatial domain approach is more computationally efficient for one-layered structures, while the spectral domain approach is more efficient in dealing with multi-layered structures. The sensor capacitances calculated from both approaches agree with each other and very good agreement with experimental data (to within 4%) is also observed.---This work is supported by the Air Force Research Laboratory under contract FA8650-04-C-5228 and by NASA under cooperative agreement NNX07AU54A at Iowa State University’s Center for NDE. Tianming Chen is recipient of an American Society of Nondestructive Evaluation Graduate Fellowship Award.
Pulsed Eddy Current Inspection of Multi-Layer Aluminum Structures in the Presence of Ferrous Fasteners

---Thomas W. Krause, Paul P. Whalen, Vijay K. Babbar, and Daniel R. Desjardins, Royal Military College of Canada, Department of Physics, Kingston, Ontario, Canada

---Fatigue induced cracks may develop around ferrous fasteners found on aircraft such as the F/A-18 Hornet, CC-130 Hercules and CP-140 Aurora. Normally, fastener removal is required for inspection by bolt hole eddy current techniques, since the presence of the fastener would otherwise confound detection of cracks propagating from the inner bore. However, the removal and reinsertion of fasteners extends maintenance outages and increases the risk of collateral damage to the bore. In this study, pulsed eddy current and associated probe development are examined as a method for inspection of these structures when ferrous fasteners are present. Specifically, application of abrupt magnetization to the magnetically permeable fastener by a central driving unit is used to transfer flux deeper into the aluminum structure. On the aluminum surface, differentially connected pickup coils are used to sense differences in response, due to variations in the induced eddy current field arising from the presence of a subsurface notch. Greater depths of detection are attained. Results are examined in light of the electromagnetic interactions between the fastener and surrounding aluminum structure using finite element methods and analytical analysis of the field boundary conditions.

Wireless NDE Sensor System for Continuous Monitoring

---Gerges Dib, Tariq Khan, and Lalita Udpa, Michigan State University, Department of Electrical and Computer Engineering, East Lansing, MI 48824; Lassaad Mhamdi, Nizar Lajnef, and Jung-Wuk Hong, Michigan State University, CEE Department, East Lansing, MI 48824; Pradeep Ramuhalli, Pacific Northwest National Laboratory, Applied Physics and Materials Characterization Sciences, Richland, WA 99352; Krishnan Balasubramaniam, Indian Institute of Technology, Madras, Department of Mechanical Engineering, Chennai, Tamil, India

---For continuous monitoring of power-plant components, the use of in-situ sensors (i.e., sensors that are permanently mounted on the structure) is necessary. In-situ wired sensors require an unrealistic amount of cabling for power and data transfer, which can drive up costs of installation and maintenance. In addition, the use of cabling in hostile environments (high temperature/pressure environments) is not a viable option. This paper presents a wireless system for continuous monitoring, identification of anomalous events, NDE data acquisition and data transfer. NDE sensors are integrated with a wireless radio unit such as a MICA mote. Measurements from the sensors are typically acquired at prescribed intervals, encoded and compressed, and transmitted to a central processing server, where appropriate signal processing techniques may be used to filter out noise in the measurements, enhance the desired signal and quantify the damage in terms of severity.
Ultrasonic Wave Field Modeling in a Conical Scanning Probe Tip
---Arthur G. Every, University of the Witwatersrand, School of Physics, WITS 2050, South Africa; Ingo Wenke and Jurg Dual, Department of Mechanical and Process Engineering, ETH, CH-8092 Zurich, Switzerland

---The wave field modeling reported here is aimed at optimizing the design of a conical scanning probe microscope tip for measuring the near surface elastic properties of solids at high frequencies and high spatial resolution. The modeling traces the evolution of a pulse launched from the upper spherical shaped surface of the tip, and is aimed at achieving the greatest possible concentration of acoustic energy at the lower sharp end of the tip. The calculations assume a transversely isotropic medium. Two complementary approaches have been taken, firstly the discretization of the equations of motion on a 1000x1000 mesh and solution using the commercial FE package ABAQUS, and secondly an analytical approach based on the angular spectrum method and stationary phase approximation. A high degree of consistency is achieved between the two approaches regarding the characteristics of the focal region, dispersion of the pulse attendant on the discretization of the system, and other features of the wave field. With the combination of the two approaches we are able to model the wave field from low frequencies, where advantage lies with the FE method, to high frequencies where the computational cost of the FE method is inordinate and the analytical approach becomes progressively more accurate.

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

---We report on a means to non-destructively measure the strain profile for shot peening in several materials including aluminum and Titanium. The technique is based on using the kα line from a typical 320 kVp industrial x-ray tube. The 70keV kα line provides two important advantages, first the necessary penetration that allows x-ray photons to penetrate as much as several millimeters in aluminum and secondly provides the means to achieve the strain sensitivity needed to measure strain depth profiles. The approach is to set the energy dispersive detector at the proper 2θ diffraction angle dictated by the nominal lattice parameter of the unstrained material and the kα energy. The small change in the lattice parameter results in a shift in the energy meeting the diffraction condition set by the 2θ diffraction angle. The very narrow Ka line means that there is a very sharp intensity change in the diffraction signal. We discuss the method of obtaining the strain from these high energy diffraction measurements. Comparisons to traditional θ-2θ measurements will be discusses together with results on measurements on aluminum, titanium and nickel.---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 Nondestructive Evaluation.
Development of General X-Ray Scattering Model
---Scott Wendt and Joe Gray, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---X-ray scattering is a complex process made difficult to describe due to the effects of a complex energy spectrum interacting with a wide range of material types in complex geometry. The scattering is further complicated by the volume of material illuminated and the experimental configuration of the data acquisition. To date two extremes in treatment of scattering limit the ability to model x-ray scattering processes. Monte Carlo calculations are difficult to compute due to convergence issues typical for many industrial parts or experimental configurations. Transport equation treatments often are severely limited by computer resources. Look up tables are often limited to simple geometry and limited treatment of the energy distribution of typical x-ray sources. We report on a semi-empirical treatment of x-ray scattering that includes a full energy treatment for a wide range of material types. We also include complex geometry effects that the part shape introduces. The treatment is based on experimental measurements using an energy dispersive germanium detector over energies from 20kEv to 320keV. Detector stripping routines for detector artifacts were developed. The model is based on a look up table developed from experimental measurements and Monte Carlo calculations. This treatment is showing good results with experimental measurements of the scattering component agreeing with the model results to the 10% level over the range of x-ray energies and materials typical in industrial applications. Computation times for this model are in the range of a few minutes on a typical PC.---This work was supported by the NSF Industry/University Cooperative Research program.
TUESDAY

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Session 7
SESSION 7
FLAW SIZING TECHNIQUES
Marc Kreutzbruck, Chairperson
Salons A-C

8:30 AM Characterization of a Straight Crack by Performing Measurements at Two Different Directions
---H. G. Ramos and A. L. Ribeiro, Instituto de Telecomunicacoes, Instituto Superior Técnico, Lisbon, Portugal; L. Kufrin and O. Postolache, Instituto de Telecomunicacoes, Lisbon, Portugal

8:50 AM Surface-Breaking Crack Depth Assessment Using Near-Field Surface Acoustic Wave Signal Response
---J. L. Blackshire and A. Modic, Air Force Research Laboratory, AFRL/RXLP, Wright-Patterson AFB, OH 45433

9:10 AM Flaw Sizing in Pipes Using Long-Range Guided Wave Testing
---R. M. Sanderson, TWI Ltd., Structural Integrity Technology Group, Cambridge, United Kingdom; P. P. Catton, TWI Ltd., Non-Destructive Testing Group, Cambridge, United Kingdom

9:30 AM Sizing Disbonds Between a Stiffener and a Composite Plate Using Ultrasonic Guided Waves
---D. Singh and M. Castaings, University of Bordeaux, Laboratoire de Mécanique Physique, UMR CNRS 5469, 351 cours Liberation, 33400 Talence, France

9:50 AM Application of Bayesian Approach for Damage Characterization in Beams Utilizing Guided Waves
---C. T. Ng\textsuperscript{1,2} and M. Veidt\textsuperscript{1}, \textsuperscript{1}The University of Queensland, School of Mechanical and Mining, Brisbane, QLD, Australia; \textsuperscript{2}Cooperative Research Centre for Advanced Composites Structures Ltd., Fisherman’s Bend, VIC, Australia; H. F. Lam, City University of Hong Kong, Department of Building and Construction, Hong Kong, China

10:10 AM Break

10:30 AM SAFT and TOFD for UT-Inspection of Power Plant Components – A Comparison of Two Defect Sizing Techniques

10:50 AM Defect Imaging Technique Using a Scanning Laser Source
---T. Hayashi, M. Murase, and T. Kitayama, Toyota Central R&D Labs, Inc., Research Instruments Development Division, Nagakute, Aichi, 480-1192, Japan

11:10 AM Improved Weld Inspection Using Wave Equation Based Imaging of Back Wall Reflected Ultrasonic Data
---X. G. J. Deleye and A. Gisolf, Applus RTD, Technological Center, Rotterdam, The Netherlands

11:30 AM Lunch (Please note: Lunch buffet lines open at 11:45 AM)
Characterization of a Straight Crack by Performing Measurements at Two Different Directions
---Helena G. Ramos and Artur L. Ribeiro, Instituto de Telecomunicações, Instituto Superior Técnico, Lisbon, Portugal; Luka Kufrin and Octavian Postolache, Instituto de Telecomunicações, Lisbon, Portugal

---This paper presents the characterization of machined long cracks by performing measurements at two different directions not necessarily orthogonal. Without knowing the orientation of a crack two components of the secondary magnetic field created by eddy currents induced in a conductive metallic plate are measured using a probe with axial symmetry and having a giant magnetoresistor sensor (GMR) as the sensing element in the axis of the excitation coil. The orientation and the width of the crack are computed from images obtained from scanning the specimen for two different directions. Within the paper a normalization algorithm is proposed to determine the images. Then, by performing measurements at any two directions, the images obtained can be compared and the real orientation and width of the crack can be previewed. As eddy current technique is a very sensitive method, a reproducible noise is always added to the measurements and data processing is mandatory in order to improve the informative contents of the raw data. The paper compares the experimental result obtained by scanning the conductive plate specimen in a direction perpendicular to a crack and the result obtained by previewing the orientation and width of the same crack from processing the raw data taken by scanning the plate specimen at any two scanning directions. The highest accuracy of the calculated result, obtained when two orthogonal components of the magnetic field are measured, is also computed.

Surface-Breaking Crack Depth Assessment Using Near-Field Surface Acoustic Wave Signal Response
---James L. Blackshire and Aaron Modic, Air Force Research Laboratory, AFRL/RXLP, Wright-Patterson AFB, OH 45433

---A method for determining the local depth of a surface-breaking crack is presented based on near-field surface acoustic wave signal responses. Finite element models were used to study the forward problem, where the characteristic response of a surface acoustic wave incident on a surface-breaking crack oriented normal to the material surface was investigated. Experimental validation of the modeling predictions was accomplished using a wedge transducer for surface wave generation and a scanning laser vibrometry system for surface wave detection. The characteristic near-field amplitude response in reflection and in transmission showed several unique features, which are attributed to the superposition of incident, transmitted, reflected, and scattered energy fields. In the d/lambda range of 0.1 – 0.4, an approximate linear trend was observed, which provides an opportunity to characterize and quantify local crack depth based on a simple linear inversion method. Finite element and experimental evidence of this effect are presented for surface-breaking slots and cracks with depths between 100um to 1mm.
Flaw Sizing in Pipes Using Long-Range Guided Wave Testing
---Ruth M. Sanderson, TWI Ltd, Structural Integrity Technology Group, Cambridge, United Kingdom; Phil P. Catton, TWI Ltd, Non-Destructive Testing Group, Cambridge, United Kingdom

---The absence of adequate inspection data from difficult-to-access areas on pipelines, such as cased road crossings, makes determination of fitness for continued service and compliance with increasingly stringent regulatory requirements problematic. Screening for corrosion using long-range guided wave testing (GWT) is a relatively new inspection technique. The complexity of the possible modes of vibration means the technique can be difficult to implement effectively but this also means that it has great potential for both detecting and characterising flaws. The ability to determine flaw size would enable the direct application of standard procedures for determining fitness-for-service, such as ASME B31G, RSTRENG, or equivalent for tens of metres of pipeline from a single inspection location. This paper presents a new technique for flaw sizing using GWT inspection data. The technique was developed using finite element models and has been experimentally validated on 6” Schedule 40 steel pipe. Some basic fitness-for-service assessments have been carried out using the measured values and the maximum allowable operating pressure was accurately determined.

Sizing Disbonds Between a Stiffener and a Composite Plate Using Ultrasonic Guided Waves
---Dilbag Singh and Michel Castaings, University of Bordeaux, Laboratoire de Mécanique Physique, UMR CNRS 5469, 351 cours Liberation, 33400 Talence, France

---The use of composite materials in aircraft industry is becoming more common because of high stiffness-to-weight ratio. Adhesively bonded, metallic stiffeners are also widely used for increasing the stiffness of thin composite components. However, small defects in the adhesive (porosity, cracks) may exist after the bonding is realized, and become larger during the in-service life, thus causing severe damages to the whole structure. For obvious safety reasons, the non-destructive testing of such critical bond-lines is very important. More specifically, it is of importance to size disbonds that may exist between a stiffener and a composite component. Recently, a 2D, Finite-Element-based inverse technique has been developed for sizing defects in plates, using Lamb waves. Here, this technique is used for sizing the width of a disbond running parallel to an Aluminum stiffener adhesively attached to a Carbon-Epoxy plate. A pure incident S0 mode is experimentally sent towards the stiffener, and the amplitudes of reflected and transmitted S0 and A0 modes are measured, and used as input data for the inversion process. The FE model and post-processing are optimized so that fast computations can be run for numerous values of the aimed disbond width. The inversion process shows very good and fast convergence to the actual width of the hidden disbond.
Application of Bayesian Approach for Damage Characterization in Beams Utilizing Guided Waves

---C. T. Ng$^{1,2}$ and M. Veidt$^1$, $^1$The University of Queensland, School of Mechanical and Mining, Brisbane, QLD, Australia; $^2$Cooperative Research Centre for Advanced Composite Structures Ltd., Fisherman’s Bend, VIC, Australia; H. F. Lam, City University of Hong Kong, Department of Building and Construction, Hong Kong, China

---A Bayesian approach for characterizing the damage in beams utilizing guided waves is presented. The proposed methodology treats the damage location, length, depth and the Young’s modulus of the material as unknown model parameters. A two-stage optimization approach is applied for damage characterization using first simulated annealing to guarantee that the solution is close to the global optimum, followed by a standard simplex search method that maximizes the probability density function of a damage scenario conditional on the measurement data. One advantage of the proposed method is that instead of only pinpointing the damage location and extent, the uncertainty associated with the damage characterization results is also quantified. A series of comprehensive numerical case studies utilizing the spectral finite element method to model the wave propagation and scattering at the step damage are used to examine the accuracy and robustness of the proposed methodology. The studies include investigations of the influence of practical situations such as the effects of measurement noise, uncertainty of Young’s modulus due to the temperature change, and interference of boundary reflections and scattered waves on the damage characterization results.

SAFT and TOFD for UT-Inspection of Power Plant Components – A Comparison of Two Defect Sizing Techniques

---Jessica Kitze, Daniel Brackrock, Mate Gaal, Jens Prager, Gerhard Brekow, and Marc Kreutzbruck, Federal Institute for Materials Research and Testing, Non Destructive Testing Department, Berlin, Germany; Gyöző Paczolay, Krisztina Kuti, Dénes Szabó, and Paksi Átomérőmű, Material Testing Section, Paks, Hungary

---Defect sizing analysis is commonly based on proper signal-to-noise ratio and high spatial resolution. SAFT and TOFD are such promising sizing candidates extracting more information from the raw UT data and the included crack tip response. In this work the phased array technique was used to inspect a cladded mock-up model of a pressure vessel section. The full scale model with a wall thickness of 149 mm contains artificial test reflectors which are located in both the weld and in the cladding region as well. These defects -representing typical material failures in a very early stage- were analyzed with different frequencies, beam angles and directions of incidence. For the reconstruction of reflector indications a SAFT algorithm was applied by considering several transmitted and received beam angles. Additionally the reflectors were analyzed by means of the Time of Flight Diffraction Technique (TOFD – Technique), again simultaneously using different beam angles. Both analyzing methods were performed using opposite directions of incidence considering the preferred orientation of dendrites in the cladding underneath the inner surface of the mock-up model. We report on a direct comparison of applicability of SAFT and TOFD technique for the sizing approach.
Defect Imaging Technique Using a Scanning Laser Source
---Takahiro Hayashi, M. Murase, and T. Kitayama, Toyota Central R&D Labs., Inc., Research Instruments Development Division, Nagakute, Aichi, 480-1192, Japan

---In guided wave inspection, generally, defects are found and located using echo signals from the defects. In recent years, as increasing demands of more precise evaluation, imaging techniques using guided waves have been investigated. This study describes defect imaging technique using a scanning laser source. Laser beam was emitted onto a surface of a plate, and then guided waves generated from the laser source were detected by ultrasonic sensors. After the detected signals were filtered by a band pass filter with a suitable frequency band, amplitude distributions corresponding to remaining thickness distributions at the location of laser beam were obtained. Using multiple receiving sensors and synthesizing multiple images, more distinct images were obtained.

Improved Weld Inspection Using Wave Equation Based Imaging of Back Wall Reflected Ultrasonic Data
---Xavier G. J. Deleye and Andries Gisolf, Applus RTD, Technological Center, Rotterdam, The Netherlands

---Non-Destructive Testing (NDT) based on ultrasonic wave propagation is a well known method for detection of defects in steel components such as girth welds. For accurate sizing, 2D imaging techniques with ultrasonic array measurements have been developed and demonstrated in practice. One of such techniques is Inverse Wavefield Extrapolation. The IWEX technique images the volume below the probe. The weld cap often prevents correct positioning of the probe above the weld volume. This paper describes a novel approach used in IWEX that uses back wall reflections to image the weld under inspection, despite the weld cap. The main advantage of this development is that the weld cap can be circumvented by using two separate probes on each side of the weld cap. Imaging is effectively done by processing the measurement data in the frequency and wave vector domains. This allows for straightforward implementation of the reflection coefficient for the waves reflected by the back wall. This paper presents measurement results obtained with the proposed approach on carbon steel samples containing artificial defects. These results are compared to results obtained with conventional ultrasonic techniques. Significant image quality improvements can be observed when using the proposed approach.
Session 8
SESSION 8  
NDE OF ARMOR AND ARMOR SYSTEMS  
Ray Brennan, Chairperson  
Salon D

8:30 AM  Low Velocity Impact Testing and Nondestructive Evaluation of Transparent Materials  
---R. E. Brennan and W. H. Green, U.S. Army Research Laboratory, 4600 Deer Creek Loop, Aberdeen Proving Ground, MD 21005

8:50 AM  Investigation of Ultrasonic Nondestructive Characterization for Armor Grade Alumina  
---S. Bottiglieri and R. A. Haber, Rutgers University, Materials Science and Engineering, 607 Taylor Road, Piscataway, NJ 08854

9:10 AM  NDT Characterization of Boron Carbide for Ballistic Applications  
---D. Liaptsis, I. Cooper, P. Wallace, N. Ludford, and A. Gunner, TWI Ltd., NDT Validation Centre Wales, Port Talbot, Margam, United Kingdom; M. Williams and D. Willis, Kennametal Sintec Ltd., Newport, South Wales, United Kingdom; C. Roberson, Advanced Defence Materials Ltd., Rugby, United Kingdom; P. Brown, DSTL, Physical Sciences Department, Wiltshire, United Kingdom

9:30 AM  Nondestructive Characterization of As-Fabricated Composite Ceramic Panels  

9:50 AM  Modern Resonance Inspection: PCRT for Ceramic Components  
---L. Hunter and L. Jauriqui, Vibrant Corporation, Albuquerque, NM 87109; R. Sisneros, Magnaflux, Quasar Systems, Albuquerque, NM 87109

10:10 AM  Break

10:30 AM  NDE of Hybrid Armor Structures Using Acoustography  
---J. S. Sandhu, Santec Systems, Inc., 716 S. Milwaukee Avenue, Wheeling, IL 60090; C. Pergantis, U.S. Army Research Laboratory, Aberdeen Proving Ground, MD 21005

10:50 AM  Design of Smart Armor Systems Using Embedded SMART Layer Technology  
---S. J. Beard, X. P. Qing, and H. Chung, Acellent Technologies, Inc., Sunnyvale, CA 94085; F.-K. Chang, Stanford University, Stanford, CA 94305

11:10 AM  Miniaturized Hand Held Microwave Interference Scanning System for NDE of Dielectric Armor and Armor Systems  

11:30 AM  Line Scanning Thermography for Rapid Nondestructive Inspection of Large Scale Composites  
---O. Ley and V. Godinez-Azcuaga, MISTRAS Group, Physical Acoustics Corporation, Princeton Junction, NJ 08550-5392; S. Chung and A. A. Calazzo, Materials Sciences Corporation, Horsham, PA 19044; B. Bandos, Naval Surface Warfare Center, Philadelphia, PA 19102

11:50 AM  Low Frequency Ultrasonics and Line Scanning Thermography in the Inspection of Multilayered Armor Composites  
---V. F. Godinez-Azcuaga, O. Ley, S. Momendi, and M. A. Gonzalez-Nunez, MISTRAS Group, Inc., 195 Clarksville Road, Princeton Junction, NJ 08550

12:10 PM  Lunch
Low Velocity Impact Testing and Nondestructive Evaluation of Transparent Materials
---Raymond E. Brennan and William H. Green, U.S. Army Research Laboratory, 4600 Deer Creek Loop, Aberdeen Proving Ground, MD 21005

--- Advanced transparent materials are utilized to significantly improve the protection efficiency for lightweight vehicles and warfighters. It is critical to ensure the structural and visual integrity of these materials in both combat and non-combat situations. If any damage occurs, the ability to withstand single or multiple hits from various threats could be compromised. While these types of issues are most likely to occur during impact from high velocity projectiles during combat, they may also be the result of low velocity impacts from collisions, rough handling, encounters with harsh terrain or environmental conditions, or foreign object debris from persons of interest, other vehicles in convoy, or shrapnel from nearby explosions. For this reason, it is critical to determine the damage mechanisms and dynamic behavior of materials that are subject to low velocity impact events in order to establish damage tolerance levels that can indicate whether or not a protective system component should be replaced. In this study, transparent materials will be tested by comparing baseline conditions to experimentally controlled damage states. Destructive testing including air gun and sphere impact testing will be used to simulate velocity and energy conditions representative of low velocity impacts in the field. Characterization of the damaged state will include (1) basic visual and optical evaluation and (2) bulk and internal imaging and property analysis of the damaged state using optical, x-ray, ultrasound, and dielectric techniques. The combination of destructive testing and characterization of the resulting damage can help to establish a damage acceptance criterion for materials used in protective systems.

Investigation of Ultrasonic Nondestructive Characterization for Armor Grade Alumina
---Stephen Bottiglieri and Richard A. Haber, Rutgers University, Materials Science and Engineering, 607 Taylor Road, Piscataway, NJ 08854

---Ceramic materials have attractive attributes for applications that experience high stresses or strain rates. Compared to metal-based systems, ceramics offer a lower areal density which reduces weight, but does not depreciate the integrity of other properties. The ability to tailor microstructure of ceramics used in armor systems is a common way to increase specific mechanical properties. Properties such as elastic modulus, hardness, and density are those that are typically desired to be enhanced. The testing of these properties and ballistic performance is usually destructive, expensive, and time consuming. Common assessments using ultrasonic NDE usually include spatially locating large flaws, sonic velocity measurements, and elastic property measurements. The use of acoustic spectroscopy to go beyond typical ultrasonic NDE in structural ceramics and allow for the use of a microstructural characterization tool is investigated in this paper. Aluminum oxide (alumina) is a common ceramic material used as an armor-ceramic. It is one the most studied ceramic materials available for extreme situations. This paper focuses on acoustically studying several armor-grade alumina tiles with varying grain sizes in the 10 – 80MHz range. Preliminary work in tying acoustic spectroscopy to alumina microstructure and microstructural related properties are shown in this work.
NDT Characterization of Boron Carbide for Ballistic Applications
---D. Liaptsis, Ian Cooper, Philip Wallace, Nick Ludford, and Alec Gunner, TWI Ltd., NDT Validation Centre Wales, Port Talbot, Margam, United Kingdom; Mike Williams and David Willis, Kennametal Sintec Ltd., Newport, South Wales, United Kingdom; Colin Roberson, Advanced Defence Materials Ltd., Rugby, United Kingdom; Peter Brown, DSTL, Physical Sciences Department, Wiltshire, United Kingdom

---Boron carbide is widely used to provide ballistic protection in many challenging service environments. This work was undertaken to determine a suitable process for NDT characterization of Boron Carbide. The project involves the introduction of deliberate flaws within the Boron Carbide during processing. An extensive experimental program of work has been undertaken to establish the best NDT technique for the defect detection and material characterization of Boron Carbide tiles. A number of different techniques such as ultrasonic immersion testing, digital X-ray testing and microwave testing have been employed to establish the capabilities and limitations of each of the techniques. Ultrasonic immersion characterization of the material was found to be able to detect both subtle material density variation and flaws within the material. The detection capabilities and resolution of the technique was found to be dependent upon the focus depth of the ultrasonic beam. The data obtained from the ultrasonic characterization will be correlated with ballistic performance obtained by V50 testing.

Nondestructive Characterization of As-Fabricated Composite Ceramic Panels

---Decreasing the weight of protective systems, while minimizing the decrease in ballistic performance, is an ongoing goal of the Army. Ceramic materials are currently combined with other materials in these types of structures in order to decrease weight without losing ballistic performance. This includes structures in which the ceramic material is confined in some way and in which the ceramic material is completely encapsulated. Confinement or encapsulation of ceramic material within a structure generally adds complexity and cost. Relatively simple panel specimens fabricated with ceramic tiles on aluminum backings and side confinement using steel were evaluated using nondestructive methods, including x-ray computed tomography and ultrasonic testing. The nondestructive evaluation results will be discussed and compared, including the detectability and mapping of fabrication features.
Modern Resonance Inspection: PCRT for Ceramic Components
---Lemna Hunter and Leanne Jauriqui, Vibrant Corporation, Albuquerque, NM 87109; Robert Sisneros, Magnaflux, Quasar Systems, Albuquerque, NM 87109

---Resonance testing has been used in many industries for over 100 years. While more traditional ‘impact’ methods may be inappropriate for ceramic materials, Process Compensated Resonance Testing (PCRT) shows immense opportunity for a variety of ceramic materials, including those used for hybrid bearing rolling elements, vehicle and personnel armor, seal rings and other engine components. Many ceramic materials have excellent resonance characteristics, enabling a whole body inspection that can detect internal defects such as cracks, voids, and inclusions. PCRT can also perform surface inspection of some geometries, using Surface Acoustical Waves. Applications with industrial partners have shown successful detection of cracks and density issues with armor plates, cracking and chipping in seal rings, and material defects within ceramic balls. PCRT goes beyond traditional resonance testing by applying pattern recognition algorithms and process control statistics to precise resonant data. PCRT can be used to supplement model outputs, and determine material properties, such as elastic moduli. PCRT can be performed in real manufacturing time, with inspection times measured in seconds, and computer control eliminates operator error and subjectivity. PCRT is a proven, emerging technique for quality verification and process control.

NDE of Hybrid Armor Structures Using Acoustography
---Jaswinder S. Sandhu, Santec Systems, Inc., 716 S. Milwaukee Avenue, Wheeling, IL 60090; Charles Pergantis, U.S. Army Research Laboratory, Aberdeen Proving Ground, MD 21005

---The US Army is investigating the use of composite materials to deliver lightweight and more effective armor protection systems to soldiers and other army assets. However, widespread use of such hybrid armor will require a reliable but fast NDE methodology to ensure integrity of these components during manufacturing and while in service. Traditional ultrasonic inspection of such hybrid armor structures may prove to be very effective, but point-by-point ultrasonic scanning is inherently time-consuming and manufacturing slowdowns could develop in high-volume production of such armor systems. In this work, we report the application of Acoustography for the NDE of hybrid armor structures. Acoustography differs from conventional ultrasonic testing in that test objects are inspected in full field, analogously to real time x-ray imaging. The approach uses a novel, super high resolution large area acousto-optic (AO) sensor, which allows image formation through simple ultrasound shadow casting, analogous to x-ray image formation. This NDE approach offers significant inspection speed advantage over conventional point-by-point ultrasonic scanning procedures and is well-suited for high volume production. We will report initial results on a number of hybrid armor plate specimens employing composite materials that are being investigated by the US Army. Acoustography NDE results will be verified using other complimentary NDE methods.
Design of Smart Armor Systems Using Embedded SMART Layer Technology
---Shawn J. Beard, Xinlin P. Qing, and Howard Chung, Acellent Technologies, Inc., Sunnyvale, CA 94085; Fu-Kuo Chang, Stanford University, Stanford, CA 94305

---Armor systems are generally comprised of multiple layers of energy absorption materials including fiber-reinforced composites and ceramic plates. The protective effectiveness greatly depends on the structural integrity of the armor system. Due to the inherent interface incompatibility among the various materials, non-ballistic events may induce hidden damage, leaving soldiers and assets vulnerable to enemy fire. Real-time assessment of the armor integrity is critical and essential to ensure the safety of our soldiers and assets. Traditional nondestructive inspection techniques typically need to be performed in a well-controlled laboratory environment, thus making field use difficult. Structural Health Monitoring (SHM) using a built-in sensor network offers a promising solution to these inspection challenges. An SHM system utilizing SMART Layer technology for in-situ assessment of the health of multi-layered thick ceramic-composite structures has been developed. The SMART Layer technology consists of a modular sensor network, data acquisition electronics, and data interpretation software. Sensors were integrated inside multi-layered thick ceramic-composite structures and used to detect internal disbond damage. This paper summarizes the SMART Layer designs, the inspection technique, and presents examples of the inspection results from impact tests.

Miniaturized Hand Held Microwave Interference Scanning System For NDE of Dielectric Armor and Armor Systems
---Karl F. Schmidt and Jack R. Little, Evisive, Inc., 8867 Highland Road, #378, Baton Rouge, LA 70808; William A. Ellingson, Argonne National Laboratory, Argonne, IL 60439; Thomas J. Meitzler, U.S. Army Research and Development Command Tank Automotive Research Development and Engineering Center, Warren, MI 48397; William Green, U.S. Army Research Laboratory, Aberdeen Proving Ground, MD 21005

---Inspection of ceramic-based armor has advanced through development of a microwave-based, portable, non-contact NDE system. Recently, this system was miniaturized and made wireless for maximum utility in field applications. The electronic components and functionality of the laboratory system are retained, with alternative means of position input for creation of scan images. Validation of the detection capability was recently demonstrated using specially fabricated surrogates and ballistic impact-damaged specimens, including test pieces in situ. Corroboration of the microwave data results have been compared to laboratory-based microwave interferometry system and by digital x-ray imaging. The microwave interference scanning has been shown to reliably detect cracks, laminar features and material properties variations. This paper will present details of the system, descriptions of the test samples used and discuss results obtained.
Line Scanning Thermography for Rapid Nondestructive Inspection of Large Scale Composites
---Obdulia Ley and Valery Godinez, MISTRAS Group, Physical Acoustics Corporation, Princeton Junction, NJ 08550-5392; Simon Chung and Anthony A. Caiazzo, Materials Sciences Corporation, Horsham, PA 19044; Bruce Bandos, Naval Surface Warfare Center, Philadelphia, PA 19102

--- As next generation structures are utilizing larger amounts of composite materials, a rigorous and reliable method is needed to inspect these structures in order to prevent catastrophic failure and extend service life. Current inspection methods, such as ultrasonic, generally require extended down time and man hours as they are typically carried out via point-by-point measurements. In this program, a novel Line Scanning Thermography (LST) System has been developed for the non-contact, large-scale field inspection of composite structures with faster scanning times than conventional thermography systems. LST is a patented dynamic thermography technique where the heat source and thermal camera move in tandem, which allows the continuous scan of long surfaces without the loss of resolution. The current system can inspect an area of 10 in2 per 1 second, and has a resolution of 0.05X0.03 in2. Advanced data gathering protocols have been implemented for near-real time damage visualization and post-analysis algorithms for damage interpretation. The system has been used to successfully detect defects (delamination, dry areas) in fiber-reinforced composite sandwich panels for Navy applications, as well as impact damage in composite missile cases and light armor ceramic panels.

Low Frequency Ultrasonics and Line Scanning Thermography in the Inspection of Multilayered Armor Composite
---Valery F. Godínez-Azcuaga, Obdulia Ley, Sepan Momendi, and Miguel Angel Gonzalez-Nuñez, MISTRAS Group, Inc., 195 Clarksville Road, Princeton Junction, NJ 08550

---In this paper we discuss recent advances in the use of an oblique incidence, low frequency ultrasonic technique for the inspection of multilayered composite armor. In order to implement this technique for fast inspection during manufacturing and in the field, an improved portable multi-channel ultrasonic system with specially designed sensors and the capability for automated and manual inspection was designed and built. The high resolution C-scans produced with this system were compared to images produced with an innovative imaging technique known as Line Scanning Thermography in samples of composite armor. Advantages and limitations of both techniques will be presented and discussed.
SESSION 9
STRUCTURAL HEALTH MONITORING II
Sridhar Krishnaswamy, Chairperson
Salon E

8:30 AM Development of a Stamp Size Pulser-Receiver for Structural Health Monitoring Applications
---J. M. Padiyar, C. V. Krishnamurthy, and K. Balasubramaniam, Indian Institute of Technology Madras, Center for Nondestructive Evaluation, Department of Mechanical Engineering, Chennai 600 036, India

8:50 AM Diagnostic and Prognostic Tools for Residual Life Estimation in Aging Nuclear Power Plant Components
---P. Ramuhalli, L. J. Bond, J. W. Griffin, C. H. Henager, Jr., and M. Dixit, Pacific Northwest National Laboratory, Richland, WA 93352

9:10 AM Interaction of Guided Lamb Waves with Delaminations and Discontinuities in Composite Plate-Like Structures
---K. Balasubramaniam, C. Ramadas, J. Padiyar, and C. V. Krishnamurthy, Center for Nondestructive Evaluation, Department of Mechanical Engineering, Indian Institute of Technology Madras, Chennai 600 036, India

9:30 AM Application of IDT Sensors for Structural Health Monitoring of Windmill Turbine Blades Made of Composite Material
---V. Nalladega and J.-K. Na, University of Dayton Research Institute, Dayton, OH 45469; C. Druffner, Mound Laser & Photonics Center, Inc., Miamisburg, OH 45342

9:50 AM Concrete Structure Monitoring by OFDR Technique
---J.-M. Hénault, J. Salin, and G. Moreau, EDF, R&D, Chatou, France; S. Lesoille and J. Bertrand, ANDRA, DS-OS, Chatenay-Malabry, France; F. Taillade, M. Quiertant, and K. Benzarti, LCPC Université Paris, Paris, France

10:10 AM Break

10:30 AM Location of Damage in Metallic Plate Structure Using Graph Theory Based Geodesic Approach
---R. Gangadharan, C. R. L. Murthy, M. R. Bhat, and S. Gopalakrishnan, Indian Institute of Science, Department of Aerospace Engineering, Bangalore, Karnataka, India

10:50 AM Quantitative Enhancement of Fatigue Crack Monitoring by Imaging Surface Acoustic Wave Reflection in a Space-Cycle Stress Domain
---G. D. Connolly and S. I. Rokhlin, The Ohio State University, Edison Joining Technology Center, Columbus, OH 43221

11:10 AM SHM of Large Structures Using Guided Waves for Crack Detection
---P. Fromme, University College London, Mechanical Engineering, London, United Kingdom

11:30 AM Impact of Applied Loads on Guided Wave Structural Health Monitoring
---J. E. Michaels, S. J. Lee, and T. E. Michaels, Georgia Institute of Technology, School of Electrical and Computer Engineering, Atlanta, GA 30332

11:50 AM Imaging of a Defect in Thin Plates Using the Time Reversal of Single Mode Lamb Waves
---H. Jeong, J.-S. Lee, and S.-M. Bae, Wonkwang University, Division of Mechanical and Automotive Engineering, Iksan, Jeonbuk 570-749, Korea

12:10 PM Lunch
Development of a Stamp Size Pulser-Receiver for Structural Health Monitoring Applications
---Janardhan M. Padiyar, C. V. Krishnamurthy, and Krishnan Balasubramaniam, Indian Institute of Technology Madras, Center for Nondestructive Evaluation, Dept. of Mechanical Engineering, Chennai 600 036, India

---Lamb wave-based Structural Health Monitoring of structures using sparse PWAS sensors remains a significant challenge due to several technological obstacles. One of the major obstacles preventing the widespread adoption of Lamb wave-based SHM is that availability of simple portable low power, low cost instrumentation operating in 50 KHz to 1 MHz region of interest. Pulser-Receiver is fundamental building blocks for excitation and reception of signal from PWAS sensors. Conventional Pulser-Receiver circuits are not suited for integration in SHM Circuits due to physical size, power and nature of the pulse. On the contrary existing SHM instrumentation pumps 40V to 100 volts signal into the piezoelectric sensor to generate perceptible mechanical response with high SNR; which itself makes battery operation infeasible. A key element in adapting portable low power is to excite PWAS with a very low voltage between 5-10 V, impedance matching at the transmitter and high amplification at the receiver with minimum of stages. This paper has attempted to use off-the shelf video amplifiers for development of a practical, compact, low power, low cost Pulser-Receiver Module for SHM Applications. Also we present circuits, layouts and demonstrate the performance of the module in Lamb wave based SHM applications.

Diagnostic and Prognostic Tools for Residual Life Estimation in Ageing Nuclear Power Plant Components
---Pradeep Ramuhalli, Leonard J. Bond, Jeffrey W. Griffin, Charles H. Henager Jr., and Mukul Dixit, Pacific Northwest National Laboratory, Richland, WA 99352

---A central issue in life extension for the current fleet of light water nuclear power reactors is the early detection and monitoring of significant materials degradation. To meet this need, nondestructive measurement methods that are suitable for continuous monitoring over extended time periods (months to years) are needed. A related issue is the ability to estimate remaining useful life of components and systems based on condition assessment or degradation information. Monitoring for early detection of materials degradation requires novel sensors and enhanced data integration techniques. A range of acoustic and electromagnetic measurement methods may be suitable, including acoustic microscopy, eddy current and magnetic Barkhausen emission. Prognostic methods that predict remaining life based on phenomena that can be described by linear elastic fracture mechanics have been reported by several researchers. However, the challenge of predicting remaining life for earlier phases of degradation is largely unsolved. This paper discusses experimental assessment of selected diagnostic techniques, and the application of Bayesian prognostic algorithms to detection of early degradation and life prediction. Such measurement and modeling methods are expected to form the basis for a new range of advanced diagnostic and prognostic approaches for life extension of ageing light water reactors.
Interaction of Guided Lamb Waves With Delaminations and Discontinuities in Composite Plate-Like Structures
---Krishnan Balasubramaniam, C. Ramadas, Janardhan Padiyar, and C. V. Krishnamurthy, Center for Nondestructive Evaluation, Department of Mechanical Engineering, Indian Institute of Technology Madras, Chennai, 600 036, India

---Delamination is one of the critical failure modes that laminated composites structures encounter during their fabrication and/or in-service. When guided Lamb wave (Ao) is employed for sizing of delamination, it is necessary to understand the wave interaction with the defect. Studies were carried out on the interaction of Ao mode with symmetric and asymmetric delaminations and transmission of turning modes in the sub-laminates. An attempt was also made to understand the propagation of Ao mode in composite structural T – joint. During the interaction of Ao mode with structural discontinuity in T - joint, generation of a new mode, So, and propagation of turning modes in T – joint were observed. Length and width of interface delamination in composite T – joint have been worked out using D – scan and B-scan respectively. All studied were carried out through numerical simulations and experimental verifications through Non-Contact Ultrasound (NCU) technique.

Application of IDT Sensors for Structural Health Monitoring of Windmill Turbine Blades Made of Composite Material
---Vijay Nalladega and Jeong-Kwan Na, University of Dayton Research Institute, Dayton OH 45469; Carl Druffner, Mound Laser & Photonics Center Inc, Miamisburg, OH 45342

---Interdigital transducers (IDT) generate and receive ultrasonic surface waves without the complexity involved with secondary devices such as angled wedges or combs. The IDT sensors have been successfully applied for the NDE of homogeneous materials like metals in order to detect cracks and de-bond. However, these transducers have not been yet adapted for complex and anisotropic materials like composites. This work presents the possibility of using IDT sensors for monitoring structural damages in wind turbine blades, typically made of fiberglass composites. IDT sensors with a range of operating frequency between 250 kHz and 1 MHz are initially tested on representative composite test panels for ultrasonic surface wave properties including beam spread, propagation distance and effect of material's anisotropy. Based on these results, an optimum frequency range for the IDT sensor is found to be 250-500 kHz. Subsequently, IDT sensors with operating frequency 500 kHz are used to detect and quantify artificial defects created in the composite test samples. Discussions are made on the interaction of ultrasonic fields with these defects along with the effects of fiber directionality and composite layer stacking.
Concrete Structure Monitoring by OFDR Technique
---Jean-Marie Hénault, Jean Salin, and Gautier Moreau, EDF, R&D, Chatou, France; Sylvie Lesoille and Johan Bertrand, ANDRA, DS-OS, Chatenay-Malabry, France; Frédéric Taillade, Marc Quiertant, and Karim Benzarti, LCPC Université Paris Est, Paris, France

---Structural health monitoring is a key factor in life cycle management of infrastructures. Truly distributed fiber optic sensors are able to provide representative information about large dimension structures like bridges, dikes, nuclear power plants or nuclear waste disposal facilities. The sensing chain includes an optoelectronic instrument and a sensing cable made of one or more optical fibers. A new instrument based on Optical Frequency Domain Reflectometry (OFDR), enables to perform temperature and strain measurement with a centimeter-sized spatial resolution over hundred of meters with a level of precision equal to 1 microstrain and 0.1°C. Several sensing cables are designed with different materials targeting to last for decades in concrete aggressive environment and to ensure an optimal transfer of temperature and strain values from the concrete matrix to the optical fiber. Tests were carried out by embedding various sensing cables into plain concrete samples and representative-scale reinforced concrete structural elements. Measurements were performed with an OFDR instrument, meanwhile mechanical solicitations were imposed to the concrete element. Optical fiber sensor measurements were compared (i) to conventional sensors used in civil engineering, namely Pt100 temperature sensors and vibrating wire gauges and (ii) to strength of materials modelling.

Location of Damage in Metallic Plate Structure Using Graph Theory Based Geodesic Approach
---R. Gangadharan, C. R. L. Murthy, M. R. Bhat, and S. Gopalakrishnan, Indian Institute of Science, Department of Aerospace Engineering, Bangalore, Karnataka, India

---Lamb wave based damage detection methods using triangulation technique are not suitable for locating damage in structures with structural discontinuities and complex shape. The problem is due to the difficulty in the analytical/parametrical representation of the interrogated structure in the triangulation formulation. In this work, the geodesic approach using Lamb waves is shown suitable to identify damage location in a metallic plate structure containing finite discontinuities. This approach is based on the principle of the shortest path taken by the elastic waves from the damage source to the sensor array bonded to the plate structure. For the given sensor array distribution, the wave response matrix for the healthy and the damaged structure is obtained experimentally. The healthy and damage response matrix is compared and their difference gives the information about the reflection of waves from damage. Dijkstra's algorithm is used to compute the discrete geodesics on the meshed surface of the structure. By propagating the waves in reverse virtually from the sensors along the geodesic path and by locating the first intersection point of these waves, one can get the damage location. Experiments were conducted on aluminum specimens of simple and complex geometry to validate this method.
Quantitative Enhancement of Fatigue Crack Monitoring by Imaging Surface Acoustic Wave Reflection in a Space-Cycle Stress Domain
---George D. Connolly and Stanislav I. Rokhlin, The Ohio State University, Edison Joining Technology Center, Columbus OH 43221

---The surface wave acoustic method is applied to the in-situ monitoring of fatigue crack initiation and evolution on tension specimens. A small low-frequency periodic loading is also applied, resulting in a nonlinear modulation of reflected pulses. The acoustic wave reflections are collected for: each experimental cycle; a range of applied tension and modulation stress levels; and a range of spatial propagation positions, and are presented in image form to aid pattern identification. Salient features of the image are then extracted and processed to evaluate the initiation time of the crack, its opening/closing behavior and its subsequent size evolution until sample failure. Additionally, the low frequency scattering model is used to perform small crack sizing.

SHM of Large Structures Using Guided Waves for Crack Detection
---Paul Fromme, University College London, Mechanical Engineering, London, United Kingdom

---Guided ultrasonic waves offer an efficient way for the long-term integrity monitoring of large structures. Permanently attached distributed or localized sensor arrays have been shown to be able to detect and localize simulated corrosion damage. Crack-like defects have a directivity pattern of the scattered field depending on the crack orientation, which must be taken into account for the data processing algorithm. The directivity pattern of the scattered field for the A0 Lamb wave mode has been predicted from 3D Finite Element simulations and verified from experimental measurements at machined part-through and through-thickness notches. Good agreement was found and the directivity pattern and amplitude of the scattered wave can be quantified for a variation of defect geometry and orientation. These results provide the basis for the quantification of the detection sensitivity for defects in plate structures using guided wave arrays. Using a hybrid model to account for the propagation distance and scattering characteristics, the relative amplitudes of received pulses for given sensor locations can be calculated. From a comparison with the signal to noise ratio of the array system, detection capabilities can be predicted for various defect sizes and orientation.
Impact of Applied Loads on Guided Wave Structural Health Monitoring  
---Jennifer E. Michaels, Sang Jun Lee, and Thomas E. Michaels, Georgia Institute of Technology, School of Electrical and Computer Engineering, Atlanta, GA 30332

---Guided wave structural health monitoring is a challenging problem, in part because of the complexity of signals received in a real structure containing geometrical features and boundaries. Signals scattered from damage can be one or two orders of magnitude smaller in amplitude than the direct arrival. Detection of these small, scattered signals is often accomplished by comparing signals of interest to one or more baseline signals recorded from the undamaged structure. Previous work by many researchers has shown that homogeneous temperature changes as small as a few degrees Celsius can mask damage unless compensation is made. Here we consider the impact of applied loads on complex guided wave signals because such loading effects may be unavoidable in the in situ environment. Experimental data are reviewed that quantify the change in phase velocity as a function of direction of propagation. These anisotropic phase velocities are then used to numerically simulate guided waves propagating and reflecting from boundaries in a finite, homogeneous plate that is subjected to varying uniaxial loads. Signal changes in both short and long time regimes are compared to experimental observations, and the impact on structural health monitoring is discussed.

Imaging of a Defect in Thin Plates Using the Time Reversal of Single Mode Lamb Waves  
---Hyunjo Jeong, Jeong-Sik Lee, and Sung-Min Bae, Wonkwang University, Division of Mechanical and Automotive Engineering, Iksan, Jeonbuk 570-749, Korea

---This paper presents an analytical investigation for a baseline-free imaging of a defect in plate-like structures using the time-reversal of Lamb waves. We first consider the flexural wave (A0 mode) propagation in a plate containing a defect, and reception and time reversal process of the output signal at the receiver. The received output signal is then composed of two parts: a directly propagated wave and a scattered wave from the defect. The time reversal of these waves recovers the original input signal, and produces two additional sidebands that contain the time-of-flight information on the defect location. One of the side band signals is then extracted as a pure defect signal. A defect localization image is then constructed from a beamforming technique based on the time-frequency analysis of the side band signal for each transducer pair in a network of sensors. The simulation results show that the proposed scheme enables the accurate, baseline-free detection of a defect, so that experimental studies are needed to verify the proposed method and to be applied to real structure.
SESSION 10
NDE FOR CIVIL STRUCTURES
Hailan Zhang and Martin Spies, Co-Chairpersons
Salons F-H

8:30 AM  On-Site Evaluation of Large Components Using SAFT and TOFD Ultrasonic Imaging
---H. Rieder, M. Spies, and A. Dillhoefer, Fraunhofer Institute for Industrial Mathematics ITWM, Image Processing Department Fraunhofer-Platz 1, 67663 Kaiserslautern, Germany

8:50 AM  Real Time Damage Detection System Using Guided Waves in ACSR Cables
---R. Mijarez and F. Martinez, Instituto de Investigaciones Electricas, Gerencia de Control e Instrumentacion, Cuernavaca, Morelos, Mexico; A. Baltazar, Centro de Investigacion y Estudios Avanzados del IPN, Unidad Saltillo, Ramos Arizpe, Coahuila, Mexico

9:10 AM  Monitoring of Longitudinal Stress Using Diffuse Ultrasonic Backscatter
---C. M. Kube and J. A. Turner, University of Nebraska at Lincoln, Department of Engineering Mechanics, Lincoln, NE 68588; G. Ghoshal, University of Illinois at Urbana-Champaign, Bioacoustic Research Laboratory, Urbana, IL 61801

9:30 AM  NDT of Railway Trackbed Using the Frequency Response Function
---R. De Bold, D. Connolly, S. Patience, and M. Forde, University of Edinburgh, School of Engineering, Edinburgh, EH9 3JL, United Kingdom

9:50 AM  NDT of a Mixed Railway Trackbed Using Ground Penetrating Radar
---R. De Bold, G. O'Connor, J. P. Morrissey, and M. Forde, University of Edinburgh, School of Engineering, Edinburgh, EH9 3JL, United Kingdom

10:10 AM  Break

10:30 AM  Dynamic Strain Sensing of a Model Long Span Bridge Using Fiber Bragg Grating Sensors
---Y. Zhu, O. Balogun, Y. Zhu, and S. Krishnaswamy, Northwestern University, Department of Mechanical Engineering, Center for Quality Engineering and Failure Prevention, Evanston, IL 60208-3020; Y.-L. Xu and S. Zhu, The Hong Kong Polytechnic University, Department of Civil and Structural Engineering, Research Center for Urban Hazards Mitigation, Hunghom, Kowloon, Hong Kong

10:50 AM  Numerical Study on Acoustic Field Generated by Dipole Sources in Noncircular Pipe
---H. Zhang, W. Lin, and X. Wang, Institute of Acoustics, Chinese Academy of Sciences, State Key Laboratory of Acoustics, Beijing, 100190, China

11:10 AM  Magnetostrictive Sensing Using Dry-Coupling to Inspect Thick Plate-Like Structures in Nuclear Power Plants
---M. Capps, A. C. Cobb, and J. L. Fisher, Southwest Research Institute, Mechanical Engineering Division, San Antonio, TX 78228

11:30 AM  Lunch (Please note: Lunch buffet lines open at 11:45 AM)
On-Site Evaluation of Large Components Using SAFT and TOFD Ultrasonic Imaging
---Hans Rieder, Martin Spies, and Alexander Dillhoefer, Fraunhofer Institute for Industrial Mathematics ITWM, Image Processing Department, Fraunhofer-Platz 1, 67663 Kaiserslautern, Germany

---The safe operation of transportation vehicles such as ships and ferries requires inspection of the highly stressed parts and components. The same holds for other safety relevant constructions such as pipelines where emphasis is on quality assurance prior to the final installation. Failure of such components can lead to serious environmental as well as economic damage. In this contribution we concentrate on ultrasonic inspection and evaluation of welds in such large components. The most endangered part of ships is the propeller. Therefore a solution has been developed in order to enhance the reliability of welded propellers and to extend the scope of repairable blade damages in order to avoid long term restrictions until a spare propeller is available. The Synthetic Aperture Focusing Technique (SAFT) has been modified to cope with the curved surfaces and the sound attenuation of cast Ni-Al bronzes. Using mechanized scanning ultrasonic evaluation has been optimized in view of the least detectable defect sizes. For weld inspection in steels the Time-of-Flight Diffraction technique (TOFD) can provide additional information for specific defect orientations. We have therefore combined both techniques in view of the determination of defect sizes and shapes in longitudinal welds of pipes with diameters of up to 48 inches. We present details on the inspection and evaluation concepts as well as experimental results obtained on test specimens during the validation process. For on-site inspection in dry-dock or at the manufacturing sites, mobile equipment has been design and build-up; respective inspection actions and results will be presented as well.

Real Time Damage Detection System Using Guided Waves in ACSR Cables
---Rito Mijarez and Fernando Martinez, Instituto de Investigaciones Eléctricas, Gerencia de Control e Instrumentación, Cuernavaca, Morelos, Mexico; Arturo Baltazar, Centro de Investigación y Estudios Avanzados del IPN, Unidad Saltillo, Ramos Arizpe, Coahuila, Mexico

---Aluminium Conductor Steel Reinforced (ACSR) cables are multiple metal strands that constitute overhead transmission lines. These cables are exposed to environmental degradation such as random overloads and corrosion, which could lead to expensive breakdowns. Continuous monitoring of the structural integrity of these wires is still an engineering challenge in the Nondestructive Testing (NDT) and Structural Health Monitoring (SHM) communities. This work presents an experimental investigation of damage detection on overhead transmission lines using a guided wave system in a pitch and catch configuration. The system is composed of a transmitter module based on a microcontroller that excites 70 kHz guided wave energy packages via an ultrasound transducer; the receiver is made of an ultrasound transducer and a processing microcontroller module, which performs real-time damage detection. The receiver module is connected to a computer through a USB cable for continuous monitoring purposes. Experiments carried out in the laboratory, attaching the transducers to the periphery of a 1.4 m long ACSR cable, have successfully detected 1.5 mm artificial damage.
Monitoring of Longitudinal Stress Using Diffuse Ultrasonic Backscatter
---Christopher M. Kube and Joseph A. Turner, University of Nebraska at Lincoln, Department of Engineering Mechanics, Lincoln, NE 68588; Goutam Ghoshal, University of Illinois at Urbana-Champaign, Bioacoustic Research Laboratory, Urbana, IL 61801

---Monitoring stress in structures is very important for a variety of safety reasons. One of the challenging problems is to quantify stress non-destructively in structural components as a function of loading conditions so that accurate maintenance can be performed before failure. In this presentation, the influence of material stress on the scattering of ultrasound in polycrystalline materials is discussed. Ultrasonic backscatter results from the multitude of reflections and refractions that occur at the grain boundaries due to variation of the single-crystal elastic moduli. First, the theoretical framework is outlined in which the scattering of ultrasound is related to applied stresses through the single-crystal acoustoelastic response. The covariance of the elastic moduli is calculated in closed-form for statistically isotropic distributions of grains. The impact of applied stress on the longitudinal and shear scattering is then discussed with a focus on measurement configurations of interest. Next, experimental laboratory results are presented that highlight the dependence of scattering on applied stress. Both normal incidence (longitudinal) and oblique incidence (shear) measurements are shown to vary with applied stress, although the degree of variation is a function of several parameters. This work has led to the development of a portable device for field monitoring of structures. This device magnetically attaches to a structure and provides ultrasonic scattering data using longitudinal and shear wave scattering. Finally, future prospects and applications of this work are discussed.---Work supported by FRA.

NDT of Railway Trackbed Using the Frequency Response Function
---Robert De Bold, David Connolly, Scott Patience, and Mike Forde, University of Edinburgh, School of Engineering, Edinburgh EH9 3JL, United Kingdom

---The increase in both freight and passenger rail travel worldwide has driven the demand for more efficient and rapid investigation of railway trackbed ballast. One of the current approaches to evaluating the stiffness of railway ballast is to use a Falling Weight Deflectometer. While this is very effective, it requires the rails to be unclipped from the ties – thus, it is very intrusive and expensive. This paper explores the option of using a frequency response function (FRF) generated by using a 12lb instrumented hammer to excite the railway trackbed. Finally, the FRF is correlated with the ballast deterioration or fouling.
NDT of a Mixed Railway Trackbed Using Ground Penetrating Radar
---Robert De Bold, Gerard O'Connor, John P. Morrissey, and Mike Forde, University of Edinburgh, School of Engineering, Edinburgh EH9 3JL, United Kingdom

---The overall aim of this project was to relate Ground Penetrating Radar (GPR) to ballast fouling. The 10-year old University of Edinburgh full-scale trackbed was re-visited and the fouling of the ballast was re-calibrated following environmental changes, using the Ionescu fouling index. A series of GPR experiments were undertaken on the trackbed using a range of bowtie antennas from 500MHz to 2.6GHz. Scatter analyses of the GPR waveforms included area analyses, axis crossing analyses and inflexion point analyses. When predicting Fouling Index, a correlation coefficient greater than 0.9 was obtained by using a 500 MHz bowtie antenna in the parallel orientation in conjunction with a scan area analysis. This paper will outline the recent work of other researchers and the detailed experimental program at the University of Edinburgh.

Dynamic Strain Sensing of a Model Long Span Bridge Using Fiber Bragg Grating Sensors
---Yan Zhu, Oluwaseyi Balogun, Yinian Zhu, and Sridhar Krishnaswamy, Northwestern University, Department of Mechanical Engineering, Center for Quality Engineering and Failure Prevention, Evanston, IL 60208-3020; You-Lin Xu and Songye Zhu, The Hong Kong Polytechnic University, Department of Civil and structural Engineering, Research Center for Urban Hazards Mitigation, Hunghom, Kowloon, Hong Kong

---The diagnostic optical sensor development for intelligent structural health monitoring of in-service structures is of great interest for the improvement of structural safety and reliability while providing for lower inspection and maintenance costs. Optical fiber sensors are ideal for monitoring continuous deterioration conditions of civil infrastructures, especially long-span bridges. Typically, a network of sensors is used to measure the strains or low frequency vibrational response of the structure. In this work, we demonstrate dynamic spectral demodulation of fiber Bragg grating (FBG) sensor responses for monitoring mechanical strains in a model of a long span bridge. A series of experiments have been performed, including the measurements of the natural resonant modes of the model bridge, the impact response of a bridge member and the acoustic emissions in a fractured aluminum bar. The experimental results reveal the potential for dynamic spectral demodulation of FBG strain responses at frequencies extending up to about 3.5 MHz using this interferometer. The experimental results suggest that the method may be suitable for monitoring high frequency mechanical strains in civil structures that result from cracking or impact loading, thus providing a tool for local detection of structural damage.
Numerical Study on Acoustic Field Generated by Dipole Sources in Noncircular Pipe
---Hailan Zhang, Weijun Lin, and Xiuming Wang, Institute of Acoustics, Chinese Academy of Sciences, State Key Laboratory of Acoustics, Beijing 100190, China

---Acoustical well logging is an important technology for petroleum industry. During manufacturing and maintaining, the logging tools are usually tested in a fluid filled circular pipe, which is much simpler and more controllable than the test in real wells. Dipole logging tools are widely used recently. It transmits nonaxisymmetric acoustical fields of various directivities. The information provided by the circular pipe test is a kind of average over all directions, not suitable for nonaxisymmetric dipole tools. It is proposed that the test in the noncircular pipe might provide useful information. In this report the acoustic fields generated by dipole sources with different polarizations in noncircular pipes are calculated by using Comsol Multiphysics, a finite-element software package. Firstly, the transformed acoustic field in the frequency wavenumber domain is calculated. The PDE mode of Comsol Multiphysics is used and the coefficients for the transformed field are deduced. Then the results are transformed into the time space domain. It is shown that the received waveforms of the dipole tools in noncircular pipes are more complicated than that in the circular pipes because more modes are excited. Further works are needed to extract useful information.

Magnetostrictive Sensing Using Dry-Coupling to Inspect Thick Plate-Like Structures in Nuclear Power Plants
---Matt Capps, Adam C. Cobb, and Jay L. Fisher, Southwest Research Institute, Mechanical Engineering Division, San Antonio, TX 78228

---Prior efforts at Southwest Research Institute have focused on the inspection of thick-walled, carbon steel structures using a combination of magnetostrictively-generated guided waves and beam forming strategies for localizing defects. A key advantage of magnetostrictive sensing (MsS) approaches over piezoelectric transduction is the relative simplicity of generating the fundamental shear horizontal (SH$_0$) wave mode at frequencies below the cut-off frequency for higher-order mode generation in thick structures (<50 kHz). Experimental results were previously presented for a variety of damage configurations, demonstrating the efficacy of this technique for detecting damage smaller than the ultrasonic wavelength. A limitation of this approach, however, is that until now, it was necessary to adhesively bond the magnetostrictive sensor to the structure under inspection. The objective of this study was to develop a procedure that eliminates the need for the adhesive bonds (and liquid couplants), by mechanically pressing the sensor against the structure under inspection. Experimental results are shown comparing conventional, adhesive coupling with the “dry-coupled” process that was developed. A mechanical system using pneumatically-driven cylinders was created to provide the required forces. This system is field deployable, can be mounted onto a vertical wall, and can linearly position the sensor at any location across its length of approximately two meters.
Session 11
NOTE: Student posters are to be mounted Monday, July 19th 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.) should 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 20th from 1:30-3:10 p.m. For more details, see the Student Poster Competition section of the “Conference Guide” document located on the QNDE web site at: http://www.qndeprograms.org/2010/Conference2010.html

**SESSION 11**
**STUDENT POSTER COMPETITION**
Cabrillo Salons 1 and 2

- Application of Bayesian Approach for Damage Characterization in Beams Utilizing Guided Waves
- Low Frequency Eddy Current Finite Element Model Validation and Benchmark Studies
- Evaluation of Electromagnetic Acoustic Transducer Performance on Steel Materials
- Time of Flight Diffraction and Imaging (ToFDI) Combining B-Scans and Cross-Sectional Imaging
- Characterization of Alkali-Silica Reaction in Concrete Specimens Using a Nonlinear Vibration Technique
- Experimental Determination of Efficient Second Harmonic Generation of Lamb Wave Modes in a Nonlinear Elastic Isotropic Plate
- Analysis of Second Harmonic Generation at a Free Boundary for Oblique Incidence
- Investigation of Velocity Variations in Concrete Using CODA Wave Interferometry
- Ultrasonic Rayleigh Wave Enhancements from Angled Defects in Aluminium
- Investigation of Signal Processing Methods for Long-Range Inspection of Pipes Using Ultrasonic Guided Waves
- Characterization of Thermal Damage in 2205 Duplex Stainless Steel with Nonlinear Ultrasonics (NLU)
- Transmission Measurement of Air-Coupled Lamb Waves to Evaluate the Depth of a Surface-Breaking Crack in Plate-Like Structures
- Geometrical Characterization of a Diffusion Controlled Degradation Layer on a Polymer Surface
- Boundary Reflection Compensation in Guided Wave Baseline-Free Imaging
- Acoustoelastic Lamb Wave Propagation in a Homogeneous, Isotropic Aluminum Plate
- The Investigation on the Nonlinear Parameters Induced by Thermal Aging
- A Nonlinear Ultrasonic Evaluation of Thermal Fatigue in Composites

3:10 PM Break
Ultrasonic Applications

**A Method for Quantitatively Evaluating Thickness of Elastic Plates Using High-Overtone Bulk Acoustic Resonance**
---H. Zhang, Y.-R. Wang, and S.-Y. Zhang, Nanjing University, Lab of Modern Acoustics, Institute of Acoustics, Nanjing, China

**Wedge Waves Induce Acoustic Streaming**
---W.-C. Wang and C.-H. Yang, National Taipei University of Technology, Institute of Mechatronic Engineering, Taipei, Taiwan

**Image-Based FIT Modeling for Coupled Elastodynamic and Acoustic Problems**
---K. Takata and K. Nakahata, Ehime University, Department of Civil and Environmental Engineering, Ehime, Japan; F. Schubert and B. Koehler, Fraunhofer Institute for Nondestructive Testing, Dresden Branch (IZFP-D), Dresden, Germany

**An Ultrasonic Model for Revealing Electronic Package's Inner Structure Using Acoustic Impedance**
---C. Xu, Z. Liu, J. Hao, and X. Zhao, Beijing Institute of Technology, Key Laboratory of Fundamental Science for Advanced Machining, Beijing, China

**Acoustic Field Calculation for the Phased Array Acoustic Transducers on the Irregular Surface**
---C. Xu, L. Wang, D. Xiao, and S. Zhou, Beijing Institute of Technology, Key Lab of Fundamental Science for Advanced Machining, 5 South Zhongguancun Street, Haidian District, Beijing, China

Sensors, Techniques, and Systems

**Nondestructive Inspection of a Composite Material Sample Using a Laser Ultrasonics System with a Beam Homogenizer**
---J. M. S. Sakamoto and G. M. Pacheco, Instituto Tecnológico de Aeronáutica, Departamento de Microondas e Optoeletrônica, São José dos Campos, São Paulo, Brazil; A. Baba, Hitachi Ltd., Energy and Environmental Systems Laboratory, Hitachi, Omika/Ibaraki, Japan; B. R. Tittmann, J. Mulry, and M. Kropf, Pennsylvania State University, Engineering Science and Mechanics, University Park, PA 16802

**A Modular Bulk Shear Horizontal Wave Transducer Using a Thin Fe-Co Alloy Patch**

**Development of High Temperature Ultrasonic Transducer for Structural Health Monitoring**
---A. Baba¹, C. T. Searfass,² and B. R. Tittmann³, ¹Energy and Environmental Systems Laboratory, Hitachi, Ltd., 7-2-1, Omika-cho, Hitachi-shi, Ibaraki-ken, 319-1221, Japan; ²Department of Engineering Science and Mechanics, The Pennsylvania State University, University Park, PA 16802

**Capacitive Imaging Technique for NDE**
---X. Yin, D. A. Hutchins, and G. G. Diamond, University of Warwick, School of Engineering, Coventry, CV4 7AL, United Kingdom
C-130 Hercules Rainbow Fitting Inspection: Methods for Tracking in Eddy Current Probe to Ensure Complete Coverage
---D. J. Barnard, A. Patz, and D. K. Hsu, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

Guided Wave Ultrasound Field Mapping Using a Network of Removable Bragg Grating Ultrasound Transducers

Detection of Minor Outer Flaws in Titanium Alloys Using Lockin Eddy Current Testing System
---T. Chady, G. Psuj, and J. Kowalczyk, West Pomeranian University of Technology in Szczecin, Faculty of Electrical Engineering, Szczecin, Poland

Feedback Algorithm for Identification of Multi-Segmented Cracks
---T. Chady and L. Napierala, West Pomeranian University of Technology in Szczecin, Faculty of Electrical Engineering, Szczecin, Poland

3D Modeling of Zero-Width Cracks for Nondestructive Evaluation Applications
---Y. J. Deng, University of Colorado-Denver, Departments of Electrical Engineering, Bioengineering and Radiology, Denver, CO 80217; X. Liu, University of Colorado-Denver, Department of Electrical Engineering, Denver, CO 80217; Y. Sun, Innovative Materials Testing Technologies, Inc., Superior, CO 80027

Scanning Laser Source Technique for Thickness Evaluation in Pipe
---M. Nor Salim, T. Hayashi, M. Murase, T. Ito, and S. Kamiya, Faculty of Engineering, Nagoya Institute of Technology, Japan

Signal to Noise Comparison of Flash Thermography and Vibration Excitation Shearography
---S. G. Pickering and D. P. Almond, University of Bath, Department of Mechanical Engineering, Bath, BA2 7AY, United Kingdom

Guided Wave Travel Time Tomography for Bends
---A. Volker and J. Bloom, TNO, Stieltjesweg, P. O. Box 155, Delft, 2600 AD, The Netherlands

Development of a Portable Mechanical Hysteresis Measurement and Imaging System for Impact Characterization in Honeycomb Sandwich Structures
---D. J. Barnard, D. K. Hsu, and L. J. Smart, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

Simple Go/No-Go Test for Subcritical Damage in Body Armor Panels
---J. Fisher and D. E. Chimenti, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

Geometrical Gauge Factor of Directional Electric Potential Drop Sensors for Creep Monitoring
---E. Madhi and P. B. Nagy, University of Cincinnati, Department of Aerospace Engineering and Engineering Mechanics, Cincinnati, OH 45221-0070

3:10 PM  Break
Application of Bayesian Approach for Damage Characterization in Beams Utilizing Guided Waves

---A Bayesian approach for characterizing the damage in beams utilizing guided waves is presented. The proposed methodology treats the damage location, length, depth and the Young’s modulus of the material as unknown model parameters. A two-stage optimization approach is applied for damage characterization using first simulated annealing to guarantee that the solution is close to the global optimum, followed by a standard simplex search method that maximizes the probability density function of a damage scenario conditional on the measurement data. One advantage of the proposed method is that instead of only pinpointing the damage location and extent, the uncertainty associated with the damage characterization results is also quantified. A series of comprehensive numerical case studies utilizing the spectral finite element method to model the wave propagation and scattering at the step damage are used to examine the accuracy and robustness of the proposed methodology. The studies include investigations of the influence of practical situations such as the effects of measurement noise, uncertainty of Young’s modulus due to the temperature change, and interference of boundary reflections and scattered waves on the damage characterization results.

Low Frequency Eddy Current Finite Element Model Validation and Benchmark Studies

---A finite element analysis (FEA) model was created to calculate impedance change of a coil due to the presence of several different notches manufactured by electrical discharge machining (EDM). The notch dimensions and the coil geometry were chosen to match those of a similar benchmark study done previously. The rectangular notches were cut into a thick aluminum plate and were each positioned at different tilt angles (0, 10, 20, and 30 degrees) with respect to the vertical axis of the coil. The FEA method was chosen for this model due to its ability to handle more complicated geometries with the use of irregular mesh elements to discretize the solution domain. Scans in each parallel axis of the plates were run across each of the notches, and changes in impedance of the coil were calculated from the solution of the field variables. An impedance spectroscopy system was used to obtain experimental data for scans over the different notches with a coil of the same geometry as the coil generated in the model, and the data was compared with the results from the FEA solution. The impedance component data calculated by the model matched experimental data to within ~4% for most cases and to within ~6% at least.
Evaluation of Electromagnetic Acoustic Transducer Performance on Steel Materials

---Electromagnetic Acoustic Transducers (EMATs) are an attractive alternative to standard piezoelectric probes in a number of applications thanks to their contactless nature. EMATs do not require any couplant liquid and are able to generate a wide range of wave-modes; however these positive features are partly counterbalanced by a relatively low signal-to-noise ratio and by the dependence of EMAT performance on the material properties of the test object. A wide variety of steel materials is employed in many industrial applications, so it is important to assess the material-dependent behavior of EMATs when used in the inspection of different types of steel. Experimental data showing the performance of EMATs on a wide range of steels is presented, showing the typical range of physical properties encountered in practice. A previously validated Finite Element model, including the main transduction mechanisms, the Lorentz force and magnetostriction, is used to evaluate the experimental data. The relative importance of the transduction mechanisms for different EMAT configurations is also analyzed and conclusions are drawn on EMAT performance on steel materials.

Time of Flight Diffraction and Imaging (ToFDI) Combining B-Scans and Cross-Sectional Imaging

---Time of Flight Diffraction and Imaging (ToFDI) is based on Time of Flight Diffraction (ToFD), but uses a sparse transducer array (generally laser-EMAT for non-contact applications), and adds an imaging stage by exploiting the diffraction of signals from defects. Additionally, it contains a range of image processing techniques designed to improve B-scans by removing direct and reflected surface waves, combining multiple B-scans, and applying matched and band-pass filters. ToFDI operates on multiple wave modes and mode-conversions to exploit as much information as possible. For easier interpretation by an operator, ToFDI outputs an improved B-scan and a cross-sectional image, allowing for identification of multiple defects including those near the surface and further within the bulk. The prototype application is testing the rough steel products of continuous casting without disrupting the production line, although it is not limited to this application. The final objective is for fast and automated detection, identification, positioning and sizing for all defects in a sample with known basic characteristics, such as wave speeds. The EPSRC and Corus financially support this work.
Characterization of Alkali-Silica Reaction in Concrete Specimens Using a Nonlinear Vibration Technique

---A nonlinear vibration technique has been developed for the nondestructive characterization of damage introduced by alkali-silica reactions (ASR) in concrete. The response of a concrete specimen to increasing impact load is analyzed to obtain a relationship between the amplitude of the response and the resonance frequency, and thus the nonlinearity of the specimen. As commonly observed in nonlinear hysteretic materials, the resonance frequency of a specimen decreases with an increasing level of excitation strain. Concrete is a nonlinear hysteretic material to begin with, but the progress of the alkali-silica reaction causes an increase in nonlinearity through the formation of ASR gel and microcracks. This increase in material nonlinearity is measured with the aforementioned procedure. The specimens used in the research are of varying reactivity with respect to ASR, which is induced in accordance with ASTM C 1293. The results show a substantial difference in nonlinearity between samples with highly reactive aggregate, and those with a non-reactive one. Complementary expansion measurements are also performed to independently verify the reactivity of the aggregate used. These results show that the developed nonlinear vibration technique has the potential to characterize the amount of ASR induced damage in concrete.

Experimental Determination of Efficient Second Harmonic Generation of Lamb Wave Modes in a Nonlinear Elastic Isotropic Plate

---This research experimentally characterizes the most efficient Lamb wave mode pair that generates the cumulative second harmonic in an undamaged aluminum plate to characterize the most efficient mode pair. Specific Lamb wave modes in a nonlinear elastic isotropic plate exhibit second harmonic generation if certain conditions are satisfied, such as phase velocity matching and group velocity matching. Second harmonic generation has been related to material nonlinearity – specifically, the nonlinear parameter has been shown to increase linearly with ultrasonic wave propagation distance. Since nonlinear parameters are sensitive to substructural damage in materials, this method has the potential to predict damage prior to crack initiation. This research gives a direct comparison of experimental results for mode pairs at the longitudinal velocity and at crossing points of symmetric and antisymmetric modes. The determination of the most efficient pair is based on the mode pair having the highest rate of second harmonic generation, or rather the mode pair with the strongest dependence of the relative nonlinear parameter on propagation distance. A discussion of experimental parameters and analysis techniques is also given.
Analysis of Second Harmonic Generation at a Free Boundary for Oblique Incidence

---The complete physical process of the nonlinear reflection of an obliquely incident P- (or SV-) wave from a stress-free boundary has been investigated analytically. The objective of this research is to evaluate the feasibility of using the second harmonic generation technique in reflection mode. The primary wave field consists of an incident plane P- or SV- wave and linearly reflected P- and SV- waves. Self- and cross-interaction of these primary waves generate secondary waves, some of which, together with the primary waves, produce the nonlinear stress field at the boundary. The involved nonlinear boundary value problem (BVP) is decomposed into two linear BVPs by perturbation and general solutions of them are given. The obtained solution for the secondary field shows that there are two mechanisms of second harmonic generation: nonlinear boundary stress in addition to the self-interaction of the primary waves. Changes in the second harmonic amplitude upon the boundary reflection are shown for different angles of incidence and material properties.

Investigation of Velocity Variations in Concrete Using CODA Wave Interferometry

---Coda Wave Interferometry (CWI) is a nondestructive imaging for monitoring small changes in multiple scattering media, as demonstrated in previous seismic and acoustic experiments. The small changes in the medium are seen more markedly in the arrival time of the late coda waves, from which the Stretching Interpolating Technique is used to calculate the relative velocity change. In this work, the authors apply CWI based on the Stretching Interpolating Technique to a heterogeneous, nonlinear, highly-scattering and multiphase medium—concrete—to detect damage in an early stage of degradation. Ultrasound signals are measured in different concrete samples with the following imaging setup: one transducer acting as a source, and one as a receiver. The relative velocity change obtained is used to calculate material constants of the concrete, such as the nonlinear parameter. This research investigates the relative velocity changes due to the following material degradation in concrete samples: applied stress, chemical reaction, plus the effects of temperature.
Ultrasonic Rayleigh Wave Enhancements From Angled Defects in Aluminium

---Non-linear enhancements of ultrasonic surface wave amplitudes and frequencies have been observed when the incident wave interacts with a surface defect. Previous measurements have considered only defects which are inclined normal to the surface. The enhancement effects have been studied in aluminium samples with machined slots of fixed length and of varying angle to the horizontal; the degree of enhancement was studied as a function of defect angle using both a scanning laser source, and a scanning laser detector. An automated scanning system has been developed for use with the detector, an IOS two-wave mixer interferometer, capable of measuring the out-of-plane surface displacement on rough surfaces. B-scans, consisting of many A-scans stacked together, were used to identify wave modes present in the near field, the arrival times of which are dependent upon the angle of the defect. The observed enhancement is caused by superposition of the incident Rayleigh wave with reflected and mode converted waves, thereby making it angle dependent. For shallow defects, a large enhancement has been investigated using a 10° angled aluminium wedge. The behavior observed in the wedge sample was compared to that observed in a sample containing a defect of similar angle.

Investigation of Signal Processing Methods for Long-Range Inspection of Pipes Using Ultrasonic Guided Waves

---For long range nondestructive inspection of pipelines, ultrasonic guided wave regarded as one of promising methods. However, dispersion nature of guided wave in pipe is one of major drawbacks, since it makes truly difficult to interpret propagated guided wave signals through the pipes. Especially, there are infinite number of axisymmetric modes and doubly infinite number of non-axisymmetric modes which are caused by interaction of shear and longitudinal bulk waves with the boundaries of pipes. Therefore, in this study, to overcome these problems, mode extraction and dispersion compensation for guided wave will be investigated to reduce dispersive nature of guided wave. To verify these methods, experiments will be performed for two ASTM A106 6-inch schedule #40 carbon steel pipes with a through-wall hole and a circumferential notch embedded. In this presentation, principle of signal processing methods, mode extraction and dispersion compensation will be discussed, and their performances will be presented.
Characterization of Thermal Damage in 2205 Duplex Stainless Steel With Nonlinear Ultrasonics (NLU)

---Duplex stainless steels have a microstructure that consists of almost equal shares of austenite and ferrite, which leads to excellent material properties. During production and processing, the steel can be exposed to high temperatures which leads to the development of a third (sigma) phase, and thus to a change in material properties. The objective of this research is to assess the material damage in thermally degraded 2205 duplex stainless steel using nonlinear ultrasonics (NLU). Seven 2205 duplex stainless steel specimens are thermally degraded at 700 C for a series of different time durations. Nonlinear Ultrasonic measurements are conducted in a pitch-catch setup to avoid any adverse nonlinear influences of reflections and wave interference. The material nonlinearity parameter, beta, is then obtained using both the pulse inversion technique and directly applying the fast Fourier Transform (FFT) to the measured time-domain signal. The results show that the nonlinearity parameter beta increases with increasing thermal damage. This demonstrates that the nonlinearity parameter has the potential to be used as a quantitative tool to estimate thermal damage in a specimen.

Transmission Measurement of Air-Coupled Lamb Waves to Evaluate the Depth of a Surface-Breaking Crack in Plate-Like Structures

---Transmission measurement of surface waves across a surface-breaking crack is effective to evaluate the depth of a crack in solids. However, it is still difficult to apply the theory to in-situ plate-like structures mainly due to complexity of frequency-dependent multi-mode analysis of Lamb waves. In addition, near-field effects around a crack and imperfect sensor coupling of contacted sensors also make difficult to obtain reliable and accurate transmission measurements. In this study, the authors investigate near-field scattering of impact-induced Lamb waves interacting with a surface-breaking crack in Plexiglas through experimental studies using non contact air-coupled sensors and numerical simulations (finite element method). First, spectral energy distribution of individual Lamb wave mode is calculated in the wide range of frequency-thickness regions, and then, dominant Lamb wave modes at a certain frequency range are determined. Second, transmission functions of dominant Lamb waves (i.e., Rayleigh-like waves in high frequency regions and a0 mode in low frequency regions) are measured using air-coupled sensors. The results are also compared with those from FE models. As a result, we observed that transmission coefficients of Lamb waves (Rayleigh-like waves, and a0 mode) depend on wavelength (λ) and the depth (h) of a surface-breaking crack, and that transmission coefficients versus normalized transmission coefficients (h/λ) tend to converge to a single curve. Finally, the findings in this study demonstrated that transmission measurements of Lamb waves using air-coupled sensor is effective to evaluate the depth of a surface-breaking crack in plate-like structures.
Geometrical Characterization of a Diffusion Controlled Degradation Layer on a Polymer Surface

---Characterizing a polymer that has experienced long term thermal oxidative aging is an interesting challenge. Degradation exists predominantly within a thin surface layer that grows deeper and more severe with continued aging. Unfortunately, traditional techniques characterize either bulk or surface properties alone. To avoid needing cross-sectioned specimens, ultrasonic Rayleigh waves are being studied as a nondestructive alternative for characterization. The depth of penetration of a Rayleigh wave is roughly equal to the wavelength. Therefore, a sweep of measurements at different frequencies can be used to probe different depths. The mediator wedge style transducer being used for Rayleigh wave generation has been discovered to also generate surface skimming longitudinal waves and bulk propagating longitudinal and transverse waves. Interestingly, each wave mode travels through a different volume of material. Therefore, the material conditions of the bulk and a layer at the surface can be determined simultaneously. Since individual parameters must be extracted from a complicated pattern of wave interference at the surface, this capability is only possible through high resolution detection in combination with proper data processing. The novel analysis being presented has been successful to not only quantify the depth and mechanical properties of the aged layer but also the interior.

Boundary Reflection Compensation in Guided Wave Baseline-Free Imaging

---Guided ultrasonic waves are frequently used for both structural health monitoring and nondestructive testing of metallic plate-like structures. Signals resulting from waves generated by one or more fixed piezoelectric transducers can be recorded outside of an area of interest using a non-contact approach such as a scanning laser vibrometer. It is desired to determine the location of a possible flaw from this recorded data without using any baseline information. Prior work has employed delay-and-sum imaging after applying a source removal algorithm, but this process did not consider the effects of boundary reflections. While these effects may be sufficiently small to neglect in a large plate, in smaller structures boundary effects are significant and can completely obscure small flaws. Proposed here is an iterative method to perform baseline-free imaging of damage in a rectangular plate with edge reflections. Results are shown for both simulated and experimental data to evaluate the efficacy of the proposed method.
Acoustoelastic Lamb Wave Propagation in a Homogeneous, Isotropic Aluminum Plate

---The effect of stress on Lamb wave propagation is relevant to both nondestructive evaluation and structural health monitoring because of changes in received signals due to both the associated strain and the acoustoelastic effect. A homogeneous plate that is initially isotropic becomes anisotropic under uniaxial stress, and dispersion of propagating waves becomes directionally dependent. The problem is similar to Lamb wave propagation in an anisotropic plate, except the fourth order tensor in the resulting wave equation does not have the same symmetry as that for the unstressed anisotropic plate, and the constitutive equation relating incremental stress to incremental strain is more complicated. Here we consider the theory of acoustoelastic Lamb wave propagation and show how dispersion curves shift anisotropically for an aluminum plate under uniaxial tension. Theoretical predictions of changes in phase velocity as a function of propagation direction are compared to experimental results for a single wave mode.

The Investigation on the Nonlinear Parameters Induced by Thermal Aging

---Nonlinear ultrasonic has considerable potential to characterize material microstructure. This paper attempts to evaluate the material microstructure before and after different heat treatment conditions by nonlinear ultrasound. The second harmonic generation technique is used to represent the material nonlinearity. The relation between thermal loading and the nonlinear parameter is explained from the material micro-structure. The experimental result shows that the thermal loading can change the material nonlinearity. Moreover, it shows the possibility to evaluate the heat treatment process nondestructively by nonlinear ultrasound based on the measurement of a nonlinear parameter.
A Nonlinear Ultrasonic Evaluation of Thermal Fatigue in Composites

In this study, a new approach to evaluate the material degradation caused by thermal fatigue of composite laminates is introduced by using nonlinear Lamb waves. The correlation between normalized nonlinear parameters and degradation states was studied. The S1 mode was chosen to generate the nonlinear lamb wave. The group delay method was used to separate multi-modes of the wave-packet. An extra experimental procedure was introduced to eliminate the nonlinearity from the instrument system. The results show that it is possible to measure the nonlinearity of composite laminates by using Lamb waves and the measured nonlinearity is directly related to material degradation. On the basis of these results, it is possible to use nonlinear Lamb waves to evaluate composite laminates degradation.
Ultrasonic Applications

A Method for Quantitatively Evaluating Thickness of Elastic Plates Using High-Overtone Bulk Acoustic Resonance
---Hui Zhang, Yu-ran Wang, and Shu-yi Zhang, Nanjing University, Lab of Modern Acoustics, Institute of Acoustics, Nanjing, China

---For structures composed of elastic plates and piezoelectric patches, based on the relations between the resonant frequency of the structure with high-overtone bulk acoustic resonance and thickness of the elastic plate, a method to evaluate the thickness of elastic plates is presented. In the structure, the resonant mode with the maximum effective electromechanical coupling factor $k^2_{\text{eff(max)}}$ has a high excitation efficiency. However, the distribution of the mode in the resonant spectrum changes with the acoustic impedance ratio between the elastic plate and piezoelectric patch. According to Mason model, the calculated results show, when the acoustic impedance ratio is less than 0.6, the order number of the mode with $k^2_{\text{eff(max)}}$ is equal to the order number of the first normal region in the spacing of parallel resonance frequency (SPRF); but when the acoustic impedance ratio is larger than 1.5, the order number of the mode is equal to the order number of the first transition region in SPRF. The ultrasonic waves at both regions can be used as the detection signals to evaluate the elastic plate thickness variations. The method has a high sensitivity of $500\text{Hz}/1\text{μm}$ for nondestructive evaluations of thickness, thickness variations and surface conditions of elastic plates.

Ultrasonic Applications

Wedge Waves Induce Acoustic Streaming
---Wen-Chih Wang, Institute of Mechatronic Engineering, National Taipei University of Technology Taipei, Taiwan; Che-Hua Yang, National Taipei University of Technology, Institute of Mechatronic Engineering, Taipei, Taiwan

---For Recent years, the active micro devices have been viewed as important components for the micro systems, where micro-pumping or micro-mixing behaviors based on the acoustic streaming (AS) principles are interested. AS is a fluid flow induced by acoustic waves traveling along solids through the solid/liquid interface. Anti-symmetric flexural (ASF) modes are wedge waves with their particle motion anti-symmetric about the apex mid-plane. With the energy tightly confined near the wedge-tip, ASF modes have relatively high acoustic energy density near the wedge tips which can be used for micro-mixing or micro-pumping purpose. In this study, the AS behaviors induced by ASF modes are investigated by numerical method employing computational fluid dynamics (CFD). And it is found out that the velocity is found to increase as the number of cycle increases. Also, maximum AS velocity is found out to be located 0.1 below the wedge tip. The ASF induced flow fields exhibit 3D complex nature which could be favorable to the mixing applications. Also, AS behaviors along the wedge tip remains as interesting problem to be investigated.
**Ultrasonic Applications**

**Image-Based FIT Modeling for Coupled Elastodynamic and Acoustic Problems**
---Kyohei Takata and Kazuyuki Nakahata, Ehime University, Department of Civil and Environmental Engineering, Ehime, Japan; Frank Schubert and Bernd Koehler, Fraunhofer Institute for Nondestructive Testing, Dresden Branch (IZFP-D), Dresden, Germany

---Our study presents a numerical time domain modeling of acoustic, elastodynamic, and coupled waves. Our simulation tool is based on the finite integration technique (FIT) and combined with an image-based modeling approach. The FIT is a grid-based spatial discretization method that works in conjunction with a leap-frog time marching scheme. In our simulation, geometries of targets are determined by digital images such as X-ray pictures or CAD data, and the processed pixel or voxel data are directly fed into the wave simulation by the image-based FIT. Here the modeling and simulation of wave propagation in concrete material including fluid-solid interactions and a non-contact ultrasonic testing are demonstrated.

---An Ultrasonic Model for Revealing Electronic Package’s Inner Structure Using Acoustic Impedance
---Chunguang Xu, Zhongzhu Liu, Juan Hao, and Xinyu Zhao, Beijing Institute of Technology, Key Laboratory of Fundamental Science for Advanced Machining, Beijing, P. R. China

---Electronic package’s inner structure is complex with multi-element including layered structure, chip, mold compound, substrate, and some defects, etc. Revealing the package’s inner structure is very important for the package’s inspecting and test. Acoustic microscopy is now a commonly used tool to inspect electronic package, but the ultrasonic propagation rule in the complex structure should be exactly known before. In this paper, an ultrasonic model is suggested to reveal electronic package’s inner structure using acoustic impedance. As all known, acoustic impedance is a basic parameter of acoustic wave field, but using the impedance to represent the transferring medium structure is not normal. The reflected or transmission waves’ sound pressure is affected by the medium’s acoustic impedance, so we can use acoustic impedance matrix to reveal the medium’s inner structure, which is the model’s theory origin. This paper describes the detailed method of establishing the ultrasonic model in electronic package. In the end, the model is validated with matlab software. The validation result shows that this ultrasonic model can reveal electronic package’s inner structure accurately.
Ultrasonic Applications

Acoustic Field Calculation for the Phased Array Acoustic Transducers on the Irregular Surface
---Chunguang Xu, Lijiu Wang, Dingguo Xiao, and Shiyuan Zhou, Beijing Institute of Technology, Key Lab of Fundamental Science for Advanced Machining, 5 South Zhongguancun Street, Haidian District, Beijing, China

---Nowadays, the contact surface of ultrasonic phased array is generally on a rigid plane. If the surface of component is not a plane, it can reduce the testing sensitivity due to unmatched contact. Thus it is necessary to develop the phased array acoustic transducers on the irregular surface to fit actual surface of the piece. The focal law and field computation method for the phased array acoustic transducers on the irregular surface were introduced. And, some Matlab programs were developed to validate the analytic method. The influence on acoustic field caused by geometric parameters of transducers, such as element number, element elevation, element space and element width were studied. Key words: ultrasonic phased array; acoustic field calculation.

Sensors, Techniques, and Systems

Nondestructive Inspection of a Composite Material Sample Using a Laser Ultrasonics System with a Beam Homogenizer
---João M. S. Sakamoto and Gefeson M. Pacheco, Instituto Tecnológico de Aeronáutica, Departamento de Microondas e Optoeletrônica, São José dos Campos, São Paulo, Brazil; Atsushi Baba, Hitachi Ltd, Energy and Environmental Systems Laboratory, Hitachi, Omika/Ibaraki, Japan; Bernhard R. Tittmann, John Mulry, and Matthew Kropf, Pennsylvania State University, Engineering Science and Mechanics, University Park, PA 16802

---A laser ultrasonics system was used to detect impact damage in samples of composite material used in the Brazilian aeronautics industry. The ultrasonic generation was accomplished with a high power Nd:YAG laser operating at 1064 nm. The detector was a commercial Mach-Zehnder interferometer. The setup also had optical components such as IR mirrors, a beam splitter, a lens, and a beam homogenizer. The Nd:YAG laser was configured so as not to cause damage to the sample by generating pulses of 6 mJ of energy, that dropped to 3.4 mJ after the beam splitter. The homogenizer was an important piece used to decrease the density of energy in the center of the beam spot, distributing its energy homogeneously over the cross section. Then, the density of energy was approximately 0.03 J/cm² and the surface of the composite material was not damaged by the laser. A region of 20 mm x 20 mm containing the impact damage was scanned with a step size of 1 mm. For each position, a waveform was measured by the interferometer and recorded by an oscilloscope. The data obtained were used to generate images of the area inspected and to detect the internal defect.
Sensors, Techniques, and Systems

A Modular Bulk Shear Horizontal Wave Transducer Using a Thin Fe-Co Alloy Patch

---Seung Hyun Cho, Jae Ha Park, and Bongyoung Ahn, Korea Research Institute of Standards and Science, Center for Safety Measurement, Yuseong-gu, Daejon, Korea; Hyu-Sang Kwon, Korea Research Institute of Standards and Science, Center for Fluid Flow and Acoustics, Yuseong-gu, Daejon, Korea

---Recently, many studies have been showing successful performance of magnetostrictive transducers using a ferromagnetic patch for the transduction of guided shear waves since a thin ferromagnetic patch bearing strong magnetostriction is very useful to generate and measure shear waves. This investigation concerns bulk shear wave transduction using a thin magnetostrictive patch while the existing studies have been mainly focused on the guided shear waves such as torsional waves and SH waves. A modular transducer comprising a coil, magnets, and a ferromagnetic patch made of a thin Fe-Co alloy was developed for bulk SH waves. Some experiments were conducted to verify the bulk shear wave transduction performance of the developed transducer. The radiation directivity pattern of the developed transducer was obtained and the damage detection test was also carried out on an artificial side drill hole of a steel block specimen. Consequently, the considerable performance of the transducer for nondestructive testing was verified on the basis of signal-to-noise ratio and narrow beam directivity.

Sensors, Techniques, and Systems

Development of High Temperature Ultrasonic Transducer for Structural Health Monitoring

---A. Baba1, C. T. Searfass,2 and B. R. Tittmann2, 1Energy and Environmental Systems Laboratory, Hitachi, Ltd., 7-2-1, Omika-cho, Hitachi-shi, Ibaraki-ken, 319-1221, Japan; 2Department of Engineering Science and Mechanics, The Pennsylvania State University, University Park, PA 16802

---Structural health monitoring (SHM) techniques are needed to maintain the reliability of aging power plants for long term operation. The high temperature transducers are necessary to realize SHM (monitor wall thickness of the pipings, crack growth in the materials and material evaluation) under the working condition of power plants. We have developed high temperature transducer using lithium niobate (LiNbO3) single crystal which is well known as a high Curie temperature piezoelectric material. The LiNbO3 was bonded onto a stainless steel substrate. The transducer was heated in an electric furnace while measuring the bottom echoes from the substrate. We confirmed that the high temperature transducer could work up to 1000°C.
Sensors, Techniques, and Systems

Capacitive Imaging Technique for NDE
---X. Yin, D. A. Hutchins, and G. G. Diamond, University of Warwick, School of Engineering, Coventry CV4 7AL, United Kingdom

---Investigations are presented into the capacitive imaging (CI) technique for NDE applications. The CI technique employs a pair of electrodes to form a co-planar capacitor and uses the established electric fringing field across the electrodes as a probe to detect defects within a sample. This CI technique is advantageous for its non-contact and non-invasive nature and the capacitive coupling allows the technique to work on a wide variety of material properties, without the disadvantages associated with conventional eddy current, potential drop, and ultrasound methods. Penetration depth, image resolution and signal strength are discussed to evaluate the performance of the CI probes under different circumstances. Results obtained from a wide range of material types, from insulators (including high density polystyrene and glass fiber composites) to metals are presented. The potential of this technique for making realistic predictions to the in-service performance of practical structures is then shown in detecting corrosion under insulation (CUI) and indentifying cracks and voids in concrete. The work is backed up by FE simulations, which demonstrate the physical principles behind the technique.

C-130 Hercules Rainbow Fitting Inspection: Methods for Tracking in Eddy Current Probe to Ensure Complete Coverage
---Daniel J. Barnard, Andrew Patz, and David K. Hsu, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---Cracking in the C-130 Hercules' wing box rainbow fitting present a significant safety risk and a limiting of the aircrafts availability for multiple mission profiles. Manually applied eddy current inspection is the most common NDI method currently utilized by USAF and Air National Guard maintenance staffs, but is highly labor intensive. The prime issue is the small size of the probe, 0.125” diameter, versus the large inspection area, where a concerted effort by the inspector is required to ensure complete coverage of the inspection area. A typical inspection involves manually scanning the probe in a horizontal path over the part surface, then rescanning using a vertical path. In an initial effort to evaluate percentage of area covered and guide this manual inspection, the probe was tracked with a modified PC Notes Taker, a commercial product designed for hand writing capture. Additional work has involved the development of a pantograph-based probe holder/tracker, with the intention of eliminating/minimizing probe tilt, liftoff (particularly in the under wing rainbow fitting inspection), and allowing either just probe track images or C-scan production with data from the EC instrument analog outputs. Result of the initial tests and subsequent equipment development and testing are discussed.---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 Nondestructive Evaluation.
Guided Wave Ultrasound Field Mapping Using a Network of Removable Bragg Grating Ultrasound Transducers
---Indu Fiesler Saxena and Lothar U. Kempen, Intelligent Optical Systems, Inc., 2520 W. 237th Street, Torrance, CA 90505

---In-situ portable damage detection for depot maintenance can be extremely useful as considerable savings in time and labor can be realized that is necessary for contemporary fixed location detection systems, such as is the case for water-coupled ultrasound imaging with the “squirter”, for instance. Structural dis-assembly and transport to and from dedicated NDE system location for larger aircraft structures can take up to a week, at times. An ultrasound field mapping method that uses fiber Bragg gratings embedded in a flexible, removable sheet that can be re-used over different structures, is described. It is shown that this can be used to map the guided wave ultrasound over approximately 2 square feet area in a few tens of minutes where the test sample is a composite skin with aluminum metal honeycomb of an aircraft structure. The data thus collected, comprising 612 locations over the area, can enable in-situ damage detection once signal analysis algorithms are applied.

Detection of Minor Outer Flaws in Titanium Alloys Using Lockin Eddy Current Testing System
---Tomasz Chady, Grzegorz Psuj, and Jacek Kowalczyk, West Pomeranian University of Technology in Szczecin, Faculty of Electrical Engineering, Szczecin, Poland

---The importance of titanium alloys as a resource material in modern leading industry branches such as aerospace is rapidly growing. Therefore, occurs the need of introducing new nondestructive testing measuring system that allows detection of outer flaw in thick titanium structures. In this paper a newly developed lockin amplifier based eddy current NDT system was applied. Such system enables to detect signals caused by minor defects and having the amplitude lower than the noise level. The proposed system allows to monitor amplitude and phase responses of a transducer using single testing frequency ranging form 1 kHz up to 100 kHz. A software written in LabView was used to control the whole system, proceed data analysis and display results. A differential eddy current transducer was proposed and optimized taking into account testing requirements. Very high sensitivity of the proposed system was confirmed during experiments with test specimens. A set of flat and cylindrical titanium alloy test samples with artificial notches were used in order to evaluate performance of the proposed system and transducer. The full description of the system as well as the full set of results and discussion will be present in the final version of the paper. This work was supported in part by Polish Ministry of Science and Higher Education and by European Commission sponsored project QualiT which is a collaboration between the following organizations: I.S.O.TEST Engineering s.r.l, Technical University of Szczecin (PUZ), Tecnitest Ingenieros S.L., TIMET UK Ltd, TWI Ltd and Vermon SA. The project is co-ordinated and managed by TWI Ltd and is partly funded by the EC under the Research for the Benefit of Specific Groups Project (ref: FP7-SME-2007-1-GA-222476).
Sensors, Techniques, and Systems

Feedback Algorithm for Identification of Multi-Segmented Cracks  
---Tomasz Chady and Lech Napierala, West Pomeranian University of Technology in Szczecin, Faculty of Electrical Engineering, Szczecin, Poland

---In this paper, algorithm for accurate reconstruction of real-life multi-segmented cracks from two dimensional radiographic images is presented. It's an extension to our previous algorithm, together their work in the following way: Firstly, real-life image of a crack is analyzed. Information about amount of branches, their interconnections, shape etc. is estimated. Basing on those parameters, a model of a crack is prepared. This model is then examined with use of x-ray simulation tool, effect of which then is compared to the real-life radiogram. Here the feedback part of algorithm begins. Basing on results of comparison between real-life and simulated radiogram, model is slightly modified. Those modifications occur in a loop for as long as simulated radiograms are not enough similar to the original image. This work was supported by the Ministry of Education and Science, Poland, under grant N R01 0037 06 (2009–2012).

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Sensors, Techniques, and Systems

3D Modeling of Zero-Width Cracks for Nondestructive Evaluation Applications  
---Yiming J. Deng, Departments of Electrical Engineering, Bioengineering and Radiology, University of Colorado-Denver, Denver, CO 80217; Xin Liu, Department of Electrical Engineering, University of Colorado-Denver, Denver, CO 80217; Yushi Sun, Innovative Materials Testing Technologies, Inc., Superior, CO 80027

---The availability of an accurate numerical model is essential to help understanding the cause of the zero-width crack and the crack propagation dynamics. The challenge for modeling zero-width discontinuities was to capture the crack, including the sizes, locations (corner or center), and directions. Previously, finite element methods (FEM) have been developed and shown the validity and effectiveness for zero-width crack study in eddy current testing (ECT) problems. The major drawbacks of conventional FEM include: difficulty to generate the mesh geometry due to the complex shapes and the narrow gap; large amount of computing resources to achieve accurate results; and no guarantees that you won't run into analysis instability because of singularities. This paper presents an innovative meshless method for studying the zero-width crack and position propagation in ECT problems. Both FEM and meshless model results are compared and the computational accuracy, efficiency and stability issues are discussed.
**Scanning Laser Source Technique for Thickness Evaluation in Pipe**
---Muhammad Nor Salim, Takahiro Hayashi, Morimasa Murase, Toshihiro Ito, and Shoji Kamiya, Faculty of Engineering, Nagoya Institute of Technology, Japan

---Pipes are widely used in petrochemical industries for distributions of fuels and liquid chemicals. During the process, old pipes are predominantly suffered of corrosion and aging, which can result leaks, or explosions. Nondestructive evaluation helps to avoid such failure in pipe networks and suggest a proper maintenance to repair the pipes with critical defects. Use of guided wave in pipe inspections has advantage to rapidly screen a pipe network over a long distance at a lower cost than using the conventional pulse echo testing using a single normal beam transducer. However, the remaining thicknesses over defects are more important than the locations of defects in pipes. This problem motivated us to carry out a study using guided wave for measurement of remaining thicknesses over internal defects in pipes. The proposed inspection use a YAG laser and a laser galvano scanner to scans over visible curved surfaces of pipes, and 8 of equally spaced separate piezoelectric transducers with wedges were bounded around pipes from a certain distance to measure the displacement of L(0,1) mode produced from the scanning laser source. Measurement of L(0,1) mode shows very close similarity to the measurement of A0 mode on plates in the previous study. High amplitude distributions were also observed over internal defect with thinned wall and low amplitudes were also observed over intact surface. The images obtained from the scanning laser source are successfully indicated amplitude distributions over pipe surfaces for 1 mm and 2 mm deep circumferential defects in aluminium pipes with diameter of 110 mm and thickness of 3.5 mm. The inspection also shows capability to characterize internal defects at distance equivalent to about 10 m from the bounded transducers. This kind of guided wave pipe inspection is practical for on field applications to characterize the thickness over defect using a remote measurement.

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**Signal to Noise Comparison of Flash Thermography and Vibration Excitation Shearography**
---Simon G. Pickering and Darryl P. Almond, University of Bath, Department of Mechanical Engineering, Bath, BA2 7AY, United Kingdom

---Flash thermography involves the generation of a transient heat flux inside the test sample using flash lamp surface excitation. Subsurface defects produce anomalies in the surface cooling characteristics captured by an infrared camera. Shearography, otherwise known as shearing speckle interferometry, is a technique that uses interferometry to measure the out of plane displacement gradient of a sample’s surface. The presence of defects will alter the way in which a sample reacts to an applied stress and this change can be observed using shearography thereby inferring the presence of the defect. The work presented in this poster presents a comparison of the defect detection capabilities of transient thermography and shearography using short pulse heating for thermography and vibration excitation using a piezoelectric transducer for shearography. A signal-to-noise ratio and limit of detection analysis has been performed on defect images obtained by the two techniques using the different excitation methods. Test samples considered in this paper are flat-plate samples made from aluminium, mild steel, stainless steel, CFRP and thermoplastic, containing flat-bottomed hole artificial defects of 20mm diameter at depths ranging from 0.5mm to 3.0mm.
Sensors, Techniques, and Systems

Guided Wave Travel Time Tomography for Bends
---Arno Volker and Joost Bloom, TNO, Stieltjesweg 1, P. O. Box 155, Delft, 2600 AD, The Netherlands

---The concept of predictive maintenance using permanent sensors that monitor the integrity of an installation is an interesting addition to the current method of periodic inspections. Guided wave tomography has been developed to map the wall thickness using the travel times of guided waves. The method has been demonstrated for straight pipes. The extension of this method to bends is not straightforward because natural focusing occurs due to geometrical path differences. This yields a phase jump, which complicates travel time picking. Because ray-tracing is no longer sufficient to predict the travel times a recursive wave field extrapolation has been developed. The method uses a short spatial convolution operator to propagate a wave field through a bend. The method allows to calculate the wave field at the detector ring, including the phase jump as a consequence of the natural focusing. The recursive wave field extrapolation is done in the space-frequency domain. Therefore dispersion effects can be included easily in the forward modeling. Comparison with measurements shows the accuracy of the method.

Development of a Portable Mechanical Hysteresis Measurement and Imaging System for Impact Characterization in Honeycomb Sandwich Structures
---Daniel J. Barnard, David K. Hsu, and Lucinda J. Smart, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---Honeycomb sandwich materials are commonly used for aero-structures, but because the outer skins are typically thin, 2-10 plys, the structures are susceptible to impact damage. NDI methods such as tap tests, bond testers and TTU ultrasound are successfully deployed to find impact damage, but identifying the type/degree of damage is troublesome. As the type/degree of impact damage guides decisions by the maintenance, repair and overhaul (MRO) community regarding repair, the ability to characterize impacts is of interest. Previous work demonstrated that additional impact characterization may be gleaned from hysteresis loop area, as determined from an out-of-plane load-vs-displacement plot, where this parameter shows a correlation with impact energy. This presentation reports on current work involving the development of a portable hysteresis measurement and imaging system based on an instrumented tapper. Data processing and analysis methods that allow production of the load/displacement data from a single accelerometer are discussed, with additional reporting of tests of software to automatically vary pixel size during scanning to decrease C-scans inspection time.---This material is based upon work supported by the Federal Aviation Administration under Contract Number DTFACT-09-C-00004 and performed at Iowa State University’s Center for NDE.
Simple Go/No-Go Test for Subcritical Damage in Body Armor Panels
---J. Fisher and D. E. Chimenti, Iowa State University, Center for NDE and Department of Aerospace Engineering, Ames, IA 50011

---The goal of this project is a simple test for subcritical damage in body armor panels. We rejected the idea of complicated electronic sensors that can easily malfunction or that need external electrical power to function. Instead, our studies center on the adaptation of pressure-sensitive dye-indicator (PSD) film to perform the test. Preliminary measurements have shown that static indicator levels are accurately reproduced in dynamic loading events. Both hard (blunt object) and soft (shot-filled ball) impactors have been explored. Both give the expected response with the PSD film. To make the tests more realistic we have employed a CPR manikin, where the PSD film is applied to body armor in a carrier vest resting on the human torso model. Impacts are monitored in realtime with both a force sensor and an accelerometer, so that the impact event is fully instrumented. The manikin chest model is fitted with a spring having a rebound similar to a live human. Impact tests have been done from 6 to 45 joules, about half of the 92-joule federal acceptance standard. We observe strong correlation between impact energy and PSD indication at all impact energies. We find that chest compression increases sharply with impact momentum, and simultaneously the maximum force decreases with increasing impactor mass at similar energies. In diagnostic X-ray inspections we observe ceramic element cracking at energies well below the acceptance standard. These and further measurements will be presented.

Geometrical Gauge Factor of Directional Electrical Potential Drop Sensors for Creep Monitoring
---E. Madhi and P. B. Nagy, University of Cincinnati, Department of Aerospace Engineering and Engineering Mechanics, Cincinnati, OH 45221-0070

---Directional electric potential drop measurements can be exploited for in-situ monitoring of creep in metals. The sensor monitors the variation in the ratio of the resistances measured simultaneously in the axial and lateral directions using a square-electrode configuration. This method can efficiently separate the mostly isotropic common part of the resistivity variation caused by reversible temperature variations from the mostly anisotropic differential part caused by direct geometrical and indirect material effects of creep. Initially, this ratio is rough proportional to the applied axial creep strain, while at later stages, the resistance ratio increases even faster with creep strain because of the formation of directional discontinuities such as preferentially oriented grain boundary cavities and multiple-site cracks in the material. Similarly to ordinary strain gauges, the relative sensitivity of the sensor is defined as a gauge factor that can be approximated as a sum of geometrical and material parts. This work investigated the geometrical gauge factor by analytical and experimental means. We found that under uniaxial stress square-electrode sensors exhibit geometrical gauge factors of about 4 and 5 in the elastic and plastic regimes, respectively, i.e., more than twice those of conventional strain gauges. Experimental results obtained on 304 stainless steel using a square-electrode electric potential drop creep sensor agree well with our theoretical predictions.
Session 12
SESSION 12
TERAHERTZ NDE
Harry Ringermacher, Chairperson
Salons A-C

3:30 PM  An Exploration of the Utilities of Terahertz Waves for the NDE of Composites
---D. K. Hsu, K.-H. Im, C.-P. Chiou, and D. J. Barnard, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

3:50 PM  Hand-Held Portable High-Speed Time-Domain Terahertz Composite Inspection System
---D. Zimdars, G. Fichter, C. Megdanoff, J. Duquette, M. Murdock, I. Duling, J. White, and S. Williamson, Picometrix LLC, 2925 Boardwalk Drive, Ann Arbor, MI 48104

4:10 PM  Time of Flight Diffraction (ToFD) with THz Radiation – An Alternative to the Ultra Sound – ToFD Technique for Non-Metallic Materials
---U. Ewert, J. Beckmann, L. S. von Chrzanowski, and G. Brekow, BAM, Non Destructive Testing, Unter den Eichen 87, 12205, Berlin, Germany
An Exploration of the Utilities of Terahertz Waves for the NDE of Composites
---David K. Hsu, Kwang-Hee Im, Chien-Ping Chiou, and Daniel J. Barnard, Iowa State University, Center for Nondestructive Evaluation, 1915 Scholl Road, Ames, IA 50011

---We report here an investigation of terahertz waves for the nondestructive evaluation of composite materials and structures. The modalities of the terahertz radiation used were time domain spectroscopy (TDS) and continuous wave (CW). The composite materials and structures investigated include both non-conducting polymeric composites and conducting carbon fiber composites. Terahertz signals in the TDS mode resemble that of ultrasound; however, unlike ultrasound, a terahertz pulse was able to detect a smaller crack hidden behind a larger crack. This was demonstrated in thick GFRP laminates using saw slots. In carbon composites the penetration of terahertz waves is quite limited and the detection of flaws is strongly affected by the angle between the electric field direction of the terahertz waves and the intervening fiber directions. The structures used in this study included both solid laminates and honeycomb sandwiches. The defects and anomalies investigated by terahertz radiation were foreign material inclusions, simulated disbond and delamination, mechanical impact damage, heat damage, and water or hydraulic fluid ingression. The effectiveness and limitations of terahertz radiation for the NDE of composites are discussed.---Work was supported by NSF under WRI grant and I/U CRC program and partially supported by FAA under contract DTFACT09C00004.

Hand-Held Portable High-Speed Time-Domain Terahertz Composite Inspection System
---David Zimdars, Greg Fichter, Chris Megdanoff, John Duquette, Margaret Murdock, Irl Duling, Jeff White, and Steve Williamson, Picometrix LLC., 2925 Boardwalk Drive, Ann Arbor, MI 48104

---A hand-held, high-speed time-domain terahertz (TD-THz) reflection line-scanner for non-destructive examination (NDE) is described. The imager scans a line 150 mm wide and collects a TD-THz cross-sectional "B-scan" of the sub-surface structure at rates up to 15 Hz. By rolling the scanner over a surface, a 2D "C-Scan" image can be stitched together from the individual lines at a rate of 25-200 mm/s. The system is 15 times faster than typical THz gantry imagers. The case is 8.7 in. wide, 12.5 in. long, and 7.9 in. high. The weight is approximately 7 lbs. The imaging characteristics of the scanner will be presented. Imaging results on ground based and aircraft radome panels will be presented.
Time of Flight Diffraction (ToFD) With THz Radiation - An Alternative to the Ultra Sound – ToFD Technique for Non-Metallic Materials
---Uwe Ewert, Jörg Beckmann, Lars S. von Chrzanowski, and Gerhard Brekow, BAM, Non Destructive Testing, Unter den Eichen 87, 12205, Berlin, Germany

---A time domain spectrometer in the range of 0.5 - 2 THz is used for time of flight measurements of THz pulses for flaw detection in non metallic materials. The measurements are performed in comparison to the established ultra sound ToFD technique. An object is tested in the flight of time mode. An electromagnetic pico second pulse is generated as optoelectronic response to a femto second laser pulse. Transmitter and receiver head are positioned in an angle of ± 45° to the surface of the test object. The time of flight response is recorded in dependence on the object position. The radiation geometry is fixed in analogy to the known UT ToFD technique. No coupling agent and no contact to the surface is required for THz ToFD measurements. A plastic pipe with notches and drilled side holes was used to study the diffracted response signals and calibrate the system. No major differences were observed between the UT and THz ToFD records. The measurement is fast and has the potential to substitute UT applications in some industrial areas. Within the German project “Handheld” the potential for miniaturization of the time domain equipment is explored for efficient application.
Tuesday, July 20, 2010

SESSION 13
BENCHMARK VALIDATION NDE
Les W. Schmerr, Jr., Chairperson
Salon D

3:30 PM  Developing and Using Benchmarks for Eddy Current Simulation Codes Validation to Address Industrial Issues
---M. Mayos and F. Buvat, EDF/CEIDRE, Saint Denis, France; V. Costan and O. Moreau, EDF R&D, Clamart, France; C. Gilles-Pascaud and C. Reboud, CEA, LIST, Saclay, France; F. Foucher, EXTENDE, Orsay, France

3:50 PM  Results of the 2010 UT Modeling Benchmark Obtained with CIVA: Responses of Backwall and Surface Breaking Notches of Various Sizes
---A. Dubois, S. Bey, R. Raillon, S. Mahaut, and M. Darmon, CEA, LIST, F-91191, Gif-sur-Yvette, Cedex, France

4:10 PM  Magnetic Flux Leakage: A Benchmark Problem
---J. Etcheverry, G. Sanchez, and N. Bonadeo, CINI, Applied Physics Department, Campana, Buenos Aires, Argentina

4:30 PM  Validation of Magnetic Flux Leakage Computational Results Against Experimental Data
---J. Etcheverry and G. Sanchez, CINI, Applied Physics Department, Campana, Buenos Aires, Argentina
Developing and Using Benchmarks for Eddy Current Simulation Codes Validation to Address Industrial Issues

---Michel Mayos and Fabrice Buvat, EDF/CEIDRE, Saint Denis, France; Valentin Costan and Olivier Moreau, EDF R&D, Clamart, France; Catherine Gilles-Pascaud and Christophe Reboud, CEA, LIST, Saclay, France; Fabrice Foucher, EXTEENDE, Orsay, France

---Nowadays, industrial NDE applications are facing a growing demand for qualification and performance assessment, sometimes under regulatory requirements, such as for the in-service inspection of French nuclear power plants, where eddy currents are a major NDE method. In this process, simulation tools represent a valuable support, allowing a reduced use of costly mock-ups and studies over extensive ranges of influential parameters. Nonetheless, modeling codes used for this purpose have to undergo a preliminary validation of their abilities. Feedback from experience from the eddy current NDE of steam generator tubes show that the use of well-known academic benchmarks is inappropriate to make a first-step code selection for the qualification process and that alternative industrially-aimed benchmarks are needed. This concern, shared by other industrial fields involved in NDT in France (aerospace, automotive, steel industry), has led to the creation of a dedicated working group in the frame of COFREND (French Association for NDT), whose goal is to define benchmark problems with an industrial background for eddy current NDE and to promote their resolution by the widest range of simulation codes. Examples of test-case definitions and resolutions are shown, implying several codes of different origins and complexities.

Results of the 2010 UT Modeling Benchmark Obtained with CIVA: Responses of Backwall and Surface Breaking Notches of Various Sizes

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

---This communication presents the results obtained on the configurations proposed in the 2010 UT modelling benchmark with the ultrasonic models implemented in the CIVA software. Experiments have been performed upon a planar block containing vertical planar backwall and surface breaking notches of different heights and extensions. The aim is to study the relative amplitudes of the notches echoes obtained after one bound on the backwall or after two bounds, on the backwall and then on the surface of the block. Side drilled holes and flat bottom holes were also present in the block for comparison. Two immersion probes of 5 MHz central frequency, for two different apertures, were used. The echoes are simulated by applying an integral formulation for the field radiated by the probe (the pencil-model) and a scattering model based on the Kirchhoff approximation. Comparison between simulated and experimental results are presented and discussed.
Magnetic Flux Leakage: A Benchmark Problem
---J. Etcheverry, G. Sánchez, and N. Bonadeo, CINI, Applied Physics Department, Campana, Buenos Aires, Argentina

---The magnetic flux leaked by artificial notches machined by EDM is measured for two different rectangular steel plates. The measurements were performed for different field intensities, different liftoffs, and both sides, simultaneously recording the three components of the magnetic field. Attention was paid to the accurate measurement of the liftoff, and to make the magnetic history of the material as predictable as possible. This was achieved by measuring for decreasing magnetic excitations, starting from saturation. The descending branch of the major loop is measured and reported, to allow for a detailed comparison against numerical experiments.

Validation of Magnetic Flux Leakage Computational Results Against Experimental Data
---Javier I. Etcheverry and Gustavo A. Sánchez, CINI, Applied Physics Department, Campana, Pcia. Buenos Aires, Argentina

---Results of detailed experimental measurements of the leaked magnetic field for two different steel plates with a machined notch were compared against the numerical predictions using COMSOL. The accuracy of the results is discussed in detail, as well as the ingredients that allow obtaining satisfactory computational results. Some interesting conclusions that derive from the numerical computations are also presented. For instance, the influence of the notch length on the amplitude of the recorded signal, the decay of the signal amplitude as the liftoff is increased, the need to have a precise measurement of the magnetic permeability up to magnetic fields much higher than the magnetic field in the bulk of the material, etc.
Session 14
3:30 PM  Inspection of Nickel Alloy Welds Results from Five-Year International Program
        ---I. G. Prokofiev, U. S. Nuclear Regulatory Commission, Washington, DC 20555-0001;
                  S. E. Cumblidge and S. R. Doctor, Pacific Northwest National Laboratory, Richland, WA 99352

3:50 PM  Characterization of Friction Stir Weld Joining of A356/6061 Al Alloy by Acoustic Imaging Technique
        ---S. P. Sagar, M. Sahu, and M. Ghosh, National Metallurgical Laboratory, Materials Science & Technology Division, Jamshedpur, Jharkhand, India; C. Mayasaka and B. R. Tittmann, Pennsylvania State University, Department of Engineering Science & Mechanics, State College, PA 16802

4:10 PM  A Study Into the Effects of an Austenitic Weld on Ultrasonic Array Imaging Performance
        ---A. J. Hunter, B. W. Drinkwater, and P. D. Wilcox, University of Bristol, Department of Mechanical Engineering, Bristol, United Kingdom

4:30 PM  Ultrasonic Characterization of Interfaces in Composite Bonds
        ---N. Wang, O. I. Lobkis, and S. I. Rokhlin, The Ohio State University, Edison Joining Technology Center, Columbus, OH 43221

4:50 PM  Evaluation of Bond Strength in Composite Lap Shear Joints Using Non Destructive Test Methods
        ---R. L. V. Kumar, M. R. Bhat, and C. R. L. Murthy, Indian Institute of Science, Department of Aerospace Engineering, Bangalore, Karnataka, India
Inspection of Nickel Alloy Welds Results from Five-Year International Program


---The U.S. Nuclear Regulatory Commission established the international Program for the inspection of Nickel alloy Components (PINC). The goal of PINC was to evaluate the capabilities of various nondestructive examination (NDE) techniques to detect and characterize primary water stress corrosion cracking (PWSCC) in dissimilar metal welds. The insights gained will enhance the understanding of aging and environmental effects on materials in nuclear power plants (NPP), and improve the quality of standards for NPP in-service inspections. Extensive round-robin tests conducted by participants from Europe, Asia, and the U.S. were carried out to compare NDE effectiveness for simulated SCC detection. Observations include: a) Round-robin results showed that a combination of conventional and phased-array ultrasound provide the highest performance for flaw detection and depth sizing in dissimilar metal piping welds; b) The effective detection of flaws in bottom-mounted instrumentation penetrations by eddy current and ultrasound shows that it may be possible to reliably inspect these components in the field; c) Effective NDE techniques may need to be combined with modified inspection intervals selected based on the crack growth rates in nickel-based alloys. The analysis should be refined using PWSCC crack growth rates for small defects in nickel alloys as this information becomes available.

Characterization of Friction Stir Weld Joining of A356/6061 Al Alloy by Acoustic Imaging Technique

---S. Palit Sagar, Minati Sahu, and M. Ghosh, National Metallurgical Laboratory, Materials Science & Technology Division, Jamshedpur, Jharkhand, India; C. Mayasaka, and B R Tittmann, Pennsylvania State University, Department of Engineering Science & Mechanics, State College, PA 16802

---Friction Stir Welding (FSW) is a solid state joining technique uses heat generated by simultaneous action of penetrating, rotating and traversing of tool pin along the weld joint. The joint results by this process exhibits better mechanical properties, low residual stress and less probability of occurrence of defects. The increased application of the transition joint by very demanding industrial sectors, e.g., aerospace, naval and automotive, has generated significant research and development in FSW. Because of solid state nature of joining, FS welds are usually imperfection free. Still some imperfections may arise due to the improper stirring of the parent material or lack of penetration of the tool pin. Most of the research works on FSW are based on the microstructural characterization of joint interface by scanning electron microscopy (SEM) and optical microscopy (OM) and their tensile property evaluation. These techniques are destructive. In this paper first time non-destructive scanning acoustic microscopy (SAM) was attempted to reveal the microstructure of FSW joint of cast A356 Al alloy and wrought 6061 Al alloy and also to assess the weld quality of the joining interface. The quality of FSW joining was assessed using high frequency ultrasonic imaging. Microstructural changes at the interface of the joining were also revealed by SEM) and optical microscopy OM.
A Study Into the Effects of an Austenitic Weld on Ultrasonic Array Imaging Performance
---Alan J. Hunter, Bruce W. Drinkwater, and Paul D. Wilcox, University of Bristol, Department of Mechanical Engineering, Bristol, United Kingdom

---A relevant industrial application for ultrasonic array imaging is the detection and characterization of defects in welds; these can occur at fusion surfaces, within the weld material, or in the surrounding heat-affected zones. In many situations, e.g., for defects within the weld material or when inspection access is limited, it is necessary to propagate through the weld material. Weld material is typically inhomogeneous and, in the case of austenitic welds, it can be highly anisotropic. This results in attenuation and perturbation of the waves and can adversely affect imaging performance where, typically, a homogeneous and isotropic medium is assumed. In this paper, we investigate the effects on ultrasonic array imaging performance due to the perturbations introduced by austenitic weld material and we propose some strategies for compensating these effects.

Ultrasonic Characterization of Interfaces in Composite Bonds
---Ningyu Wang, Oleg I. Lobkis, and Stanislav I. Rokhlin, The Ohio State University, Edison Joining Technology Center, Columbus, OH 43221

---The inverse determination of imperfect interfaces from reflection spectra of normal and oblique incident ultrasonic waves in adhesive bonds of multidirectional composites is investigated. The oblique measurements are complicated by the highly dispersed nature of oblique wave spectra at frequencies above 3MHz. Different strategies for bond property reconstruction, including a modulation method, are discussed. The relation of measured interfacial spring density to the physico-chemical model of composite interface described by polymer molecular bonds to emulate loss of molecular strength on adhesive composite interface is discussed. This potentially relates the interfacial (adhesion) strength (number of bonds at the adhesive substrate interface) to the spring constant (stiffness) area density (flux), which is an ultrasonically measurable parameter.
Evaluation of Bond Strength in Composite Lap Shear Joints Using Non Destructive Test Methods
----R. L. Vijaya Kumar, M. R. Bhat, and C. R. L. Murthy, Indian Institute of Science, Department of Aerospace Engineering, Bangalore, Karnataka, India

---Adhesive bonding is an effective method of assembling complex structures, specifically for those made of different materials. Strict quality control in production and condition monitoring in service are the two aspects which ensure the successful exploitation of structures up to the point of withdrawal from service. In this context Non destructive evaluation of bonded structures plays an important role. Evaluation of adhesively bonded joints in composite structures has been attempted through an experimental approach. For this purpose, Glass Fiber Reinforced Plastic laminates were fabricated using unidirectional e-glass fabric as reinforcement and epoxy resin as the matrix. Rectangular strips cut from these laminates were used to form the single lap adhesive joints; bonding was accomplished using a two part adhesive system Araldite AV 138M/Hardener HV 998, which is extensively used in bonding plastics and composites. Different sets of bonded specimens with varied bond quality were obtained by induced degradation in the adhesive layer using poly vinyl alcohol which affects the polymerization of the epoxy resin system, leading to weak adhesion and cohesion. A series of experiments were performed on specimen prepared according ASTM D 5868 standard for lap shear adhesion for fiber reinforced plastic bonding. These consisted of subjecting the lap joint area to ultrasonic and X-ray imaging to evaluate and quantify the degradation. The joints were subsequently loaded to obtain their bond strength. Also, an acoustic emission sensor was bonded to monitor the emissions during failure. Details of experimental investigations, results and conclusions are elaborated in the paper.
Session 15
3:30 PM  Determination of the POD of Synthetic Hard-Alpha Inclusions in Titanium Forgings for Aircraft Engines
---R. B. Thompson, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

3:50 PM  Modeling the Reliability of Eddy Current Testing
---A. H. Ali, D. S. Baint, J. A. G. Temple, and P. Leevers, Imperial College, Department of Mechanical Engineering, London, SW7 2AZ, United Kingdom

4:10 PM  Development of Rapid, Continuous Calibration Techniques and Implementation as a Prototype System for Civil Engineering Materials Evaluation
---M. L. Scott, N. Gagarin, J. R. Mekemson, and S. R. Chintakunta, Starodub, Inc., Kensington, MD 20895

4:30 PM  Recent Improvements in Analysis and Display of NDE Data at NASA
---Don J. Roth1, R. W. Rouser2, E. Burke3, S. Zhang4, M. Marsh5, R. Cotton6, and A. Abdul-Aziz6
1MS 6-1, NASA Glenn Research Center, 21000 Brookpark Rd., Brookpark, OH 44135; 2University of Toledo, Toledo, OH 43606-3390; 3United Space Alliance, LLC, Kennedy Space Center, Cape Canaveral AFS, FL 32815; 4Visualization Sciences Group, 15 New England Executive Park, Burlington, MA 01803; 5Simpleware, Rennes Drive, Exeter EX4 4RN, United Kingdom; 6Cleveland State University, 2121 Euclid Avenue, Cleveland, OH 44115-2226

4:50 PM  Modeling of TDR Technique for Fault Detection in Electrical Wires
---G. H. Shirkoohi, London South Bank University, Faculty of Engineering, Science and Built Environment, London, United Kingdom
Determination of the POD of Synthetic Hard-Alpha Inclusions in Titanium Forgings for Aircraft Engines
---R. Bruce Thompson, W. Q. Meeker, and Lisa H. Brasche, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---The probability of detection (POD) of inspection techniques is a key input to estimating the lives of structural components such as aircraft engines. This paper describes work conducted as a part of the development of POD curves for the ultrasonic detection of synthetic hard alpha (SHA) inclusions in titanium aircraft engine forgings. The sample upon which the POD curves are to be based contains four types of right circular SHA’s that have been embedded in a representative titanium forging, as well as a number of flat bottomed holes (FBH’s). The SHA’s were of two sizes, #3 and #5, with each size including seeds with nominal nitrogen concentrations of both 3 and 17 wt. %. The FBH’s included sizes of #1, #3, and #5. This discreteness of the data poses a number of challenges to standard processes for determining POD. For example, at each concentration of nitrogen, there are only two sizes, with 10 inspection opportunities each. Fully empirical, standard methodologies such at $\hat{a}$ versus $a$ provide less than an ideal framework for such an analysis. For example, there is no way to describe the “beam limiting” effect whereby the signal no longer increases the flaw grows larger than the beam, one can only determine POD at the two concentration levels present in the block, and confidence bounds tend to be broad because of the limited data available for each case. In this paper, we will describe strategies involving the use of physics-based models to overcome these difficulties by allowing the data from all reflectors to be analyzed by a single statistical model. Included will be a discussion of the development of the physics-based model, its comparison to the experimental data (obtained at multiple sites with multiple operators) and its implications regarding the statistical analysis, whose details will be given in a separate presentation by Meeker.---This material is based upon work supported by the Federal Aviation Administration under Contract Number DTFACT-08-C-00005 and performed at Iowa State University’s Center for NDE in cooperation with General Electric Aviation, Honeywell, Pratt & Whitney, and Rolls Royce.

Modeling the Reliability of Eddy Current Testing
---A. H. Ali, D. S. Balint, J. A. G. Temple, and P. Leewers, Imperial College, Department of Mechanical Engineering, London, SW7 2AZ, United Kingdom

---A generic model framework for predicting the reliability of NDE inspection techniques has been developed, including logic for how triangular error probability distributions combine. The model was originally specialised using the physical equations for manual ultrasonic inspection of a V-butt weld, and it was used to quantify the probabilities of missing critical defects and misclassifying harmless defects. In this study, the model was extended to cover manual eddy current inspection of a spherical defect in a substrate with a cladding layer. Quadrature sums were employed, dependent upon the derivatives of the measured impedance with respect to important inspection parameters, which were determined by analytical differentiation and numerical integration of the classical equations for a spherical defect. In this paper, the new model is presented and used to show how different parameters in eddy current inspection affect the probability of missing critical defects and misclassifying harmless defects.
Development of Rapid, Continuous Calibration Techniques and Implementation as a Prototype System for Civil Engineering Materials Evaluation

---Michael L. Scott, Nicolas Gagarin, James R. Mekemson, and Satish R. Chintakunta, Starodub, Inc., Kensington, MD 20895

---Until recently, civil engineering material calibration data could only be obtained from material sample cores or via time consuming, stationary calibration measurements in a limited number of locations. Calibration data are used to determine material propagation velocities of electromagnetic waves in test materials for use in layer thickness measurements and subsurface imaging. Limitations these calibration methods impose have been a significant impediment to broader use of nondestructive evaluation methods such as ground-penetrating radar (GPR). In 2006, a new rapid, continuous calibration approach was designed using simulation software to address these measurement limitations during a Federal Highway Administration (FHWA) research and development effort. This continuous calibration method combines a digitally-synthesized step-frequency (SF)-GPR array and a data collection protocol sequence for the common midpoint (CMP) method. Modeling and laboratory test results for various data collection protocols and materials are presented in this paper. The continuous-CMP concept was finally implemented for FHWA in a prototype demonstration system called the Advanced Pavement Evaluation (APE) system in 2009. Data from the continuous-CMP protocol is processed using a semblance/coherency analysis to determine material propagation velocities. Continuously calibrated pavement thicknesses measured with the APE system in 2009 are presented. This method is efficient, accurate, and cost-effective.

Recent Improvements in Analysis and Display of NDE Data at NASA

---Don J. Roth1, R. W. Rauser2, E. Burke3, S. Zhang4, M. Marsh5, R. Cotton5, and A. Abdul-Aziz6, 1MS 6-1, NASA Glenn Research Center, 21000 Brookpark Rd., Brookpark, OH 44135; 2University of Toledo, Toledo, OH 43606-3390; 3United Space Alliance, LLC, Kennedy Space Center, Cape Canaveral AFS, FL 32815; 4Visualization Sciences Group, 15 New England Executive Park, Burlington, MA 01803; 5Simpleware, Rennes Drive, Exeter EX4 4RN, United Kingdom; 6Cleveland State University, 2121 Euclid Avenue, Cleveland, OH 44115-2226

---This talk reviews numerous recent NDE data analysis and visualization improvements implemented at NASA Glenn Research Center over the last several years. Examples will be shown in the area of ultrasonics, acoustic emission, and X-ray computed tomography for composite and complex-shaped structures. Emphasis is on methods most useful not only for the NDE professional analyzing the data but also for sharing of the data with end users such as material processors, testers, and modelers who need to use the data for various engineering decisions.
Modeling of TDR Technique for Fault Detection in Electrical Wires
---G. H. Shirkoohi, London South Bank University, Faculty of Engineering, Science and Built Environment, London, United Kingdom

---Electrical wiring, particularly in aircraft, are susceptible to damage due to extreme mechanical and thermal variations, exposure to moisture and a range of chemicals. Degradation and failure of aircraft wiring insulation could lead to smoke and fire due to arcing. Two recent major air accidents and hundreds of major incidents over the past twenty years have resulted in increased awareness in health monitoring and sustainment of wiring, especially for aging aircraft. This paper discusses computer models of electrical wires which can be used for developing systems and test procedures that could lead to identification of this type of fault within the shielding and dielectric material used for conductor insulation. Computer models of the cables are investigated with simulated Time Domain Reflectometry type test procedure in order to resolve detection of small fault in insulation.
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Session 16
SESSION 16
UT PHASED ARRAYS I
Robert Addison, Jr., Chairperson
Salons A-C

8:30 AM Compensation for Beam Deflection in Ultrasonic Phased Array Imaging of Defects in Weld Metals
---Y. Ohara, Y. Shintaku, S. Horinouchi, M. Hashimoto, and K. Yamanaka, Tohoku University, Department of Materials Processing, Sendai, Miyagi, Japan

8:50 AM The Ultrasonic Measurement of Crystallographic Orientation for Imaging Anisotropic Components with 2D Arrays
---C. J. L. Lane and A. K. Dunhill, Rolls-Royce plc, NDE Laboratory, Bristol, United Kingdom; B. W. Drinkwater and P. D. Wilcox, University of Bristol, Department of Mechanical Engineering, Bristol, United Kingdom

9:10 AM Development of a Twin Crystal Membrane Coupled Conformable Phased Array
---J. Russell, Rolls-Royce plc, Derby, United Kingdom; R. Long and P. Cawley, Imperial College, Mechanical Engineering, London, United Kingdom

9:30 AM Variable Split Aperture Processing of Full Matrix Capture Phased Array Data
---R. Long and P. Cawley, Imperial College, Mechanical Engineering, London, United Kingdom; J. Russell, Rolls-Royce plc, Derby, United Kingdom

9:50 AM Finite Element Analysis of Ultrasonic Phased Array Inspections on Anisotropic Welds
---G. Harvey, Weidlinger Associates, 141 St. James Road, Glasgow, G4 0LT, United Kingdom; A. Tweedie, ALBA Ultrasound, West of Scotland Science Park, Todd Campus, Glasgow, G20 0XA, United Kingdom; P. Reynolds, Weidlinger Associates, 399 West El Camino Real, Mountain View, CA 94040-2607

10:10 AM Break

10:30 AM Imaging of Defects with Ultrasonic Arrays in Non Canonical Geometries
---P. Calmon, S. Robert, S. Bannouf, O. Casula, and S. Chatillon, CEA LIST, Gif-sur-Yvette, France

10:50 AM Defects Characterization Using Two-Dimensional Arrays
---A. Velichko and P. D. Wilcox, University of Bristol, Department of Mechanical Engineering, University Walk, Queens Building, Bristol, United Kingdom

11:10 AM Comparison of the Inspections of Smooth and Rough Crack-Like Defects Using Ultrasonic Arrays
---J. Zhang, B. W. Drinkwater, and P. D. Wilcox, University of Bristol, Department of Mechanical Engineering, University Walk, Bristol, BS8 1TR, United Kingdom

11:30 AM A Study on Flaw Sizing Methods Using Phased Array Ultrasound

11:50 AM Designing a Calibrated Full Matrix Capture Based Inspection
---D. Duxbury and M. J. S. Lowe, Imperial College, Mechanical Engineering, London, United Kingdom; J. Russell, Rolls-Royce plc, Derby, United Kingdom

12:10 PM Lunch
Compensation for Beam Deflection in Ultrasonic Phased Array Imaging of Defects in Weld Metals
---Y. Ohara, Y. Shintaku, S. Horinouchi, M. Hashimoto, and K. Yamanaka, Tohoku University, Department of Materials Processing, Sendai, Miyagi, Japan

---Ultrasonic phased array (PA) is applied to the inspection of weld metal in atomic power plants. However, the beam is deflected because of the strong anisotropy. This leads to poor signal-to-noise ratio (S/N) and errors. Although analyses of the anisotropy have been numerically conducted, quantitative experimental verification and incorporation to PA system are not easy because of complicated modeling and long computing time. To simulate and compensate the beam deflection in PA, we propose a simple model using analytical solutions of anisotropic group velocities. In experiment, we imaged slits in weld metal of Ni-based alloy (Inconel 600) by conventional PA using the delay lay assuming an isotropic velocity. The slit end was imaged with depth errors of less than 1 mm. However, it was laterally shifted from true position by more than 3 mm, which increased with propagation distance. In addition, the slit end images were split when the array sensor crossed the weld line. To reproduce this result, we simulated scattered waves using the group velocity and the distance between each array element and slit ends, where the group velocity was calculated as a function of the angle between crystal Z-axis and wave vector based on the Christoffel equation using reported elastic constants of similar weld metal. Then we simulated PA images using the above waves and the same delay law as in the experiment. As a result, the lateral shift and the split of slit images were reproduced by assuming an inclined single crystal model, and symmetrically inclined two-crystal model, respectively. Furthermore, by incorporating the anisotropic group velocity into the delay law, we succeeded in compensating the beam deflection and obtaining correct slit images. Relation between the role of phase and group velocities were investigated both by analytical solution and by FDTD simulation. The compensation method will improve the inspection of weld metals for the safety of atomic power plants.

The Ultrasonic Measurement of Crystallographic Orientation for Imaging Anisotropic Components with 2D Arrays
---C. J. L. Lane and A. K. Dunhill, Rolls-Royce plc, NDE Laboratory, Bristol, United Kingdom; B. W. Drinkwater and P. D. Wilcox, University of Bristol, Department of Mechanical Engineering, Bristol, United Kingdom

---Single crystal components are used widely in the gas-turbine industry for the excellent mechanical properties these materials exhibit at elevated temperatures. These components however are elastically anisotropic which causes difficulties when performing NDE inspections with ultrasound. Recently an ultrasonic algorithm for a 2D array has been corrected to perform the reliable volumetric inspection of single crystals. For the algorithm to be implemented the crystallographic orientation of the components must be known. It would be advantageous to use the same ultrasonic array to measure the orientation as to perform the inspection for potential defects. This paper, therefore, develops and reviews crystallographic orientation methods using 2D ultrasonic arrays. The methods under examination are based on the anisotropic propagation of surface and bulk waves. An image-based orientation method is also considered. This image-based method requires the reconstruction of a large number of images from collected data, which is computationally very demanding. Therefore, a more efficient frequency domain algorithm is also corrected for imaging anisotropic components to increase the speed of the orientation and inspection process.
Development of a Twin Crystal Membrane Coupled Conformable Phased Array
---Jonathan Russell, Rolls-Royce plc, Derby, United Kingdom; Robert Long and Peter Cawley, Imperial College, Mechanical Engineering, London, United Kingdom

---The inspection of welded austenitic stainless steel components commonly found in the nuclear industry can be challenging. Austenitic welds contain an anisotropic, inhomogeneous grain structure which causes attenuation, scattering and beam bending. These effects reduce the defect detection and sizing capability of any ultrasonic inspection technique. The inspection of components where the weld cap has not been removed is even more difficult due to the irregularity of the surface geometry. A membrane coupled conformable phased array device containing a linear array transducer has previously been produced. This device couples the ultrasonic energy into the component under test via a water path encapsulated by a low loss membrane. A twin crystal membrane coupled device has now been produced containing two linear phased arrays positioned adjacent to one another within the same housing. The delay laws for each array can be electronically controlled to steer and focus the ultrasonic energy. The arrays are angled relative to one another so that the transducer provides a pseudo-focusing effect at a depth corresponding to the beam crossing point. This type of design is used to improve the signal to noise ratio of the defect response in comparison to simple linear phased array transducer designs. An enhanced inspection system has also been developed that allows the rapid acquisition and processing of scanned full matrix capture (FMC) inspection data using both the linear and twin crystal membrane coupled devices. Experimental results obtained from the through weld inspection of an austenitic stainless steel component with an undressed weld cap in place will be presented. These results demonstrate that small lack of side wall fusion defects can be reliably detected in large complex structures.

Variable Split Aperture Processing of Full Matrix Capture Phased Array Data
---Robert Long and Peter Cawley, Imperial College, Mechanical Engineering, London, United Kingdom; Jonathan Russell, Rolls-Royce plc, Derby, United Kingdom

---For phased array inspections of defects lying on the fusion face of a thick walled welded pipe often we would like to use focused waves reflected and mode converted at the inner surface of the pipe. When displaying predictions or experimental results, for inspections where the transmit and return legs of the wave propagation differ, we notice that the location of the reflection from the defect within the Bscan image is inconsistent and is dependent on the depth of focus chosen from which the delay laws are derived. A solution to this anomaly is to collect data as Full Matrix Capture (FMC) and apply a processing technique that allows focusing to be ideal for every pixel within the Bscan image. Further improvements to the Bscan image can be made by having a split aperture that varies as a function of focal depth. This paper illustrates the anomaly of the wandering image of the reflection from the defect, introduces the FMC principle, and describes the signal processing algorithms for variable split aperture processing. The inspections were also modeled using the CEA CIVA software which was compared to experimental result.
**Finite Element Analysis of Ultrasonic Phased Array Inspections on Anisotropic Welds**

---Gerry Harvey, Weidlinger Associates, 141 St. James Road, Glasgow, G4 0LT, United Kingdom; Andrew Tweedie, ALBA Ultrasound, West of Scotland Science Park, Todd Campus, Glasgow, G20 0XA, United Kingdom; **Paul Reynolds**, Weidlinger Associates, 399 West El Camino Real, Mountain View, CA 94040-2607; C. Carpentier, NDT Technology Group, The Welding Institute Limited, Cambridge, United Kingdom

---This paper describes a theoretical investigation into the behavior of anisotropic welds under phased array inspection procedures using a 128 element linear array. Two advanced inspection techniques are simulated, and their suitability compared. A finite element (FE) model, configured in PZFlex, is used to represent both the variations in crystal orientation found in a typical anisotropic weld, and also the linear array configuration. Firstly, through transmission spectra of the weld are used to determine the optimum operating frequency and configuration of the array in order to detect a 3mm SDH in the weld. Next, the Full Matrix Capture (FMC) technique is simulated, and an image of the weld constructed using the Total Focussing Method (TFM). This is accomplished by transmitting on each element sequentially, while receiving on the remaining 127 elements. This approach provides spatial averaging over the weld area, reducing the distortion caused by the anisotropic media. Finally, Time Reversal Acoustic (TRA) methods were employed to coherently focus the array at the defect and compensate for the elemental timing variations caused by the complex medium. Results illustrate the potential for inspecting anisotropic welds when using correctly designed arrays and implementing novel inspection procedures.

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**Imaging of Defects with Ultrasonic Arrays in Non Canonical Geometries**

---Pierre Calmon, Sebastien Robert, Souad Bannouf, Olivier Casula, and Sylvain Chatillon, CEA LIST, Gif-sur-Yvette, France

---Since several years, advanced array techniques going beyond the classical “phased-array” applications and based on the acquisition and processing of per-channel signals have been proposed and shown to be very promising in terms of detection and defect characterization. In this communication, we present various applications of such techniques to the inspection of parts presenting non canonical geometries. The inspections are performed either in immersion (water-coupled) or in contact with flexible matrix arrays. Flexible probes, in addition to optimizing the coupling between the part and the transducers, allow a measurement of the local surface profile thanks to an embedded profilometer. In the case of immersed array the surface profile is obtained by processing ultrasonic surface echoes. The surface profile is an input of the processing of received signals making possible the imaging of defect in 3D view of the inspected part. The algorithms consist essentially in coherent summation of signals (synthetic focusing) and time of flight inverse matching. At this stage the imaging is performed off line in CIVA software. The techniques are evaluated and discussed on both simulated and experimental data.
Defects Characterization Using Two-Dimensional Arrays
---Alexander Velichko and Paul D. Wilcox, University of Bristol, Dept. of Mechanical Engineering, University Walk, Queens Building, Bristol, United Kingdom

---The use of ultrasonic arrays for non-destructive evaluation provides great flexibility, as one array probe allows a given defect to be illuminated from a wide range of angles, and hence is capable of extracting significant information about the defect. Each defect can be characterized by its far-field scattering coefficient matrix. In the case of an array with a finite-sized aperture, only part of the scattering matrix can be captured and the accuracy of defect characterization depends on the amount of data in the scattering matrix that can be reconstructed. However, the fundamental challenge associated with 2D arrays is due to the number of elements required to produce an aperture of sufficient size to allow adequate defect characterization. In this paper the quantitative comparison of 2D arrays with different element layouts is performed. Results are shown that illustrate the imaging performance of a conventional 11x11 matrix 3MHz array and a 128-element 3MHz array with optimized geometry on model and experimental data. A technique for the scattering matrix extraction from the raw 2D array data is also presented. The approach is based on the reversibility of the imaging algorithm. The method is tested on experimental data for characterization of various volumetric defects.

Comparison of the Inspections of Smooth and Rough Crack-Like Defects Using Ultrasonic Arrays
---Jie Zhang, Bruce W. Drinkwater, and Paul D. Wilcox, Department of Mechanical Engineering, University Walk, University of Bristol, Bristol BS8 1TR, UK

---The use of ultrasonic arrays to detect crack-like defects is an important area in non-destructive evaluation. The array data, which contains scattered ultrasonic waves from a scatterer, can be used to reconstruct a high resolution image, for example, using the total focusing method (TFM). In this paper, the TFM images from smooth and rough crack-like defects are compared. A hybrid model is used to predict the array data and demonstrate the inspection ability of the TFM to detect and size both smooth and rough crack-like defects. This hybrid model combines far field scattering coefficient matrices with a ray-based wave propagation model. Far field scattering coefficient matrices of smooth crack-like defects are calculated using an analytical model. For a rough crack-like defect, far field scattering coefficient matrices are computed using both a FE model and a Kirchhoff model. Comparing images from smooth and rough crack-like defects, it is shown that roughness can be either beneficial or detrimental to the detectability of crack-like defects, depending on a number of factors such as the defect roughness, length, orientation, and the inspection configuration. Extraction of surface information of a rough crack-like defect, such as surface roughness and correlation length is also discussed.
A Study on Flaw Sizing Methods Using Phased Array Ultrasound
---Hun-Hee Kim, Sung-Jin Song, and Hak-Joon Kim, Sungkyunkwan University, School of Mechanical Engineering, Suwon, Gyeonggi-do, Korea; Un-Hak Seong, Joon Soo Park, and Byung-Ha Chi, Doosan Heavy Industries and Construction Co., Advanced Process Development Team, Changwon, Gyeongnam, Korea

Flaw sizing is one of fundamental issues in ultrasonic nondestructive evaluation of various materials, components and structures. Especially, for cracks, accurate sizing is very crucial for reliable structural integrity evaluation. Therefore, robust and reliable flaw sizing methods are strongly needed. To address such a need, investigation of flaw sizing methods, using phased array ultrasonic testing will be performed. Because ultrasonic testing methods are widely adopted in various field applications, especially, nuclear plants. For that purpose, specimen with EDM notches were fabricated using the specimen, performance of the flaw sizing methods including amplitude based methods and time of flight based methods will be investigated. Thus, in this paper, principal of flaw sizing methods using PAUT will describe briefly and performance of the methods will be presented.

Designing a Calibrated Full Matrix Capture Based Inspection
---David Duxbury and Michael J.S. Lowe, Imperial College, Mechanical Engineering, London, United Kingdom; Jonathan Russell, Rolls-Royce plc, Derby, United Kingdom

---Full Matrix Capture (FMC) technology is becoming increasingly attractive to industry. The development of FMC based inspection techniques is an active area of research, offering benefits in terms of defect detection and sizing and increased flexibility. However, before his technology can be fully transferred into industry there must be a method of reliably and robustly selecting the most appropriate inspection technique. A suitable calibration procedure must also be developed. A Huygens based array beam model has been developed and validated against CIVA in a number of test cases. The model has been used as a tool to quickly allow beam visualization using the same delay laws as those used to process data, thus allowing the optimum beams for defect detection and sizing to be selected during inspection planning. A method of calibration is also presented that uses an automatic Distance Amplitude Correction (DAC) algorithm that allows DAC curves to be extracted from a single scan of a calibration block for any beam type. The calibration algorithm is also used to set inspection sensitivity. This paper demonstrates through the use of a case study how a fully calibrated FMC based inspection can be designed, using the array beam model, to detect and accurately size a defect using multiple beam types.
Session 17
SESSION 17  
**NDE FOR MICROSTRUCTURE**  
David Olson and Angelique Lasseigne, Co-Chairpersons  
Salon D  

8:30 AM  
Assessment of Microstructure in Grade T22 Alloy Steel by the Combination of Two Nondestructive Tools and Practice Simultaneously  
---P. Kiattisaksri, S. Meir, J. C. Madeni, S. Liu, B. Mishra, and D. L. Olson, Department of Metallurgical and Materials Engineering, Colorado School of Mines, Golden, CO 80401  

8:50 AM  
A Fundamental Analysis of Low Frequency Impedance Phenomenon: Application to Hydrogen Content Assessment of Coated Linepipe Steel Weldments  

9:10 AM  
Assessment of Steel Microstructure Evolution During Thermal Treatment by Magnetic and Electronic Techniques  
---S. Meir, D. L. Olson, B. Mishra, S. Liu, K. Coleman, and R. Hellner, Colorado School of Mines, Materials Engineering Department, Golden, CO 80401; 2EPRI, Charlotte, NC; 3XCEL Energy, 1653 Table Mt. Drive, Golden, CO 80401  

9:30 AM  
Advanced Non-Destructive Assessment Technology to Determine the Aging of Silicon Containing Materials for Generation IV Nuclear Reactor  

9:50 AM  
Nondestructive Evaluation of Ni-Ti Shape Memory Alloy  
---S. Meir, S. Gordon, M. Karsh, R. Ayers, and D. L. Olson, Colorado School of Mines, Department of Metallurgical and Materials Engineering, Golden, CO 80401  

10:10 AM  
Break  

10:30 AM  
Electrochemical Characterization of a Low Modulus Ti-35.5Nb-7.37r-5.7Ta Alloy in a Simulated Body Fluid Using EIS for Biomedical Applications  
---R. Bhola, S. M. Bhola, B. Mishra, and D. L. Olson, Colorado School of Mines, Department of Metallurgical and Materials Engineering, Golden, CO 80401  

10:50 AM  
Submerged Eddy Current Method of Hydrogen Content Evaluation of Zircaloy-4 Fuel Cladding  

11:10 AM  
Assessment of Corrosion Under Alternating Current on Supermartensitic Stainless Steel in Artificial Sea Water  
---T. Reyes, S. Bhola, D. L. Olson, and B. Mishra, Colorado School of Mines, Department of Metallurgical and Materials Engineering, Golden, CO 80401  

11:30 AM  
Opportunities for Advanced NDE for Materials State Awareness, Rapid Assessments and Prediction of Service Life in Boiler Power Generating Systems  
---R. Hellner, J. E. Jackson, and D. L. Olson, XCEL Energy Corporation, Golden, CO 80401; 2Generation 2 Materials Technology, Denver, CO 80208; 3Colorado School of Mines, Golden, CO 80401  

11:50 AM  
Microstructural Characterization and Residual Stress Assessment for Improved Pipeline Steel Integrity  
---J. E. Jackson and A. Lasseigne, Colorado School of Mines, Department of Metallurgical and Materials Engineering, 1500 Illinois Street, Golden, CO 80401  

12:10 PM  
Lunch
Assessment of Microstructure in Grade T22 Alloy Steel by the Combination of Two Nondestructive Tools and Practice Simultaneously

---P. Kiattisaksri, S. Meir, J. C. Madeni, S. Liu, B. Mishra, and D. L. Olson, Department of Metallurgical and Materials Engineering, Colorado School of Mines, Golden, CO 80401

---Power generating plants have used T22 steel containing 2-Cr-1Mo for boiler tube and piping. This steel offers long time service performance. It is important to be able to assess the remaining service life. In this investigation, low frequency impedance measurements with ultrasonic wave have been used together to evaluate the precipitation of carbides and characterize the different microstructures on the basis of cooling rate and aging time. The purpose of this study is to investigate the possibility of combining two wave physical property nondestructive techniques for assessing microstructure evolution and to evaluate that their simultaneous use will result in an enhanced signal to characterize their microstructural features and changes.

A Fundamental Analysis of Low Frequency Impedance Phenomenon: Application to Hydrogen Content Assessment of Coated Linepipe Steel Weldments

---K. Koenig1, A. Lasseigne2, J. Jackson2, D. L. Olson1, and B. Mishra1, 1Colorado School of Mines, Golden, CO 80401; 2Generation 2 Materials Technology, LLC, Denver, CO 80210

---Linepipe steels are more susceptible to hydrogen damage as the strength of the steel increases. Only a few parts per million of hydrogen in the high strength steel could result in detrimental hydrogen damage. A hydrogen tolerance limit has not been determined for the higher strength linepipe steels and the effect of service life makes it even more difficult to predict a single hydrogen content tolerance limit. It is essential to have a nondestructive means to monitor hydrogen content in high strength linepipe steels and weldments over the life of the linepipe to prevent significant damage or failure. A nondestructive hydrogen content sensor for field measurements must be able to operate through the linepipe structural coating, which means non-contact and nondestructive technology must be utilized. Low frequency impedance measurements provide an effective non-contact method to determine hydrogen content through a linepipe coating. Low frequency impedance measurements have been correlated to hydrogen content in steel weldments both in the laboratory and in the field. The development of a real-time, nondestructive, non-contact, in-field hydrogen sensor utilizing low frequency impedance is described. A unique theoretical physics corollary to QED is presented to explain the low frequency impedance measurement phenomenon.
Assessment of Steel Microstructure Evolution During Thermal Treatment by Magnetic and Electronic Techniques
---S. Meir¹, D. L. Olson¹, B. Mishra¹, S. Liu¹, K. Coleman², and R. Hellner³, ¹Colorado School of Mines, Materials Engineering Department, Golden, CO 80401; ²EPRI, Charlotte, NC; ³XCEL Energy, 4653 Table Mt. Drive, Golden, CO 80401

---Structural steels experience aging from fatigue, creep, corrosion, and their combinations. High temperature service advances creep and stress-corrosion cracking. Degradation with creep is one of the most serious issues determining the structural integrity of the high-temperature parts in power plants. For instance, fossil plants have been in operation for such long durations that the critical components have exceeded the design life, as they have experienced progressive damage over time. For this assessment, a nondestructive technique allowing the evaluation of the state of the materials and the prediction of their remaining life has been required for a long time. Advanced nondestructive wave assessment techniques and practices are being developed using elastic, electronic and magnetic wave perturbations analysis. These methods are being applied to ferrous materials to determine whether a designed heat treatment creates an acceptable microstructure for a specific set of required microstructures and properties for full service life of the component.

Advanced Non-Destructive Assessment Technology to Determine the Aging of Silicon Containing Materials for Generation IV Nuclear Reactor
---T. Koenig¹, S. Lawrence¹, A. Martin¹, C. Mejia¹, J. L. Fletcher¹, L. Gerstenberger¹, J. King¹, B. Mishra¹, D. L. Olson¹, M. Meyer², R. Kennedy², J. Cole², Lin-Wen Hu³, and G. Kohse³, ¹Colorado School of Mines, Golden, CO 80210; ²Idaho National Laboratory, Idaho Falls, ID; ³Massachusetts Institute of Technology, Cambridge, MA 02142

---The next generation nuclear reactor will require higher operating temperatures and the increased use of high temperature structural materials in the reactor core. There is a need for nondestructive assessment tools to assess irradiation damage in nuclear structural materials, especially for in-situ monitoring of the aging of the reactor core materials. Many potential sensory materials are silicon-based, such as SiC, Si₃N₄, and possibly Sialons, that have a semiconductor or non-stoichiometric ionic structure (excess oxygen or metal ions) which, when damaged, will cause measurable changes in their electronic concentrations. The philosophy for use of these electronic property sensors (high-frequency impedance and Hall coefficient), elastic property (ultrasonic) sensors, and gamma spectroscopy measurements, is to assess accumulated radiation damage in materials. By using these sensors in combination with a knowledge base of structurally damaged materials it is possible to establish a calibrated sensor for a given nuclear reactor core material. The specimens were prepared and irradiated at the MIT reactor by the ATR program and evaluated at the Colorado School of Mines. Results are presented and their interpretation suggests silicon carbide as a promising sensor material.
Nondestructive Evaluation of Ni-Ti Shape Memory Alloy
---S. Meir, S. Gordon, M. Karsh, R. Ayers, and D. L. Olson, Colorado School of Mines, Department of Metallurgical and Materials Engineering, Golden, CO 80401

---Ni-Ti (nitinol) and its ternary alloys are known for their pseudoelasticity and shape memory properties in addition to their superior biocompatibility which makes them widely used as a biomaterials and as a material for thermal actuators. Over the years only few attempts for nondestructive evaluation of the properties of nitinol alloys have been attempted. The aim of this work is to use low frequency impedance measurements as a new method for microstructural characterization of Ti-50.8%Ni alloy, this characterization will help in determining the martensite transformation temperatures (Ms) which is directly affected by the material microstructure and phase composition. Two analytical approaches were perused in this work. Assessment of the microstructure of the alloy as a function of heat treatment, and secondly, an attempt to evaluate a friction stir welding of nitinol, which involves thermo-mechanical processing of the alloy, the results are reported and interpretations will be presented.

Electrochemical Characterization of a Low Modulus Ti-35.5Nb-7.3Zr-5.7Ta Alloy in a Simulated Body Fluid Using EIS for Biomedical Applications
---R. Bhola1, S. M. Bhola1, B. Mishra1, R. A. Ayers1, and D. L. Olson1, 1Department of Metallurgical and Materials Engineering, Colorado School of Mines, 1500 Illinois Street, Golden, CO 80401

---Electrochemical characterization of the low modulus Ti-35.5Nb-7.3Zr-5.7Ta beta alloy (TNZT) has been performed in phosphate buffer saline solution at 37 °C using the non-destructive electrochemical impedance spectroscopy technique. Measurements were performed at various immersion intervals at the open circuit potential (OCP), which was also monitored with time. Results obtained for TNZT alloy have been compared with those for the commercially used Ti-6Al-4V mixed alloy (Ti64) and the commercially pure titanium (Ti2) alpha alloy. Potentiodynamic polarization was performed to supplement the data obtained from EIS analysis. The TNZT alloy exhibits a two time constant impedance response, whereas the Ti64 and Ti2 alloys display a one-time constant behavior. Human fetal osteoblast cells show a better adhesion and a higher cell count for the TNZT alloy compared to the other two alloys. The present investigation is an effort to understand the correlation between the electrochemical, morphological and cellular characteristics of titanium alloys to qualify them for implant applications.
Submerged Eddy Current Method of Hydrogen Content Evaluation of Zircaloy-4 Fuel Cladding
---E. A. Pfeif1, A. N. Lasseigne2, K. Koenig1, K. Krzywosz2, E. V. Mader3, S. Yagnik3, B. Mishra1, and D. L. Olson1, 1Colorado School of Mines, Golden, CO 80401; 2Generation 2 Materials Technology LLC, Firestone, CO 80504; 3Energy Power Research Institute, Palo Alto, CA 94304-1344
---Submerged eddy current testing of zircaloy-4 fuel cladding has been developed as a method for characterizing the evolution of hydrogen in zircaloy-4 fuel cladding in spent fuel pools. The parameters associated with storage in spent fuel pools must be incorporated and accounted for within the hydrogen content measurements. A focus on the effects of water, adjacent fuel rods, and temperature must be incorporated to achieve accurate hydrogen measurements. The use of submerged eddy current measurements to identify hydrogen content and hydride phases present in zircaloy-4 fuel cladding will be presented.

Assessment of Corrosion Under Alternating Current on Supermartensitic Stainless Steel in Artificial Sea Water
---T. Reyes, S. Bhola, D. L. Olson, and B. Mishra, Colorado School of Mines, Department of Metallurgical and Materials Engineering, Golden, CO 80401
--- Corrosion due to alternating current occurs when between a metal and an electrolyte an alternating current is conducted. The cycles of the current produce cyclic changes in the polarity of the electrode. The half cell reactions that occur during this cyclic polarization have different accumulative effects. For instance, the anodic half cycle when the current is anodic can lead to corrosion or pitting whereas the cathodic half cycle can lead to hydrogen charging. The presence of alternating current is accompanied by magnetic fields and depending on the physical configuration of the system the intensity and influence of the field can be significant. For a metal electrode placed in the center of a coiling coil, it has been observed that the open circuit potential becomes more negative when alternating current passes through the coil. EIS has been used as a tool to understand effect of the magnetic fields induced by alternating currents on corrosion. The equivalent circuit fits have been used to interpret the phenomena occurring at the metal-electrolyte interface. Polarization curves have been obtained under different induced magnetic fields, that is under different intensities of currents passing through the coil. The polarization curves reveal differences in open circuit potential, limiting currents, changes in slopes and pitting region. The analysis and discussion of these results are complemented with EIS at the potentials where these differences in behavior are observed.
Opportunities for Advanced QNDE for Materials State Awareness, Rapid Assessments and Prediction of Service Life in Boiler Power Generating Systems
---R. Hellner1, J. E. Jackson2, and D. L. Olson3; 1Xcel Energy Corporation, Golden, CO 80401; 2Generation 2 Materials Technology, Denver, CO 80208; 3Colorado School of Mines, Golden, CO 80401

--- The electric power generating industries rely on the long service life of components experiencing high temperatures and pressures. Component materials are subjected to both thermal and stress cycles resulting in potential corrosion, fatigue and creep damage. These systems have design lives of twenty to forty years, but have been extended up to fifty years. Unplanned outages are very expensive and are mitigated with executed planned maintenance, condition assessment and inspections.

Revolutionary methodologies, based on leading edge science and technology, needs; (1) to inspect in-situ during service conditions; such as high temperature and corrosive environments, (2) to increase significantly the inspection speed, positioning, data acquisition, interpretation rate and remaining service life prediction, (3) to increase the measurement accuracy, (4) to establish a protocol for the QNDE team; including system operator, inspector, assessor and repair personal to obtain full value of the required information. Combining on-line monitoring technology with advanced NDE methodologies to increase inspection intervals thus reduce condition assessment costs would be beneficial. This paper will identify some of the opportunities where revolutionary advancements requiring scientific and technological break troughs can achieve significant contributions to structural integrity and data accuracy and inspection efficiency.

Microstructural Characterization and Residual Stress Assessment for Improved Pipeline Steel Integrity
---Joshua E. Jackson and Angelique N. Lasseigne, Colorado School of Mines, Department of Metallurgical and Materials Engineering, 1500 Illinois Street, Golden, CO 80401

---Residual stress is a crucial determining factor in the service life of pipeline materials and can be exhibited in three different forms: (type I) macrostresses that are homogeneous across the bulk metal, (type II) homogeneous stresses across single grains or phases like polycrystalline stresses, and (type III) inter-domain stresses such as those around dislocations or defects. Premature failures are often related to residual stress, which can promote hydrogen-induced cracking, stress corrosion cracking, fatigue damage, and other failures modes. Existing practices for nondestructive assessment of pipeline residual stress do not provide consistent and quantitative results. Preliminary research to develop a nondestructive probe that measures (from outside the pipe and through coatings) the residual stress of varied specimen geometry and stress modes with greater sensitivity and flexibility than currently available tools will be described.
Session 18
SESSION 18
THERMOGRAPHY AND THERMOSONICS I
Xiaoyan Han, Chairperson
Salon E

8:30 AM  Quantitative Infrared Full-Area Imaging of Coating Thickness and Integrity
          ---H. I. Ringermacher, D. R. Howard, and B. Knight, General Electric Global Research Center,
           Schenectady, NY 12309

8:50 AM  Difference Thermography for Improved Flaw Characterization
          ---W. P. Winfree, J. Zalameda, and P. A. Howell, NASA Langley Research Center, Hampton,
           VA 23681

9:10 AM  Thermography Inspection for Detection and Tracking of Composite Cylinder Damage During
          Load Testing
          ---J. N. Zalameda, W. P. Winfree, and P. H. Johnston, NASA Langley Research Center, MS 231,
           Hampton, VA 23681; J. P. Seebo, Lockheed Martin Corporation, MS 231, Hampton, VA 23681

9:30 AM  Development of Calibration Defects for Determining Acoustic Thermography Testing
          Parameters for Part Inspection
          ---I. Doran and F. Ruhge, Siemens Energy, NDE Technologies, Orlando, FL 32826

9:50 AM  Studying Impact Damage of Carbon-Fiber Reinforced Aircraft Composite Panels with
          SonicIR
          ---X. Han, D. Zhang, Q. He, Y. Song, and A. Lubowicki, Wayne State University, Department of
           Electrical and Computer Engineering, Detroit, MI 48202; X. Zhao and G. Newaz, Wayne State
           University, Department of Mechanical Engineering, Detroit, MI 48202; L. D. Favro and R. L.
           Thomas, Wayne State University, Department of Physics and Astronomy, Detroit, MI 48202

10:10 AM  Break

10:30 AM  Characterization of Piezoelectric Stack Actuators for Vibrothermography
          ---G. Vaddi, R. Reusser, and S. D. Holland, Iowa State University, Center for NDE, 1915 Scholl
           Road, Ames, IA 50011

10:50 AM  The Effects of Crack Opening and Coatings on the Detection Capability of Thermosonics
          ---B. Weekes and P. Cawley, Imperial College, Mechanical Engineering, London, United Kingdom;
           D. P. Almond, University of Bath, Engineering & Applied Science, Bath, United Kingdom

11:10 AM  Thermographic Quality Assurance of Turbine Hot Section Components
          ---S. M. Shepard, J. R. Lhota, and T. Ahmed, Thermal Wave Imaging, Inc., 845 Livernois,
           Ferndale, MI 48220

11:30 AM  Crack Imaging by Pulsed Laser Spot and Pulsed Laser Line Thermography
          ---T. Li, B. Weekes, D. P. Almond, and A. S. Rees, University of Bath, Department of Mechanical
           Engineering, Bath, United Kingdom; S. Burrows and S. Dixon, University of Warwick, Department
           of Physics, Coventry, United Kingdom

11:50 AM  Crack Detection Using Pulsed Eddy Current Stimulated Thermography
          ---E. Kostson, B. Weekes, and D. P. Almond, University of Bath, Department of Mechanical
           Engineering, Research Centre in NDE, BA2 7AY, United Kingdom; J. W. Wilson and G. Y. Tian,
           University of Newcastle upon Tyne, School of Electrical, Electronic and Computer Engineering,
           Newcastle NE1 7RX, United Kingdom

12:10 PM  Lunch
Quantitative Infrared Full-Area Imaging of Coating Thickness and Integrity
---Harry I. Ringermacher, Donald R. Howard, and Bryon Knight, General Electric Global Research Center, Schenectady, NY 12309

--- Infrared Imaging of coatings is not new. In the past it has been accomplished either comparatively, for example using additional thickness standards, as a point-wise inspection or as a simple non-quantitative image showing debonds at most. In the present paper we describe the first quantitative infrared image of both coating thickness and integrity. No reference standard is necessary. This coating thickness imaging can be applied over 100% area of complex-shape components such as airfoils. It is fast and a by-product of this inspection is an image of coating integrity which may be graded from complete disbond to poorly-coupled, for example, indications of porosity at the bondline. We will present a first quantitative coating thickness IR image.

Difference Thermography for Improved Flaw Characterization
---William P. Winfree, Joseph Zalameda, and Patricia A. Howell, NASA Langley Research Center, Hampton, VA 23681

--- Flaw detection and characterization with single sided thermographic techniques in graphite polymer composites are often limited by localized variations in the thermographic response. Variations in material properties such as porosity, variations in fiber volume content and surface polymer thickness can cause significant variations in the thermal response. These variations result in a “noise” floor that increases the difficulty of detecting and characterizing flaws. A method is presented for reducing data acquired before and after a change in state in the composite. The initial time images are registered with an affine transform. The difference between thermal responses is calculated from the aligned responses. A theoretical response of the difference is shown to agree well with the measured difference response. This method for reducing the data is shown to give a considerable improvement characterizing both the size and depth of damage. Examples are shown for data acquire before and after a change in stress state and impact damage.
Thermography Inspection for Detection and Tracking of Composite Cylinder Damage During Load Testing
---Joseph N. Zalameda, William P. Winfree, and Patrick H. Johnston, NASA Langley Research Center, MS 231, Hampton, VA 23681; Jeffrey P. Seebo, Lockheed Martin Corporation, MS 231, Hampton, VA 23681

---Advanced composite test articles are commonly tested under controlled loading. Understanding the initiation and progression of composite damage under load is critical for validating design concepts and structural analysis tools. Thermal nondestructive evaluation (NDE) has been shown to be an effective technique for detecting damage in composites during load testing. The combination of two thermography techniques, passive and active, are used to detect the initiation and progression of damage in a composite cylinder during cyclic loading. The passive thermography technique detects and tracks damage progression in real time as torsion loading is applied. A principal component analysis reduction of passive thermography data is shown to enhance visualization of the damage. In addition, an active flash thermography technique is also used to detect and track damage progression. The flash thermography technique utilizes an embedded flash tube within the cylinder. This allows for thermography of the tube while it is under load. A differential thermography processing technique is applied to remove thermal variations not associated with defects. It has been found that application of a directional torsion load during the flash inspection improves the sensitivity to and sizing of defects. Lastly, the thermography results were compared to non-immersion ultrasonic inspection results.

Development of Calibration Defects for Determining Acoustic Thermography Testing Parameters for Part Inspection
---Ian Doran and Forrest Ruhge, SIEMENS ENERGY, NDE Technologies, Orlando, FL 32826

---Acoustic thermography is a developing nondestructive testing technique which exploits the thermal response of crack-like discontinuities when subjected to an ultrasonic stimulus. To date there is no cost effective calibration defect that can be used to assess the proper acoustic thermography testing parameters for the inspection of parts. Currently, part testing parameters are determined using either adhesive strips applied onto parts or service cracks in parts. Adhesive strips serve as poor calibration defects as they do not reproduce crack-like signals and require the use of a transfer function. Defects (service cracks) on service parts are challenging to obtain since safety standards require parts to be rejected long before cracks develop. This paper outlines the development – fabrication, attachment, and in-situ use – of a cost effective and versatile calibration defect for use in the acoustic thermography parameter selection process. The calibration defects display crack-like thermal signatures superior to those of adhesive strips. The calibration defects can be applied to any location on any part, eliminating the need to find appropriate in-service parts. These defects are expected to provide a reliable assessment of the parameters under which acoustic thermography can detect a given crack in the region of the calibration defect.
Studying Impact Damage on Carbon-Fiber Reinforced Aircraft Composite Panels With SonicIR
---Xiaoyan Han, Ding Zhang, Qi He, Yuyang Song, and Anthony Lubowicki, Wayne State University, Department of Electrical and Computer Engineering, Detroit, MI 48202; Xinyue Zhao and Golam Newaz, Wayne State University, Department of Mechanical Engineering, Detroit, MI 48202; Lawrence D. Favro and Robert L. Thomas, Wayne State University, Department of Physics and Astronomy, Detroit, MI 48202

---Composites are becoming more important materials in commercial aircraft structures such as the fuselage and wings with the new B787, Dreamliner from Boeing which has the target to utilize 50% by weight of composite materials. Carbon-fiber reinforced composite is the composite material of choice in aircraft structures. This is due to their light weight and high strength (high strength-to-weight ratio), high specific stiffness, tailorability of properties, design flexibility etc. Especially, by reducing the aircraft's body weight by using such lighter structures, the cost of fuel can be greatly reduced with the high jet fuel price for commercial airlines. However, these composites are prone to impact damage and damage may occur without any observable sign on the surface resulting in delaminations and disbonds which may occur well within the layers. We are studying the impact problem with carbon-fiber reinforced composite panels and developing SonicIR for this application as a fast and wide-area NDE technology. In this paper, we will present our results in carbon-fiber reinforced composite materials, including quantitative studies on delamination type defect depth identification in the panels.

Characterization of Piezoelectric Stack Actuators for Vibrothermography
---Gyani Vaddi, Ricky Reusser, and Stephen D. Holland, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---Vibrothermography, also known as Sonic IR and thermosonics, is an NDE technique for finding cracks and flaws based on vibration-induced frictional rubbing of unbonded surfaces. The vibration is usually generated by a piezoelectric stack actuator which transducers electrical energy into large amplitude mechanical vibrations. The amplitude and impedance transfer characteristics of the transducer system control the vibration of the sample. Within a linear contact (no tip chatter) model, the interaction between the transducer system and the specimen can be characterized using the theory of linear time-invariant (LTI) systems and electro-mechanical Thevenin equivalence. We present quantitative measurements of the performance of piezoelectric stack actuators in a vibrothermography excitation system. We investigate the effect of actuator performance and specimen characteristics on the induced vibration in the specimen, and relate this to the performance of the vibrothermography inspection as a whole.---This material is based upon work supported by Thermal Wave Imaging, Inc. under an STTR contract by the US Navy (Federal Agency) and performed at the Center for Nondestructive Evaluation at Iowa State University.
The Effects of Crack Opening and Coatings on the Detection Capability of Thermosonics
---Benjamin Weekes and Peter Cawley, Imperial College, Mechanical Engineering, London, United Kingdom; Daryl P. Almond, University of Bath, Engineering & Applied Science, Bath, United Kingdom

---Thermosonics (also known as sonic IR, vibrothermography) is a full field thermal method capable of rapidly detecting surface breaking defects in metals. The inspected part is excited with high power ultrasound causing defects to generate heat by fretting of defect faces, imaged by a thermal camera. The excitation is chaotic and non-repeatable, necessitating a normalization procedure to directly compare thermosonic inspections. Earlier work at Imperial College had shown that it is possible to estimate the 'thermosonic efficiency' of a defect by measuring the heat generated for a given vibration input. The effect of crack opening was investigated by putting beam samples with fatigue cracks into 3-point loading. The crack opening was set optically by measuring the distance between micro-hardness indenters either side of the crack. The results show heat generation moves toward the crack tips as crack opening increases, with no heat generated at the middle of the crack beyond a critical crack opening. Thermosonic detectability is observed to at first increase with crack opening, then reduce with further crack opening. In the second study, a coating system of Inconel with a metallic bond coat (MCrAlY) and ceramic thermal barrier coating (YSZ) is considered. Thermosonic inspection was performed before and after the application of each coating, and benchmarked against alternative conventional and thermal NDE techniques.

Thermographic Quality Assurance of Turbine Hot Section Components
---Steven M. Shepard, James R. Lhota, and Tasdiq Ahmed, Thermal Wave Imaging, Inc., 845 Livernois, Ferndale, MI 48220

---At present, inspection of turbine blades and vanes during manufacture requires an array of techniques performed serially. These techniques range from in sophistication from radiography and neutron radiography to wire insertion and water flow. Various approaches to thermography, e.g. flash, vibro and passive observation of flow tests have been successfully demonstrated as alternatives to conventional inspection methods. While some thermographic inspections have been successfully implemented (e.g. TBC adhesion, casting wall thickness, crack detection), others are less mature, e.g. detection of blockages in internal passages and cooling holes. We have recently demonstrated a thermographic method for detection of blockages that is an attractive alternative to the laborious process of manual pin/wire or borescope testing. An entire blade can be inspected in seconds, and inspection can be performed in tandem with other blade inspection (e.g. wall thickness, crack detection).
Crack Imaging by Pulsed Laser Spot and Pulsed Laser Line Thermography
---Teng Li, Ben Weekes, Darryl P. Almond, and Andrew S. Rees, University of Bath, Department of Mechanical Engineering, Bath, United Kingdom; Sue Burrows and Steve Dixon, University of Warwick, Department of Physics, Coventry, United Kingdom

---Pulsed laser spot heating thermography has been shown experimentally and by modeling to have a sensitivity adequate to detect surface cracks a few mm in length with openings of as little as a micrometer. An image processing technique has been developed that generates crack images that are comparable to those obtained by dye penetrant inspection. The raster scanning rate of the technique has been significantly increased by converting the laser spot heat source to a line heat source ~ 15 mm in length. Modeling results and crack images obtained experimentally by the new technique will be presented and compared with those obtained using a laser spot heat source. The laser spot thermal imaging process has been found to be enhanced by a black body like effect where crack openings exceed a few micrometers. Results of this effect obtained by both laser beam scanning and test-piece raster scanning will be presented.

Crack Detection Using Pulsed Eddy Current Stimulated Thermography
---Erik Kostson, Ben Weekes, and Darryl P. Almond, University of Bath, Department of Mechanical Engineering, Research Centre in NDE, Bath BA2 7AY, United Kingdom; John W. Wilson and Gui Y. Tian, University of Newcastle upon Tyne, School of Electrical, Electronic and Computer Engineering, Newcastle NE1 7RX, United Kingdom

---Thermographic imaging with eddy current excitation is an NDT&E technique that offers a fast way for the inspection of defects over large areas. This contribution presents results from studies investigating factors that influence the detection of surface breaking cracks. The effect of crack orientation with respect to induced eddy current flow direction in both magnetic and non-magnetic metals has been investigated. It has been found that crack detection is far more sensitive to crack orientation in non-magnetic metals than in magnetic metals. The possibility of detecting surface cracks under coatings has also been studied. Results will be presented comparing crack images obtained prior and after coating a turbine blade alloy with a metallic MCrAlY bond coat and a ceramic thermal barrier coating.
Session 19
SESSION 19
PROBABILITY OF DETECTION
Eric A. Lindgren and Jeremy S. Knopp, Co-Chairpersons
Salons F-H

8:30 AM  Probability of Detection of Surface Defects in Metals Using Optical Inspection Techniques
---M. Rauhut, M. Spies, and K. Taubner, Fraunhofer Institute for Industrial Mathematics ITWM, Image Processing Department, Fraunhofer-Platz 1, 67663 Kaiserslautern, Germany

8:50 AM  Investigation of Parameters Affecting Crack Detection in Bolt Hole Eddy Current
---P. R. Underhill and T. W. Krause, Royal Military College of Canada, Department of Physics, P. O. Box 17000, Station Forces, Kingston, Ontario, K7K 7B4, Canada

9:10 AM  Nonparametric POD Estimation for Hit/Miss Data: A Goodness of Fit Comparison for Parametric Models
---F. W. Spencer, SFHire, 13812 Haines Avenue NE, Albuquerque, NM 87112-4924

9:30 AM  Recent Advances in Modeling Discontinuities in Anisotropic and Heterogeneous Materials in Eddy Current NDE
---H. A. Sabbagh, R. K. Murphy, and E. H. Sabbagh, Victor Technologies, LLC, Bloomington, IN 47407-7706; J. C. Aldrin, Computational Tools, Gurnee, IL 60031

9:50 AM  Early Work on the Use of Models in the Determination of POD/Inspection Reliability in the UK
---R. B. Thompson, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

10:10 AM  Break

10:30 AM  Physical Model Assisted Probability of Detection in Nondestructive Evaluation
---M. Li and W. Q. Meeker, Iowa State University, Center for NDE and Department of Statistics, Ames, IA 50011; R. B. Thompson, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

10:50 AM  Progress in Validation of Model-Assisted Estimation of Probability of Detection
---D. S. Forsyth, Texas Research Institute Austin, NDE Division, Austin, TX; J. C. Aldrin, Computational Tools, Gurnee, IL 60031; I. J. Gray, NDE Technologies, Charlottesville, VA; F. W. Spencer, SFHire, Albuquerque, NM 87112-4924

11:10 AM  Evaluation of NDE Techniques Based on POD Simulation
---F. Jenson and E. Iakovleva, CEA, LIST, Gif-sur-Yvette, F-91191, France; N. Dominguez, European Aeronautic Defence and Space Company (EADS), Innovation Works Department, Toulouse, France

11:30 AM  Case Study for Model-Assisted Probabilistic Reliability Assessment for Structural Health Monitoring Systems
---J. C. Aldrin, Computational Tools, Gurnee, IL 60031; E. A. Medina, E. A. Lindgren, C. Buynak, and J. S. Knopp, U.S. Air Force Research Laboratory, Wright-Patterson AFB, OH 45433

11:50 AM  Future Potential Directions for Research in Probability of Detection: Uncertainty, Extreme Values, and Metrics for Damage Characterization
---E. A. Lindgren and J. S. Knopp, Nondestructive Evaluation Branch, Materials and Manufacturing Directorate, Air Force Research Laboratory, Wright-Patterson AFB, OH 45433

12:10 PM  Lunch
Probability of Detection of Surface Defects in Metals Using Optical Inspection Techniques
---Markus Rauhut, Martin Spies, and Kai Taeubner, Fraunhofer Institute for Industrial Mathematics ITWM, Image Processing Department, Fraunhofer-Platz 1, 67663 Kaiserslautern, Germany

---The quality of industrial products is in many cases directly linked to the quality of their surfaces. For products such as metallic seals or aero engine blades the integrity of the surfaces has to be checked in order to ensure the intended performance of the respective component. Aside from the classical NDE techniques for surface inspection optical methods gain increasing importance, especially in view of automated quality control procedures. Optical inspection systems operate without contact and offer various possibilities for online defect detection and classification. Depending on the quality of the lighting and (video) camera system different resolutions with respect to the detectable defect size can be achieved. In order to quantitatively evaluate different systems used for on-site inspections, we have performed an a versus a-analysis to determine the Probability of Detection (POD) for planar specimens with boreholes and notches of different dimensions and orientations. Following the international standard according to MIL-HDBK-1823 in the 2007 update version we have determined POD-curves using the digitized and algorithmically processed data. We show that the application of more complex sensor technology and algorithms correspondingly leads to improvement of the POD. This supports the use of optical surface inspection techniques for quantitative NDE in the field of automated quality control of e.g. stampings or in production lines of steel sheets. Further valuable aspects are the objectiveness in view of quality criteria and the reduction of the human factor.

Investigation of Parameters Affecting Crack Detection in Bolt Hole Eddy Current
---P. R. Underhill and T. W. Krause, Royal Military College of Canada, Department of Physics, P. O. Box 17000, Station Forces, Kingston, Ontario, K7K 7B4, Canada

---Damage tolerant design of aircraft requires the periodic inspection of a very large number of rivet/bolt holes. In this study, the parameters affecting the sensitivity of bolt hole eddy current to fatigue cracks in aluminum aircraft structures have been investigated. The best operating conditions were found to occur at the highest frequencies used (1.6 MHz). The results have been used to optimize C-scan measurements in rivet holes. C-scan has advantages for better flaw detectability and fewer false calls because flaws have a unique signature which, for very small cracks, depends on the size of the probe coils and not the flaw size. The signature for mid bore cracks is different from corner cracks. These unique signatures open up the possibility of improved automatic flaw detection. A C-scan based probability of detection study on corner cracks in 4.6 mm (0.182 inch) diameter holes in 7075-T6 aluminum has given an a90/95 of 0.22 mm (0.009 inch). An adapter for the RA2000 rotating probe to allow easy acquisition of C-scan data has been built and tested on the horizontal stabilizer of a Hercules aircraft. Results from real in-service flaws are also presented.
Nonparametric POD Estimation for Hit/Miss Data: A Goodness of Fit Comparison for Parametric Models
---Floyd W. Spencer, SFHire, 13812 Haines Avenue NE, Albuquerque, NM 87112-4924

---The purpose of this paper is to present an estimate of the probability of detection curve based on hit/miss data without reference to a parametric function or model. The estimate is based on maximum likelihood estimation making the sole assumption that the probability of detection curve is a monotonic increasing function. With only the monotonic increasing assumption there is not a unique curve fitting the data, but rather the estimation provides probability of detection values only at those flaw sizes included in the data set. The calculations required for the estimated probabilities of detection are simple and rapid. The nonparametric estimates are similar in nature to binomial methods that have been proposed, but have the advantage that arbitrary assumptions concerning how to aggregate data are not forced upon the analyst. Rather, the data determines the grouping in accordance with the monotonic increasing criteria. It is further proposed that the nonparametric fit along with confidence bounds, can be used to provide a goodness of fit comparison for parametric models. The process and concepts are illustrated using several POD data sets that have been discussed in the open literature.

Recent Advances in Modeling Discontinuities in Anisotropic and Heterogeneous Materials in Eddy-Current NDE
---Harold A. Sabbagh, R. Kim Murphy, and Elias H. Sabbagh, Victor Technologies, LLC, Bloomington, IN 47407-7706; John C. Aldrin, Computational Tools, Gurnee, IL 60031

---In order to handle problems of random anisotropies that arise in certain materials, such as Ti64 or ferritic steels, we have enhanced our proprietary eddy-current code, VIC-3D(c), by adding two models for generating such material properties. The first allows random permutations of the nonrandom principal conductivities, and the second assigns random values to the principal axes conductivities, generated with either a uniform or Gaussian probability density function. This capability will allow us to simulate randomly distributed and correlated patches of grains. We will demonstrate both features with forward and inverse problems, and also apply the code to a model of anisotropic Ti64 when excited by a racetrack coil. Agreement between VIC-3D(c) model calculations and experimental data in titanium specimens with known flaws will be demonstrated.
Early Work on the Use of Models in the Determination of POD/Inspection Reliability in the UK
---R. Bruce Thompson, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---Early demonstrations of the use of models in the U.S. and U.K. to assist in the determination of inspection reliability and probability of detection (POD) will be reviewed. The historical context is the development of fracture mechanics in the 1960's and its incorporation in the 1970's in structural integrity strategies such as damage tolerance. Damage tolerance demanded a quantification of the effectiveness of inspection techniques in terms of what sizes of cracks could be reliably detected or might be missed. Examples will be taken from the aerospace and nuclear industries. The USAF adopted POD as the primary metric for the effectiveness of an inspection and developed/implemented empirical procedures for determining that metric. Unfortunately, those showed that inspection performance in the field was not what was desired and one response was the use of physics-based inspection models to better understand the flaw detection process. In parallel, a series of round robin trials in Europe raised issues with the effectiveness of the inspections used in nuclear power plants, and the resulting concerns became an important part of the “Public Inquiry” in the UK regarding the construction of the Sizewell B power plant. The Central Electricity Generating Board played a key role in developing the technical case for the adequacy of the inspection, and physics-based models of the inspection process played a central role. Both probabilistic and deterministic “worst case” arguments were developed. In this paper, this background will be reviewed and examples given of the early uses of models to develop solutions. The philosophies that were employed will be compared to those being used today in this area of growing interest.

Physical Model Assisted Probability of Detection in Nondestructive Evaluation
---Ming Li and William Q. Meeker, Iowa State University, Center for NDE and Department of Statistics, Ames, IA 50011; R. Bruce Thompson, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

--- Nondestructive evaluation is used widely in many engineering and industrial areas to detect defects or flaws such as cracks inside parts or structures during manufacturing or for products in service. The standard statistical model is a simple empirical linear regression between the (possibly transformed) signal response variables and the (possibly transformed) explanatory variables. For some applications, such a simple empirical approach is inadequate. An important alternative approach is to use knowledge of the physics of the inspection process to provide information about the underlying relationship between the response and explanatory variables. Use of such knowledge can greatly increase the power and accuracy of the statistical analysis and enable, when needed, proper extrapolation outside the range of the observed explanatory variables. This paper describes a set of physical model-assisted analyses to study the capability of two different ultrasonic testing inspection methods to detect synthetic hard alpha inclusion and flat-bottom hole defects in a titanium forging disk.---This material is based upon work supported by the Federal Aviation Administration under Contract Number DTFAC-08-C-00005 and performed at Iowa State University’s Center for NDE.
Progress in Validation of Model-Assisted Estimation of Probability of Detection
---David S. Forsyth, Texas Research Institute
Austin, NDE Division, Austin, TX; John C. Aldrin, Computational Tools, Guerne, IL; Irving J. Gray, NDE Technologies, Charlottesville, VA; Floyd W. Spencer, SFHire, Albuquerque, NM 87112-4924

---The use of models of NDT system response for the estimation of probability of detection (POD) has been proposed for some time. The most recent version of the United States Air Force MIL-HDBK-1823a includes model-assisted POD (MAPOD) as one potential method for POD estimation. The authors are working on a USAF-sponsored program to demonstrate the MAPOD process for practical ultrasonic inspections for fatigue cracks in aircraft structures. In this paper, we discuss two key elements of the program. First we discuss the development and validation of ultrasonic inspection models for the domain of interest. A new semi-analytical model based on the method of images is being developed for use on this class of problems. The method and validation results are presented. Second, we discuss the development of statistical approaches to MAPOD estimation analogous to the current approaches to empirical POD estimation. Issues of interest include combining empirical and model data, confidence bound estimation, range of validity.

Evaluation of NDE Techniques Based on POD Simulation
---F. Jenson and E. Iakovleva, CEA, LIST, Gif-sur-Yvette, F-91191, France; N. Dominguez, European Aeronautic Defence and Space Company (EADS), Innovation Works Dept., Toulouse, France

---Structure reliability guaranty requires initial evaluation of non destructive testing methods. The concept of Probability of Detection (POD) is generally used to obtain performances and reliability of testing operations quantitatively. Such probabilistic approaches take into account the uncertainties that appear during inspections and that are responsible for the output variability. Usually, the determination of the POD curve requires a costly and time consuming process that is based on statistical analysis of inspection data obtained during dedicated round robin programs. That is why cost reduction of POD campaigns is a major issue nowadays. A new trend is to apply simulation in the context of probabilistic approaches in order to replace some of the experimental data required to determine the POD with simulation results. This paper describes such methodologies that were adopted and implemented in the software CIVA. Applications of the methodology to UT and ECT inspections are also described.
Case Study for Model-Assisted Probabilistic Reliability Assessment for Structural Health Monitoring Systems
---John C. Aldrin, Computational Tools, Gurnee, IL 60031; Enrique A. Medina, Eric A. Lindgren, Charles Buynak, and Jeremy S. Knopp, U.S. Air Force Research Laboratory, Wright-Patterson AFB, OH 45433

---Before structural health monitoring (SHM) systems can be implemented to support aircraft condition-based maintenance strategies, it is necessary for the performance of these systems to be validated in terms of their sensitivity with respect to the variables that they intend to monitor, their robustness with respect to benign changes in their operating environment, and their reliability over their expected useful life. This paper describes progress on the development of a protocol and presents a case study for model-assisted probabilistic reliability assessment methodology. A simulation-based study for an SHM system incorporating vibration methods is first introduced to demonstrate the protocol process. Initial protocol steps emphasize the importance of assessing the key application characteristics and evaluating the important factors that control performance and reliability. For the simulated study, an approximate parametric model was created to represent an aircraft joint subject to cracking damage including varying temperature and fastener stiffness / contact conditions. To perform the stochastic numerical model evaluation, the probabilistic collocation method was used for efficiently sample the numerical model and propagate input parameter variability. Probability of detection and probability of correct characterization curves were generated for different transducer locations. Through this study, key insight was achieved on sensor placement, and expected detection and characterization performance. Lastly, the design and progress of an experimental demonstration study is presented highlighting protocol feasibility and remaining challenges.

Future Potential Directions for Research in Probability of Detection: Uncertainty, Extreme Values, and Metrics for Damage Characterization
---Eric A. Lindgren and Jeremy S. Knopp, Nondestructive Evaluation Branch, Materials and Manufacturing Directorate, Air Force Research Laboratory, Wright-Patterson AFB, OH 45433

---Recent activities performed by the Nondestructive Evaluation (NDE) Branch of the Materials and Manufacturing Directorate in the area of Probability of Detection (POD) resulted in the publication of the revised MIL HDBK 1823A, which included the use of modeling to assist in the determination of POD for different modeling methods. The feasibility of this approach for eddy current inspection of aircraft like structures was demonstrated and reported in previous QNDE presentations and current efforts are underway to demonstrate it for ultrasonic techniques. Subsequent directions in research in the area of POD need to address lingering and emerging issues. One aspect is propagation of uncertainty, especially when incorporating model-assisted methods. Another open area is the analysis of the tails of the POD curve, especially in the region where there is a very small chance of missing a large flaw. In addition, as mentioned last year, these parameters will need to be extended into multi-dimensional analysis space to address the quantitative parameters required for quantitative assessment of the location and size of damage. This presentation describes the overall approach pursued by the NDE Branch to address these needs and the research topics being explored to realize these objectives.
Session 20
Phased Array Imaging Using Subtraction of Nonlinear Ultrasonic Responses at Different External Loads
--- Y. Ohara, S. Horinouchi, Y. Shintaku, M. Hashimoto, and K. Yamanaka, Tohoku University, Department of Materials Processing, Sendai, Miyagi, Japan

Array Imaging of Noisy Materials
--- P. D. Wilcox, University of Bristol, Department of Mechanical Engineering, Queens Building, University Walk, Bristol, BS8 1TR, United Kingdom

Method to Simplify the Beamforming Process of Multi-Element Synthetic Aperture
--- C. J. Martin, O. Martinez-Graullera, D. Romero, M. Perez, and L. G. Ullate, Centro de Acustica Aplicada y Evaluacion No Destructiva (UPM-CSIC), Madrid, Spain

Simulation-Based Optimization of the Design and Settings of Ultrasonic Phased-Array Transducers with an Evolutionary Algorithm
--- P. Puel, S. Chatillon, and P. Calmon, CEA, LIST, Departement Imagerie et Simulation pour le Controle, F-91191, Gif-sur-Yvette, France; D. Lesselier, Departement de Recherche en Electromagnetisme, Laboratoire des Signaux et Systemes (UMR 8506, CNRS-Supelec-Univ. Paris Sud 11), 3 rue Joliot-Curie, 91192 Gif-sur-Yvette, Cedex, France

A Technique for Imaging with Virtual Array of Sources (TIVAS) for Improved Imaging in Thick Structures
--- S. Alavudeen, K. Balasubramaniam, and C. V. Krishnamurthy, Indian Institute of Technology Madras, Center for Non Destructive Evaluation, Department of Mechanical Engineering, Chennai, Tamil Nadu, India

Break

Pulse-Echo Phased Array Ultrasonic Inspection of Pultruded Rod Stitched Efficient Unitized Structure (PRSEUS)
--- P. H. Johnston, NASA Langley Research Center, Nondestructive Evaluation Sciences Branch, Hampton, VA 23681

The Application of Phased Array Ultrasonic Techniques for Inspection of Railway Axles from their End Face
--- D. Liaptsis, J. Jian, K. Boyle, M. Weston, and P. I. Nicholson, TWI Ltd., NDT Validation Centre Wales, Port Talbot, Margam, United Kingdom; J. A. Courinha, P. Barros, and M. Pinto, Instituto de Soldadura e Qualidade (ISQ), Portugal

UT Phased Array Inspection of Turbine Components: Experiments and Simulation
--- B. Issenmann, G. Rougeron, and S. Mahaut, CEA, LIST, F-91191, Gif-sur-Yvette, France; S. Laborde, Alstom Power Service, Steam Turbine R&D Department, La Courneuve, France
Phased Array Imaging Using Subtraction of Nonlinear Ultrasonic Responses at Different External Loads
---Y. Ohara, S. Horinouchi, Y. Shintaku, M. Hashimoto, and K. Yamanaka, Tohoku University, Department of Materials Processing, Sendai, Miyagi, Japan

---Nonlinear ultrasound has been expected as a most promising means to detect closed cracks. Among them, subharmonic phased array for crack evaluation (SPACE)[1-3] proposed by the authors has a unique capability of selectively imaging open and closed parts. Thus far, its performance has been demonstrated in closed fatigue and stress corrosion cracks. However, strong linear scatterers such as coarse grains, weld defects and back surfaces, are sometimes visualized in subharmonic images as a leak of the filter, since short-burst waves are used to obtain high temporal resolution. This artifact might degrade the performance of SPACE to identify closed cracks. To solve this problem, we propose an extension of SPACE as well as another approach using subtraction of responses at different external loads. By applying external static or dynamic loads to closed cracks, the contact state in the cracks varies, resulting in the change in the responses at the cracks. On the other hand, the linear scatterers other than cracks are not influenced by the external loads. Therefore, only the cracks can be extracted by subtraction of responses at different loads. In this study, we performed its fundamental experiments in a closed fatigue crack formed in an aluminum alloy A7075 specimen. Here we utilized static-load dependence of SPACE images and dynamic-load dependence of linear phased array images. As a result, we demonstrated that this method can extract only the variance in the responses at the closed cracks, with canceling the responses of other than cracks.

Array Imaging of Noisy Materials
---Paul D. Wilcox, University of Bristol, Department of Mechanical Engineering, Queens Building, University Walk, Bristol, BS8 1TR, United Kingdom

---The detection sensitivity of most ultrasonic NDE configurations, including array imaging, is limited by coherent noise due to microstructural scattering. In this paper, the single scattering model developed by Iowa State is extended to array imaging. The model is used to explain how different array imaging parameters, such as the choice of algorithm and array aperture size, affect the background noise level in an array image. These are quantitatively compared to experimental data obtained on various samples of noisy material. The effect of frequency and the limits of the single scattering model examined are also investigated. An automatic procedure for optimising the processing parameters is proposed. This is demonstrated using a commercial 5 MHz array on copper sample containing a side-drilled hole (SDH). Before optimization, even the back-wall of the sample is below the coherent noise floor. After optimization a signal to noise ratio of more than 40 dB is obtained for the SDH. Finally, the implications for non-linear imaging methods, such as frequency-compounding, are discussed.
Method to Simplify the Beamforming Process of Multi-Element Synthetic Aperture

---Carlos J. Martin, Oscar Martinez-Graullera, David Romero, Manuel Perez, and Luis G. Ullate, Centro de Acustica Aplicada y Evaluacion No Destructiva (UPM-CSIC), Madrid, Spain

---Multi-element synthetic aperture methods, where a subaperture is composed by one element in emission and a set of elements in reception, have been proposed as a suitable way of reducing the cost and size of complex ultrasonic imaging systems. Moreover, they achieve better signal to noise ratio (SNR) than conventional synthetic aperture techniques, approaching to the phased array performance. However, they still have some problems due to the great amount of signals involved in the dynamic focusing process, which increase as the number (n) of elements of the receiving subaperture becomes larger. In this work, a new multi-element synthetic aperture method is presented in combination with a data reduction algorithm that reduces the number of signals to those that compose the minimum redundance co-array. The method, called nR-SAFT, simplifies the beamforming process by directly adding in phase all the signals contributing to each element of the co-array (signals with same spatial frequency). This operation can be made by means of a no-time consuming specific hardware. By this method, a data reduction of approximately 2/n of the data intervening in the beamforming process is attained. Consequently, an acceleration of the beamforming process and an increase of the frame rate are achieved. This method has the advantage of controlling large arrays with simple imaging systems, with good SNR and high frame rate. The compromise between the subaperture size and the focal distance is pointed out in the paper. Finally, simulated and experimental result images are presented.

Simulation-Based Optimization of the Design and Settings of Ultrasonic Phased-Array Transducers with an Evolutionary Algorithm

---P. Puel, S. Chatillon, and P. Calmon, CEA, LIST, Département Imagerie et Simulation pour le Contrôle, F-91191, Gif-sur-Yvette, France; D. Lesselier, Département de Recherche en Electromagnétisme, Laboratoire des Signaux et Systèmes (UMR8506, CNRS-Supélec-Univ. Paris Sud 11), 3 rue Joliot-Curie, 91192 Gif-sur-Yvette, Cedex, France

---The design of an ultrasonic array and its settings for a specific inspection involves multiple parameters and is in general the result of a compromise between different requirements and limitations. In general, to ensure satisfying performances in terms of detection of the researched defects requires parametric studies involving multiple influential parameters. Such studies are often based on simulation but may be somehow delicate and fastidious. In this communication, we present an automatic optimization tool for the inspection parameters (designing, positioning and/or setting the transducer) based on the research of optimal solutions by an evolutionary algorithm applied on simulated data. More specifically, a hybrid differential evolution (DE) algorithm has been adapted to NDT applications, extended to solve constrained multi-objective problems and linked with forward modeling algorithms implemented in the ultrasonic module of CIVA. We describe the algorithm and present and discuss results obtained with this optimization tool on various examples of applications.
A Technique for Imaging With Virtual Array of Sources (Tivas) for Improved Imaging in Thick Structures
---S. Alavudeen, Krishnan Balasubramaniam, and C.V. Krishnamurthy, Center for Non Destructive Evaluation, Dept of Mechanical Engineering, Indian Institute of Technology Madras, Chennai, Tamil Nadu, India

---Phased array ultrasound has emerged as a rapid imaging technique in biomedical and non-destructive evaluation applications due to its flexibility in varying the angle of interrogation and/or focusing of the beam to the point of interest through electronic means reducing the need to move the probe physically and at the same time increasing the inspection volume. Since phased array beam generation is based on constructive interference of beams from individual elements, maximum depth to which focusing is possible is limited to near field distance of the active aperture. A new phased array inspection technique, called Technique for Imaging using Virtual Array of Sources (TIVAS), has been proposed in this work to inspect deeper locations with improved resolution without any additional hardware requirements. Inspection problem involving imaging of two side drilled holes (SDH) of 1.5 mm diameter and center to center separation of 2.5 mm in Aluminum using 5 MHz 16 X 128 element phased array system is chosen to demonstrate the capabilities of TIVAS. The SDH pair is located at depth of 60 mm (more than 3 times near field depth of a 16 element phased array). The imaging was performed using three techniques; conventional focusing technique, single element based scanning and synthetic reconstruction and TIVAS. A numerical model based on finite difference time domain (FDTD) technique is used for the simulation of phased array inspection. The imaging problem was simulated first, and then experiments were conducted. Effect of focal depth in performance of TIVAS is studied using a semi-analytical calculation and FDTD method. The simulation results as well as experimental results reveals that TIVAS can image defects at deeper locations with good resolution and improved SNR. Entirely program driven and without any additional hardware requirements, TIVAS offers an enlarged scope for array based imaging.
The Application of Phased Array Ultrasonic Techniques for Inspection of Railway Axles from Their End Face
---D. Liaptsis, J. Jian, K. Boyle, M. Weston and P. I. Nicholson, TWI Ltd, NDT Validation Centre Wales, Port Talbot, Margam, United Kingdom; J. A. Courinha, Pedro Barros, and M. Pinto, Instituto de Soldadura e Qualidade (ISQ), Portugal

---The structural integrity of wheel sets used in rolling stock is of great importance to the rail industry and its customers. A number of rail accidents have been directly related to the failure of wheels and axles, leading to increased demands for the inspection and maintenance of such components. However, the current methods of inspection based on conventional ultrasonic inspection and magnetic particles inspection necessitate the partial or full disassembly of the wheel sets in order to gain access to the inspection area. This adds to the down time of the wagon being inspected. This paper presents the initial study of the development of a phased array ultrasonic inspection system for inspection of railway axles and details the inspection of the axles from their end face. The advantage of inspecting from the end face is the ability to deploy the phased array technique in situ without the need to disassemble the wheel set. End face inspections are presented including different pulse echo and pitch-catch techniques. Results are presented and compared with a series of modelling studies undertaken using CIVA ultrasonic modelling software. The ultrasonic simulation results have shown a good agreement with the experimental results obtained during this study.

UT Phased Array Inspection of Turbines Components: Experiments and Simulation
---Bruno Issenmann, Gilles Rougeron, and Steve Mahaut, CEA, LIST, F-91191, Gif-sur-Yvette, France; Stephane Laborde, Alstom Power Service, Steam Turbine R&D Department, La Courneuve, France

---The ultrasonic inspection of turbines components like rotors and blades has to overcome drastic constraints due to very limited areas - typically, the gaps between successive blades are very small - and gives rise to multiple echoes due to echoes scattered by the complex shape of rotor and blade attachments. Potential flaws to be detected may emerge from attachments, and echoes scattered by such cracks are very close to geometrical boundaries echoes. In order to help the interpretation and the optimization of such inspection, Alstom Power Service and CEA-LIST have carried out collaborative works to develop simulation tools along with experimental validations. The UT models developed in the CIVA platform have been extended in order to take into account of multiple echoes, due to reflexion of the elastic wave over the flaw and the boundaries, as well as geometrical echoes and shadowing effects. This paper presents some experimental validation of the recently developed simulation tools over canonical specimen as well as representative mock-ups from Alstom Power Service, containing artificial flaws, inspected using UT phased arrays performing sectorial scanning. The different echoes are analyzed and discussed, as well as qualitative and quantitative agreement between simulations and experiments.
Session 21
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<th>Authors</th>
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<td>1:30 PM</td>
<td>Fundamental Limits of Active Thermography</td>
<td>R. S. Reusser and S. D. Holland, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011</td>
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<td>1:50 PM</td>
<td>Quantitative Three-Dimensional Imaging by Thermal Tomography Method</td>
<td>J. Sun, Argonne National Laboratory, 9700 South Cass Avenue, Argonne, IL 60439</td>
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<td>2:10 PM</td>
<td>Approaches to Large Area Inspection Using Thermographic Signal Reconstruction</td>
<td>S. M. Shepard, J. R. Lhota, and T. Ahmed, Thermal Wave Imaging, Inc., 845 Livernois, Ferndale, MI 48220</td>
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Fundamental Limits of Active Thermography
---Ricky S. Reusser and Stephen D. Holland, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

Active thermography is an NDE technique that uses the flow of heat resulting from energy input to find flaws, material properties, and internal discontinuities. Probing deeply is difficult because of the diffusive nature of heat. This presentation focuses on fundamental limits of active thermography methods that rely on direct thermal excitation. The excitation may be a pulse or flash, a step, or even cyclic or swept-frequency heating. All of these techniques probe the same physics and are subject to the same fundamental limits imposed by infrared camera sensitivity and convective losses. We discuss these limits in the context of different forms of excitation, and how they impact the penetration depth and detection capability of each method. This material is based on work supported by the Army Research Laboratory as part of cooperative agreement number W911NF0820036 at the Center for Nondestructive Evaluation at Iowa State University.

Quantitative Three-Dimensional Imaging by Thermal Tomography Method
---Jiangang Sun, Argonne National Laboratory, 9700 South Cass Avenue, Argonne, IL 60439

Pulsed thermal imaging has been widely used for nondestructive evaluation of engineering materials. There are however a number of problems that limit the capabilities of this technology. First, thermal imaging measures a surface temperature that is difficult to be determined accurately. Second, current data-processing methods intended for property measurement are mostly based on mathematical models that are only related to gross material properties such as thickness-averaged thermal diffusivity or sample thickness (or defect depth). These models cannot account for material property variations within the sample volume. On the other hand, data-processing methods intended for internal-flaw detection are usually not suitable for inspection of complex material systems. In addition to these fundamental issues, a prior knowledge for some parameters of the tested material is normally required in order to perform data processing with an appropriate model and to interpret result. These problems can all be addressed by a recently-developed thermal tomography method. It utilizes the one-sided flash thermal-imaging data to construct three-dimensional data of material's thermal effusivity in the entire sample volume. This presentation will discuss the capabilities of and typical experimental results obtained by the thermal tomography method.
Approaches to Large Area Inspection Using Thermographic Signal Reconstruction
---Steven M. Shepard, James R. Lhota, and Tasdiq Ahmed, Thermal Wave Imaging, Inc., 845 Livernois, Ferndale, MI 48220

---Flash thermography has become a widely accepted inspection methodology for both manufacturing and in-service applications. Modern thermographic NDT systems rely on advanced in signal processing method, such as Thermographic Signal Reconstruction (TSR), to achieve sensitivity and depth range performance that significantly exceeds visual image analysis. Commercial flash thermography systems are currently capable of precise measurement of thermophysical properties, as well automated quality control and defect recognition. However, these systems typically rely on high performance (low noise, high frame-rate) IR cameras as well as high energy flash equipment that is capable of delivering truncated rectangular pulses. For some applications, e.g. where large areas of an in-service aircraft must be inspected, a flash system may not be a practical solution, due to factors including cost, physical footprint and electrical power requirements. In these cases, it may be necessary to consider alternative approaches to excitation, as well as less sensitive uncooled cameras. It is possible to apply the TSR method to great advantage in these situations, although some different considerations do apply. We will present several alternative approaches to large area inspection using the TSR method as the basis for data processing and interpretation.

Laser Thermography for Quantitative Crack Characterization
---Joachim Schlichting, Guram N. Kervalishvili, Christiane Maierhofer, and Marc Kreutzbruck BAM Federal Institute for Materials Research and Testing, Acoustical and Electromagnetic Methods, Berlin, Germany

---Active thermography is a nowadays widely used NDT method exploiting thermal material properties for defect detection. Basically the sample is heated and the resulting surface temperature is recorded by an IR camera. For laser thermography a laser is used to locally heat the sample. The resulting spherical heat flow starting at different positions at the surface allows the detection of voids in arbitrary orientations. Today's standard procedure for laser thermography is the so called flying spot thermography, where a moving laser spot is used for qualitative detection of surface cracks. In this work a method is presented, which is suitable for the quantitative characterization of depth and angle of surface cracks. The main idea is to evaluate the crack-caused asymmetries of the resulting temperature distribution in the vicinity of a laser spot. The heat is introduced at several fixed reference-positions in regard to the crack. By investigating artificial test specimens with spark eroded notches, this method's feasibility in principle is validated. The experimental work was accomplished using a setup based on a diode laser equipped with scanning optics and an InSb IR camera. Furthermore we systematically studied the influences of geometrical parameters by using FEM simulations.
Session 22
1:30 PM  Material State Prognosis Through the Identification of Material Parameters Used in Thermo-Mechanical Constitutive Models  
---K. A. Nayak, K. Balasubramaniam, and C. V. Krishnamurthy, Indian Institute of Technology Madras, Center for Nondestructive Evaluation and Department of Mechanical Engineering, Chennai, Tamil Nadu, India

1:50 PM  Microstructure Characterization and Imaging of Fine-Grained Steel by Microscopic Ultrasonic Techniques  
---S. Hirsekorn and U. Rabe, Fraunhofer-Institut IZFP, NDT Fundamentals, Saarbruecken, Germany

2:10 PM  Nonlinearity Effects in Eddy Current Signals for Surface Characterization of Ferrous Materials  
---N. Nakagawa and C. C. H. Lo, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA  50011

2:30 PM  Evolution of Recrystallization of Changes in Magnetic Hysteresis Loop in a Non-Oriented Electric Steel Cold Rolled  
---F. E. Silva, F. N. C. Freitas, H. F. G. Abreu, L. L. Goncalves, and E. P. Moura, Universidade Federal do Ceara, Departamento de Engenharia, Metalurgica e de Materials, Fortaleza, Ceara, Brazil; M. R. Silva, Universidade Federal de Itajuba, Departamento de Fisica e Quimica, Itajuba, Minas Gerais, Brazil

2:50 PM  Multi-Parametric Approach for Assessment of Aging in Heat Treated M250 Grade Maraging Steel  
---T. Jayakumar, V. Adurthi, B. P. C. Rao, K. V. Rajkumar, and B. Raj, Indira Gandhi Centre for Atomic Research, Non Destructive Evaluation Division, Metallurgy and Materials Group, Kalpakkam, Tamil Nadu, 603 102, India

3:10 PM  Break

3:30 PM  Methods for the In-Situ Characterization of Cast Austenitic Stainless Steel Microstructures  
---P. Ramuhalli, M. S. Good, R. V. Harris, L. J. Bond, C. O. Ruud, A. A. Diaz, and M. T. Anderson, Pacific Northwest National Laboratory, Richland, WA 99352

3:50 PM  Progress in the Characterization of Shot Peened Aero Engine Materials by Rayleigh Wave Dispersion  
---M. Barth and B. Koehler, Fraunhofer Institute for Non-Destructive Testing, Dresden, Germany; J. Bamberg and H.-U. Baron, MTU Aero Engines GmbH Munich, Germany

4:10 PM  Ultrasonic Backscattering in Polycrystalline Materials or PWR Components  
---B. Chassignole, O. Dupond, and F. Rupin, EDF R&D, Materials and Mechanics of Components Branch, 77818 Moret sur Loing, France; T. Fouquet, EDF R&D, Simulation in Neutronics, Information Technology and Scientific Computation, 92141 Clamart, France

4:30 PM  Detection of Fatigue Crack Initiation and Monitoring Crack Growth in Ti-6Al-4V Alloy Using Acoustic Emission Technique  
---S. Bhavikatti, M. R. Bhat, and C. R. L. Murthy, Indian Institute of Science, Department of Aerospace Engineering, Bangalore, India
Material State Prognosis Through the Identification of Material Parameters Used in Thermo-mechanical Constitutive Models
---Ketan A. Nayak, Krishnan Balasubramaniam, and C. V. Krishnamurthy, Indian Institute of Technology Madras, Center for Nondestructive Evaluation and Department of Mechanical Engineering, Chennai, Tamil Nadu, India

---The determination of damage accumulation in materials is of considerable significance since it provides an insight to the state of the material and hence the remaining life of the component. The temperature profile observed during loading is a function of the damage accumulated in the material and can provide valuable information for the prognosis of material state. In this study, an attempt is made to characterize the damage accumulation occurred in the material, by analyzing the temperature profiles obtained at different levels of loading during low cycle fatigue. The Bodner-Partom constitutive model that has been widely used for predicting temperature evolution during loading is used to formulate an inverse model to obtain the material parameters from the temperature profile and the loading data. The inverse problem is solved using Genetic Algorithms at different stages of loading experienced by the material. Comparison of the material parameters obtained from the model at different material states provides an estimation of the damage accumulation. Interrupted tests of low cycle fatigue were conducted on SS 304 specimens and the surface temperature profiles were obtained through infrared thermography. The material parameters were computed using the inverse algorithm and a qualitative comparison of the damage accumulation was carried out. The results obtained from the inverse model were verified by comparisons between experimental results and forward model simulations.

Microstructure Characterization and Imaging of Fine-Grained Steel by Microscopic Ultrasonic Techniques
---Sigrun Hirsekorn and Ute Rabe, Fraunhofer-Institut IZFP, NDT Fundamentals, Saarbruecken, Germany

---The development of new steel grades aims at a common optimization of contradicting properties such as weight reduction and formability versus high stiffness and strength. Macroscopic elastic and plastic properties of polycrystalline materials depend on their microstructure, and prospects of success for materials design are given by a selective adjustment of the microstructure. Hence characterization techniques are required to image grain structures and probe elastic properties on the micro- and the nanoscale. This contribution reports on nondestructive characterization of the microstructure of fine-grained steel by microscopic ultrasonic methods such as the conventional scanning acoustic microscopy (SAM) and the near-field technique atomic force acoustic microscopy (AFAM), which combines atomic force microscopy (AFM) with ultrasound. AFAM is a contact resonance spectroscopy technique with a local resolution in the nm range. Similar to nanoindentation it is sensitive to the indentation modulus which accounts for the normal and shear deformation in the tip-sample contact zone.
Nonlinearity Effects in Eddy Current Signals for Surface Characterization of Ferrous Materials
---Norio Nakagawa and Chester C. H. Lo, Iowa State University, Center for Nondestructive Evaluation, 1915 Scholl Road, Ames, IA 50011

---This paper demonstrates nonlinearity effects in eddy current (EC) signals and their effectiveness for surface characterization of ferrous materials. As is well known, the constitutive B-H relationship exhibits nonlinearity in ferromagnetic materials such as steel. It is similarly known that EC measurements can be sensitive to the nonlinearity. Less well known, in contrast, is the fact that steels in hardened and unhardened phases, for example, show significantly different nonlinearity. Indeed, we have found that hardened steel exhibits significantly less nonlinearity than unhardened steel by approximately an order of magnitude. This significant disparity in the nonlinearity property provides a foundation for a characterization method of hardened surface layers, prepared on ferrous host materials by such surface treatments as case hardening and surface oxidation. Nonlinear EC (NLEC) measurements, when prepared appropriately, can exploit the significant difference in the nonlinear responses from the layer and substrate materials, leading to unambiguous and efficient characterization of the layer thickness. This paper explicitly describes our NLEC measurements that conduct varying drive-amplitude scans and higher harmonics detections. Two explicit studies are presented here, the first being a case depth characterization of case-hardened steel rod samples. The discrimination results were reported last year for 1~6 mm case depths in inductively hardened steel rods, while this paper establishes the fundamental basis for the successful characterization method in terms of the NLEC method. Second, we present NLEC characterization of oxide layer thicknesses fabricated in Ni-3at%Al samples. Microstructures of oxide layers with alumina precipitates will be shown, followed by the NLEC signals for thickness discrimination.---This work was supported by the NSF Industry/University Cooperative Research Program.

Evolution of Recrystallization by Changes in Magnetic Hysteresis Loop in a Non-Oriented Electric Steel Cold Rolled
---Francisco E. Silva, Francisco N. C. Freitas, Hamilton F. G. Abreu, Lindberg L. Gonçalves, and Elineudo P. Moura, Universidade Federal do Ceará, Departamento de Engenharia, Metalúrgica e de Materiais, Fortaleza, Ceará, Brazil; Manoel R. Silva, Universidade Federal de Itajubá, Departamento de Física e Química, Itajubá, Minas Gerais, Brazil

---Non-oriented steels, with low carbon, are widely used in the fabrication of electrical motor nucleus. The performance of these motors is affected by the level of recrystallization. These steels can come from the steel plant in two different conditions: totally processed or semi-processed. The semi-processed steels have a partially deformed structure and are submitted to the final annealing process after reaching the end shape. An adequate annealing heat treatment is important to get an appropriate magnetic property. In the present study, samples of an electric steel, with the composition (0.05 wt% C, 1.28wt% Si, 0.29wt% Mn), cold rolled 50% in thickness, were submitted to the temperatures of 575, 580, 600, 620 and 730 ºC with the objective of evaluating the evolution of recrystallization with temperature. Magnetic properties were measured at room temperature in a vibrating sample magnetometer. Although the changes in magnetic hysteresis loop with temperature are difficult to observe, they have been identified by using pattern classification techniques, such as principal-component analysis and Karhunen-Loève expansion. These tools have been applied to vectors which are built from each hysteresis loop, properly renormalized, whose components correspond to amplitude of the loop at given equally spaced values of the renormalized field. The samples have been classified in four sets, namely, set A corresponding to temperatures 575/580, set B corresponding to temperatures 600/620, set C corresponding to the samples without annealing heat treatment and set D corresponding to recrystallized samples. The results for the classification of the different microstructures have been obtained by using both techniques, and in particular a 100% success rate has been reached by using Karhunen-Loève expansion. Work partially financed by Brazilian Oil Company-Petrobrás and Brazilian agencies CAPES, CNPq and FINEP.
Multi-Parametric Approach for Assessment of Aging in Heat Treated M250 Grade Maraging Steel
---Tammana Jayakumar, Viswanath Adurthi, Bhagi Purna Chandra Rao, Kesavan Vadivelu Rajkumar, and Baldev Raj, Indira Gandhi Centre for Atomic Research, Non Destructive Evaluation Division, Metallurgy and Materials Group, Kalpakkam, Tamil Nadu, 603 102, India

---M250 grade Maraging steel is ferromagnetic and recently Magnetic Barkhausen Emission (MBE), ultrasonic, eddy current and positron annihilation techniques have been used to non-destructively characterize microstructures formed during heat treatment. Optimization of ageing duration is important for achieving a combination of mechanical properties viz. tensile strength, hardness and fracture toughness. Studies in M250 steel specimens age hardened at 755K in the range of 0.25 h to 100 h revealed that MBE rms peak voltage is more sensitive to reverted austenite that forms under over aging conditions while ultrasonic parameters are found to be influenced by the precipitation of Ni3Ti and Fe2Mo precipitates. As no single NDE parameter could be used for unambiguous identification of optimal ageing duration, this paper presents a multi-parametric approach that uses MBE rms voltage, ultrasonic longitudinal and shear wave velocities and nonlinear ultrasonic (NLU) parameter. MBE measurements were performed using an encircling pick-up coil of 5000 turns while NLU measurements were carried out using 5 MHz resonant transducer as transmitter and 10 MHz broadband transducer as receiver. Studies reveal that, multi-parametric analysis using ultrasonic velocity and NLU parameters in combination with MBE rms voltage, enables identification of under-aged, optimally aged and over-aged conditions. This paper discusses the experimental studies and highlights the effectiveness of the proposed approach.

Methods for the In-Situ Characterization of Cast Austenitic Stainless Steel Microstructures
---Pradeep Ramuhalli, Morris S. Good, Robert V. Harris, Leonard J. Bond, Clayton O. Ruud, Aaron A. Diaz, and Michael T. Anderson, Pacific Northwest National Laboratory, Richland, WA 99352

---Cast austenitic stainless steel (CASS) that was commonly used in U.S. nuclear power plants is a coarse-grained, elastically anisotropic material. Its engineering properties made it a material of choice for selected designs of nuclear power reactor systems. However, the fabrication processes result in a variety of coarse-grain microstructures that make current in-service parts difficult to inspect ultrasonically, largely due to detrimental effects of wave interactions with the microstructure and the microstructural variability that can be encountered. To address inspection needs, new approaches that are robust to these phenomena are being sought. However, overcoming the deleterious and variable effects of the microstructure on the interrogating ultrasonic beam may require knowledge of the microstructure (e.g. polycrystalline or columnar), for potential optimization of inspection parameters and selection of optimal NDE approaches to enhance the POD. This paper discusses application of ultrasonic and electromagnetic methods for classifying CASS microstructure, when making measurements from the outside surface of the component. Results to date demonstrate the potential of these measurements to discriminate between two consistent microstructures - equiaxed-grain material or columnar-grain material. The potential for fusion of ultrasonic and electromagnetic measurements for in-situ microstructure characterization in CASS materials will be explored.
Progress in the Characterization of Shot Peened Aero Engine Materials by Rayleigh Wave Dispersion
---Martin Barth and Bernd Koehler, Fraunhofer Institute for Non-Destructive Testing, Dresden, Germany; Joachim Bamberg and Hans-Uwe Baron, MTU Aero Engines GmbH Munich, Germany

---Mechanically high stressed components used in aero engines are made of high-strength alloys like IN718 and Ti64. They are surface treated usually by shot-peening. This surface treatment introduces compressive residual stress minimizing the material's sensitivity to fatigue or stress corrosion failure mechanisms resulting in improved performance and increased lifetime of components. Beside that, also cold work is introduced in an amount depending on the peening parameters. To determine the remaining lifetime of critical aero engine components, a quantitative non-destructive determination of compressive stresses is required. This paper deals with Rayleigh wave dispersion measurements over a wide frequency range for evaluating the surface treatment. Untreated, shot peened and thermally relaxed samples were investigated and compared to the destructively determined stress and cold work profile. Also the acoustoelastic coefficients were determined by using a new sample design. In addition to already published results for IN718 the aero engine material Ti6246 was investigated. It is shown that the surface treatment can be characterized by this broadband Rayleigh wave dispersion. The separation of the influence of compressive stress and cold work is still subject to ongoing work.

Ultrasonic Backscattering in Polycrystalline Materials or PWR Components
---B. Chassignole, O. Dupond, and F. Rupin, EDF R&D, Materials and Mechanics of Components Branch, 77818 Moret sur Loing, France; T. Fouquet, EDF R&D, Simulation in Neutronics, Information Technology and Scientific Computation, 92141 Clamart, France

---The ultrasonic examination of the metallic components 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. Some microstructures can lead to a significant scattering of the ultrasonic waves. A previous study presented in the last QNDE conference dealt with the wave attenuation due to this scattering. Another consequence of this phenomenon is the structural noise on the ultrasonic images due to the backscattered signal towards the probe. Both attenuation and backscattering induce low values of signal to noise ratio (SNR) that might challenge a defect detection. This paper presents a modeling approach to simulate the backscattering phenomenon. The methodology consists in mixing a grain scale description of the material and a 2D finite element code (ATHENA) developed by EDF to simulate the ultrasonic propagation in elastic media. The modeling results are confronted to experimental acquisitions on mock-ups containing artificial defects. Values of signal to noise ratio are determined for probes of various frequencies. This approach is tested on two different structures: an isotropic material (forged steel) and an anisotropic one (austenitic weld). We will pay more attention on the development of the finite element code required for the anisotropic materials.
Detection of Fatigue Crack Initiation and Monitoring Crack Growth in Ti-6Al-4V Alloy Using Acoustic Emission Technique
---Shivanand Bhavikatti, M. R. Bhat, and C. R. L. Murthy, Indian Institute of Science, Department of Aerospace Engineering, Bangalore, India

---Development of a reliable on-line monitoring tool to detect crack initiation, monitor its extension and prediction of failure of a structure, typically an aircraft for the structural health monitoring under operating loadings is still a challenge. AET though has the potential to be an effective tool for the purpose (SHM), the complexities involved in identifying and discriminating different active sources and noise have come in the way of establishing this method as a reliable solution. An attempt through a set of experimental investigations on Ti6Al4V alloy specimens subjected to constant amplitude fatigue loading with continuous AE monitoring has been attempted and is presented in this paper. The effort has been to eliminate extraneous noise, acquire genuine AE signals due to fatigue damage and characterize them to identify progressive stages to crack growth leading to the final failure. Acoustic emissions are defect related processes such as crack extension and plastic deformation of a material. Background noises that normally exist in a laboratory environment itself are difficult to handle, the operating environment of an aircraft is much more complex to deal with. An appropriate combination of noise suppression, noise elimination or noise characterization along with sophisticated advanced signal analysis approaches such as ANN go along the way in extracting the potential of technique for source identification and quantification of crack growth. Data obtained from 5 specimens right from the initiation of AE activity to final failure has been analyzed and classified using a hybrid ANN (KSOM and MLP). While KSOM is unsupervised method for obtaining natural clusters, MPL has been used to re-cluster with the aprori information, the final classification results have yielded three clusters which could be correlated to plastic deformation, crack extension and noise. Fracture surface examination using a microscope using X50. Has confirmed the classification obtained.
Session 23
Wednesday, July 21, 2010

SESSION 23
SIGNAL PROCESSING
Lalita Udpa and Tammana Jayakumar, Co-Chairpersons
Salons F-H

1:30 PM  Monte-Carlo Inversion of Travel-Time for the Estimation of Weld Model Parameters
---A. J. Hunter, B. W. Drinkwater, P. D. Wilcox, University of Bristol, Bristol, Department of Mechanical Engineering, United Kingdom

1:50 PM  Some Notes on the Application of Discreet Wavelet Transform in Image Processing
---E. D. S. Caria, Instituto Militar de Engenharia, Seção de Engenharia Mecânica e de Materiais, Rio de Janeiro, RJ, Brazil; T. A. de A. Costa, Centro Tecnológico do Exército, Grupo de Mísses e Foguetes, Rio de Janeiro, RJ, Brazil; J. M. A. Rebello, Federal University of Rio de Janeiro, Department of Metallurgical and Materials Engineering COPPE/UFRJ, Rio de Janeiro, RJ, Brazil

2:10 PM  Noise Models for Injection in Simulated NDE Signals
---T. Khan, C. Bardel, and L. Udpa, Michigan State University, Department of Electrical and Computer Engineering, 2120 Engineering Building, East Lansing, MI 48823

2:30 PM  Characterization of Indications in Ultrasonic Inspections Based on the Hilbert Transform
---D. Algernon, Swiss Association for Technical Inspections, Nuclear Inspectorate, Wallisellen, Zurich, Switzerland

2:50 PM  A Study on Optimization of Bibbin Probes for Inspection of Complex Regions in Steam Generator Tubes
---S.-J. Han, D.-K. Kim, S.-K. Jeon, and S.-J. Song, Sungkyunkwan University, 300, Chunchun-dong, Jangan-gu, Suwon 440-746, Korea; C.-H. Kim, Advanced Institute of Quality and Safety

3:10 PM  Break

3:30 PM  Signal Evaluation System of Flexible Array ECT Probes for Inspecting Complexly Shaped Surfaces
---H. Endo¹, A. Nishimizu¹, M. Tooma¹, H. Ouchi², I. Yoshida², Y. Nanaka², and K. Otani², ¹Hitachi Ltd., 7-2-1 Omika-cho, Hitachi-shi, Ibaraki 319-1221, Japan; ²Hitachi-GE Nuclear Energy, Ltd., Hitachi-shi, Ibaraki-ken, 317-0073, Japan

3:50 PM  Enhanced Detection of Sub-Surface Defects in Stainless Steel Plates Using Eddy Current Image Fusion
---T. Jayakumar, B. Sasi, B. P. C. Rao, S. Thirunavukkarasu, and B. Raj, Indira Gandhi Centre for Atomic Research, Non-Destructive Evaluation Division, Metallurgy and Materials Group, Kalpakkam 603 102, Tamil Nadu, India

4:10 PM  Exploring the Eddy Current Excitation Invariance to Infer about Defect Characteristics
---A. L. Ribeiro and H. G. Ramos, Instituto de Telecomunicações, Instituto Superior Técnico, Lisbon, Portugal

4:30 PM  A New Processing Method for SAW Resonator Torque Response Signal
---C. Xu, Y. Zhang, S. Zhou, and X. Zhao, Beijing Institute of Technology, Key Laboratory of Fundamental Science for Advanced Machining, Beijing, P. R. China
Monte-Carlo Inversion of Travel-Time Data for the Estimation of Weld Model Parameters
---Alan J. Hunter, Bruce W. Drinkwater, Paul D. Wilcox, University of Bristol, Department of Mechanical Engineering, Bristol, United Kingdom

---The quality of ultrasonic array imagery is adversely affected by uncompensated variations in the medium properties, for example, due to the presence of the complicated (inhomogeneous and anisotropic) grain structure in an austenitic weld. These effects can be compensated when an accurate model of the medium is available. However, in many cases (e.g., the weld application), models of sufficient accuracy are unavailable. This paper describes a method for estimating the parameters of a general model using the travel-times of signals propagated through the medium. The model is comprised of many homogeneous regions with unknown properties, e.g., the group velocity profile, and propagation through the medium is modelled by ray-tracing using Dijkstra’s algorithm. Bayesian estimation of the unknown model parameters is performed via a Monte-Carlo Markov chain using the Metropolis-Hastings algorithm. Results are demonstrated using simulated data.

Some Notes on the Application of Discreet Wavelet Transform in Image Processing
---Egydio C. S. Caria, Instituto Militar de Engenharia, Seção de Engenharia Mecânica e de Materiais, Rio de Janeiro, RJ, Brazil; Trajano A. de A. Costa, Centro Tecnológico do Exército, Grupo de Misseis e Foguetes, Rio de Janeiro, RJ, Brazil; João M. A. Rebello, Federal University of Rio de Janeiro, Department of Metallurgical and Materials Engineering COPPE/UFRJ, Rio de Janeiro, RJ, Brazil

---Mathematics transforms are used in signal processing in order to extract what is known as "hidden" information. One of these mathematical tools are the Discrete Wavelet Transform (DWT), which has been increasingly employed in non-destructive testing and, more specifically, in image processing. The main concern in the present work is to employ DWT to suppress noise without losing relevant image features. However, some aspects must be taken into consideration when applying DWT in image processing, mainly in the case of weld radiographs, in order to achieve consistent results. Three topics were selected as representative of these difficulties, as follows: (a) How to fill the image matrix to fit the $2^n$ lines and $2^n$ rows requirement? (b) How to select the most suitable decomposition level of the DWT function and the correct choice of their coefficient suppression? (c) Is there any influence of the scanning direction and the weld radiograph image, e.g., longitudinal or transversal, on the final processing image? It is known that some artifacts may be present in weld radiograph images. Indeed, the weld surface is frequently rough and rippled, what can be seen as gray level variation on the radiograph, being sometimes mistaken as defective areas. Depending on the position of these artifacts, longitudinal or transversal to the weld bead, they may have different influences on the image processing procedure. This influence is clearly seen in the distribution of the DWT Function coefficients. In the present work, examples of two weld radiographs of quite different image quality were given in order to exemplify it.
Noise Models for Injection in Simulated NDE Signals
---Tariq Khan, Chuck Bardel, and Lalita Udpa, Michigan State University, Department of Electrical and Computer Engineering, 2120 Engineering Building, East Lansing, MI 48823

---Computational models are used in NDE for getting better insight into the underlying physics, optimization of sensor design, training of NDE personnel, and for generating training data to be used in developing signal classification algorithms. However simulated signal are very different from noisy, real world, experimental signals in that they have zero noise. In order to use the computational models more effectively, experimental noise can be injected in the simulated signals. This paper presents a possible method for transforming a noise free simulated signal into a noisy experimental signal. Experimental noise database is generally acquired from defect free samples in the industry. Experimental noise PDF (probability density function) can be numerically calculated from the experimental noise database. Sampling from experimental signal distribution is not a straight forward task as the distribution is generally not a standard parametric distribution. Different methods of sampling from the experimental signal PDF are investigated in this research work. These include Markov chain Montecarlo based sampling techniques and approximation of experimental signal PDF as a mixture of Gaussian densities using expected maximization (EM) algorithm. Maximum-likelihood estimate of the parameters of Gaussian distributions from a given data set when the data is incomplete or has missing values can be computed using EM technique. Simulation models for steam Generator tubing in nuclear power plants is considered as a test case. Experimental noise is injected in the simulated signals using above mentioned sampling techniques. The comparison of simulated signals with injected noise and actual signals using different sampling techniques will be presented in the full paper.

Characterization of Indications in Ultrasonic Inspections Based on the Hilbert Transform
---Daniel Algernon, Swiss Association for Technical Inspections, Nuclear Inspectorate, Wallisellen, Zurich, Switzerland

---In ultrasonic inspections of pipe welds on nuclear components, the characterization and discrimination of indications plays a key role, since it has a direct effect on the outcome of the inspection. A simple, intuitive and quantitative criterion is the amplitude of the indication. However, this criterion has its limitations especially due to the major effect that the orientation of the reflector has on the amplitude and can cause misleading results. In this study, a new criterion is presented to provide a refined analysis. It is based on the observation that the signals obtained from reflections on cracks or flaws tend to be slightly deformed compared to reflections on smooth geometrical boundaries. This deformation can be quantified by means of the instantaneous frequency obtained from the Hilbert transform of the signal. While the instantaneous frequency will give mostly uniform values in the case of an undeformed echo (smooth reflector, geometrical boundary of the test object), it will show appreciable fluctuations for a deformed echo as it is obtained from a reflector with an irregular surface, e.g. a flaw. The amount of this frequency fluctuation will depend on the extent of the deformation. Being different from other characterization criteria that are based on the recognition of certain patterns within the ultrasound images by eye, it provides a quantitative parameter for the characterization of the indication. The functionality of this criterion is demonstrated in its application on data sets obtained from numerical simulations as well as on data obtained from practical measurements on different test blocks.
A Study on Optimization of Bobbin Probes for Inspection of Complex Regions in Steam Generator Tubes
---Seong-Jin Han, Dea-Kwang Kim, Su-Kyun Jeon, and Sung-Jin Song, Sungkyunkwan University, 300, Chunchun-dong, Jangan-gu, Suwon 440-746, Korea; Chang-Hwan Kim, Advanced Institute of Quality and Safety

---Safety and reliability of nuclear power plants is one of issues especially, integrity of steam generator tubes. So developing of technique to maximize probability of detection of flaws where occurring at steam generator tubes is strongly needed. Flaws most frequently occur at near the complex structure zone such as tube sheets or support plates. Using Eddy Current Test (ECT), complex signals were acquired near the complex structure zone in steam generator tubes. Therefore, Frequency Mixing process that could remove structure signals from the acquired complex signal. However, principle of frequency mixing, the reliability of obtained flaw signals is greatly changed after frequency mixing according to parameters of probe. Thus, in this paper, we simulate ECT signals using FEM software with various of parameters of ECT probes (frequency and gap of coils) and, using the simulated signals, and frequency mixing method, we will establish optimal condition of ECT probe to get the best reliability from result of the frequency mixing. In this presentation, process of ECT frequency mixing method, and FEM based optimal condition will be presented.

Signal Evaluation System of Flexible Array ECT Probes for Inspecting Complexly Shaped Surfaces
---Hisashi Endo¹, Akira Nishimizu¹, Masahiro Tooma¹, Hirofumi Ouchi², Isao Yoshida¹, Yoshio Nanaka¹, and Kenichi Otani², ¹Hitachi Ltd., 7-2-1 Omika-cho, Hitachi-shi, Ibaraki 319-1221, Japan; ²Hitachi-GE Nuclear Energy, Ltd., Hitachi-shi, Ibaraki-ken, 317-0073, Japan

---To carry out efficient inspections of complexly shaped metal surfaces, we have developed a signal evaluation system of flexible array ECT (Eddy Current Testing) probes. Our probes employ exciting and detecting coil pairs arrayed on a bendable substrate to measure curved targets with high sensitivity. Since this bendable probe produces signals due to the change in the relative position between the coil pair, the system requires a function for crack signal identification. The identification methodology developed in the present paper focuses on signal phase combination of the coil pairs. It is represented as a two-dimensional diagram constituting the phase values of two of the coil pairs with different positions. The signal phase around cracks is significantly affected by the direction of surface cracking. The diagram is therefore capable of separating crack information from other information and of imaging crack positions. We applied the system to complex geometric mock-ups having stress corrosion cracking flaws. Crack signals were successfully identified and the images obtained for identified positions could be used to efficiently measure the length of surface cracks.
Enhanced Detection of Sub-Surface Defects in Stainless Steel Plates Using Eddy Current Image Fusion
---Tammana Jayakumar, Balakrishnan Sasi, Bhagi Purna Chandra Rao, Sannasi Thirunavukkarasu, and Baldev Raj, Indira Gandhi Centre for Atomic Research, Non Destructive Evaluation Division, Metallurgy and Materials Group, Kalpakkam 603 102, Tamil Nadu, India

---Detection of sub-surface defects in AISI type 304L stainless steel plates using eddy current technique is influenced by variations in surface roughness, lift-off, electrical conductivity and magnetic permeability. Eddy current imaging automates the measurement process and enhances probability of detection of defects. This paper discusses fusion of eddy current images from pancake type probes using maximum likelihood (ML), Bayesian inference (BI) and Dempster-Shafer (DS) techniques. Eddy current images of sub-surface notches located at 2 mm, 3 mm and 5 mm below surface in a 6 mm thick plate are obtained using 5 mm and 11 mm diameter pancake probes operating at 75 kHz and 10 kHz, respectively. The images are fused by different techniques mentioned above and their performance is evaluated using contrast and signal to noise ratio for raw as well as fused images. Percentage detection success is evaluated for raw as well as fused images for comparison. Studies reveal that DS technique produces higher detection success as compared to BI and MI techniques. The paper discusses the three image fusion techniques and the evaluation of the performance of different techniques at different lift-off and surface roughness conditions.

Exploring the Eddy Current Excitation Invariance to Infer about Defect Characteristics
---Artur L. Ribeiro and Helena G. Ramos, Instituto de Telecomunicações, Instituto Superior Técnico, Lisbon, Portugal

---When the eddy current method is used to detect flaws inside conductive materials, different kinds of probes can be used. One probe is basically constructed with an excitation coil to apply a time-varying magnetic field, and a magnetic field detector to sense the perturbation field originated by the presence of flaws. In this work we focus on the invariance of the excitation field, under a probe rotation, when a solenoidal-type coil is used, or on the invariance under a probe translation, when a “constant field” probe is used. In the case of a solenoidal axisymmetric coil, the excitation invariance can be used to infer the field along directions different from those acquired by measurements. In the case of a constant field probe, that produces a spatially invariant field on a bounded area, the excitation currents inside the conductive material can be considered invariant under limited probe translations. Thus, the measurements taken on successive probe positions are identical to those that would be taken simultaneously with an array of sensors positioned on those grid locations. In our present work we show that the experimental data acquired with the measuring system developed at our laboratory agree with the computed results obtained from the theoretical assumptions.
A New Processing Method for SAW Resonator Torque Response Signal
---Chunguang Xu, Yuntao Zhang, Shiyuan Zhou, and Xinyu Zhao, Beijing Institute of Technology, Key Laboratory of Fundamental Science for Advanced Machining, Beijing, P. R. China

---When detecting the torque with passive wireless SAW (surface acoustic wave) resonator sensor, the response signal is of narrow band, high frequency, low SNR and transient attenuation. The response signal is produced only in the case that the interrogation covers the operational frequency band of the SAW resonator. Burst of sinusoidal is used in the experiment to excite the resonator, and analysis of the sensing signal reveals that the response signal is an exponential decay signal of single frequency, and changes of strain lead to a shift of the resonance frequency. Torque applied to the shaft can be acquired from changes of the center frequency of the resonator. The frequency resolution of traditional FFT spectrum analysis method is limited by sampling length, which can't meet the accuracy requirement of SAW torque measurement. Parameter estimation method, such as MLE (Maximum likelihood estimate) or LSE (Least Square estimate) can be used, but it is time-consuming. In this paper, GA (Genetic algorithm) is employed to estimate parameters of the sensing signal, in particular, the center frequency. Before the introduction of genetic algorithms, response signal should be converted to sinusoid with Hilbert envelope-demodulation. This can simplify the waveform greatly. Hence, the work is converted into extracting sinusoidal signal parameters from the limited sampling, including frequency, amplitude, phase and DC offset. For the demodulated single frequency signal, the resonance frequency can be got directly in time domain by genetic algorithm. The results show that this method can estimate the frequency more accurately and faster.
Session 24
SESSION 24
SPECIAL EVENING SESSION
Lisa Brasche, Chairperson
Salon D

8:00 PM  Wind Energy Growth and the Implications for Inspection and Sensors
THURSDAY

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   Signal Processing, Materials and Material Properties,
   Composite Materials, NDE for Civil Structures, New
   Techniques and Systems, Reliability .................... 155
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**Session 29 – POSTERS – 1:30 – 3:10 PM – Cabrillo Salons 1 and 2**

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SESSION 25
GUIDED WAVES I
Peter Cawley, Chairperson
Salons A-C

8:30 AM  Hybrid SAFE/FE Simulation of Inspections of Elastic Waveguides Containing Several Local Discontinuities or Defects
---V. Baronian, A. Lhémery, and Karim Jezzine, CEA, LIST, Gif-sur-Yvette, France

8:50 AM  Scattering of Plane Guided Waves Obliquely Incident on Straight Features
---P. D. Wilcox, A. Velichko, B. W. Drinkwater, and A. J. Croxford, University of Bristol, Bristol, United Kingdom; M. D. Todd, University of California, San Diego, CA 92103

9:10 AM  Nonlinear Guided Waves in Continuously Welded Rails for Buckling Prediction
---I. Bartoli1, R. Phillips1, S. Coccia1, F. Lanza di Scalea1, S. Salamone1, C. Nucera1, M. Fateh2, and G. Carr2, 1NDE & SHM Laboratory, University of California, Department of Structural Engineering, San Diego, CA 92093; 2Office of Research and Development, Federal Railroad Administration, Washington, DC, 20590

9:30 AM  Analysis of Distributed Sparse Array Configurations for Guided Wave Imaging Applications
---J. S. Hall and J. E. Michaels, Georgia Institute of Technology, School of Electrical and Computer Engineering, Atlanta, GA 30332-0250

9:50 AM  The Reflection of Guided Waves from Simple Supports in Pipes
---A. Galvagni and P. Cawley, Imperial College, Mechanical Engineering, London, United Kingdom

10:10 AM  Break

10:30 AM  In-Line Corrosion Inspection Using Circumferential and Longitudinal Ultrasonic Guided Waves
---M. Lindsey, Penn State, Mechanical Engineering, University Park, PA 16802; R. Then, C. J. Lissenden, and J. L. Rose, Penn State, Engineering Science and Mechanics, University Park, PA 16802; J. Van Velsor, FBS Inc., State College, PA 16801

10:50 AM  The Reflection of the Fundamental Torsional Mode from Multiple Small Circular Defects in Pipes
---A. Lovstad1,2 and P. Cawley1, 1Imperial College, Mechanical Engineering, London, United Kingdom; 2Norwegian University of Science & Technology, Engineering, Trondheim, Norway

11:10 AM  The Effect of Complex Defect Profiles on the Reflection of Guided Waves in Pipes
---R. Carandente and P. Cawley, Imperial College, Mechanical Engineering, London, United Kingdom

11:30 AM  Field Experience of Guided Wave Travel Time Tomography
---A. Volker and J. Bloom TNO, Stieltjesweg 1, P. O. Box 155, Delft, 2600 AD, The Netherlands

11:50 AM  Comparison of the Effects to Applied Loads and Temperature Variations on Guided Wave Propagation
---S. J. Lee, N. Gandhi, J. E. Michaels, and T. E. Michaels, Georgia Institute of Technology, School of Electrical and Computer Engineering, Atlanta, GA 30332-0250

12:10 PM  Lunch
Hybrid SAFE/FE Simulation of Inspections of Elastic Waveguides Containing Several Local Discontinuities or Defects
---Vahan Baronian, A. Lhémery, and Karim Jezzine, CEA, LIST, Gif-sur-Yvette, France

---An extension of two modal formulations (presented in this series) to simulate configurations of NDT by guided waves (pitch-catch, pulse-echo) is presented: extended formulations handle wave propagation in several uniform guides and scattering by several discontinuities such as defects or junctions as well as multiple scattering phenomena that can take place between scatterers. A typical configuration of interest is a pitch-catch measurement where two different waveguides are linked by a junction of complex shape and one of the waveguides (or both) contains defects close to or far from the junction. The formulations treat separately the radiation and reception by transducers, the diffraction by junctions or defects and the propagation in uniform waveguides. The complexity of guided wave diffraction makes it necessary to compute it numerically; this is done using a finite element formulation completed by specific transparent boundary conditions restricting the computation to a minimum. The calculation of propagation in uniform parts benefits from numerically efficient methods; here, the semi-analytical finite element method used concentrates the computation on a discrete solution in the sole guide section. The theoretical formulations will be described and their interest for simulating complex NDT configurations involving guided waves will be illustrated by a few examples.

Scattering of Plane Guided Waves Obliquely Incident on Straight Features
---Paul D. Wilcox, Alexander Velichko, Bruce W. Drinkwater, and Anthony J. Croxford, University of Bristol, Bristol, United Kingdom; Michael D. Todd, University of California, San Diego, CA 92103

---A frequency-domain finite element (FE) method is presented for modeling the scattering of plane guided waves obliquely incident on an infinitely-long, straight feature with uniform cross-section in a planar host waveguide. The method utilizes a mesh of 2-dimensional finite elements with harmonic shape functions in the perpendicular direction. The model domain comprises a cross-section through the feature and short lengths of the adjoining host waveguide. An integral representation of the incident mode at the desired angle is used to determine a suitable system of harmonic forces to uniquely excite that mode on one side of the feature. The displacement field is measured on either side of the feature and decomposed into reflected and transmitted modes. The cases of guided wave transmission in a featureless waveguide and the reflection of guided waves from a free-edge are examined as validation cases for the FE model. Then the case of an hollow, square-section, adhesively-bonded stiffener is modeled. The transmission coefficient results for the $S_0$ guided wave mode using this model are compared with experimental measurements made using a pair of electromagnetic acoustic transducers (EMATs) to transmit waves across a stiffener with the same geometry. Excellent agreement is obtained.
Nonlinear Guided Waves In Continuously Welded Rails For Buckling Prediction
---Ivan Bartoli¹, Robert Phillips¹, Stefano Coccia¹, Francesco Lanza di Scalea¹, Salvatore Salamone¹, Claudio Nucera¹, Mahmood Fateh², and Gary Carr². ¹NDE & SHM Laboratory, Department of Structural Engineering, University of California, San Diego, CA 92093; ²Office of Research and Development, Federal Railroad Administration, Washington, DC, 20590

---Rail buckling may occur in Continuously Welded Rails (CWR) when high ambient temperatures generate large compressive stresses. Information on the stress level in the rail and related imminent buckling could represent the basis for effective preventive measures. Alternatively, the knowledge of the Neutral Temperature (NT) that corresponds to a stress free condition in the rail, would allow an estimate of the critical temperature corresponding to the critical load and incipient buckling. This paper focuses on numerical and experimental studies on nonlinear ultrasonic guided waves in CWR subjected to axial stresses. The study discusses the sensitivity of ultrasonic guided waves to stress variations. Experimental tests will be performed on an indoor 21.3m long Continuously Welded Rail constrained with two reaction concrete blocks. Effect of thermal stress will be simulated using an electrical heating system controlling temperature/stress in the rail. Guided waves will be excited and recorded in a broad frequency range spanning from few kilohertz to 1 MHz. This work is funded under a Federal Railroad Administration grant to develop a system able to determine NT and to predict incipient buckling in CWR.

Analysis of Distributed Sparse Array Configurations for Guided Wave Imaging Applications
---James S. Hall and Jennifer E. Michaels, Georgia Institute of Technology, School of Electrical and Computer Engineering, Atlanta, GA 30332-0250

---Permanently attached, distributed sparse arrays of piezoelectric transducers have been proposed as a cost-effective solution for the rapid interrogation of large, plate-like structures for structural health monitoring. These distributed sparse arrays rely on guided wave imaging techniques to interpret and graphically display information for damage detection and localization. Unfortunately, guided wave imaging algorithms contain some imaging artifacts that are due to reflections from boundaries and other structural features even in a noise-free environment. The magnitude relationship between pixel values corresponding to actual damage and imaging artifacts is dependent on a number of variables, including structural geometry, the location of damage, scattering behavior, and the number and location of transducers in the sensor array. This study utilizes numerical simulations to analyze the imaging performance of distributed sparse arrays as a function of array geometry, damage location, and scattering characteristics in the context of a single flaw in a rectangular aluminum plate.
The Reflection of Guided Waves From Simple Supports in Pipes
---Andrea Galvagni and Peter Cawley, Imperial College, Mechanical Engineering, London, United Kingdom

---Pipe supports are an integral part of any petrochemical plant. In outdoor environments moisture and dirt often accumulate at the contact interfaces between pipes and reaction supports, leading to localized corrosion initiation. Unlike common methods employed to measure pipe wall thickness, long-range ultrasonic guided waves allow inspection of pipes at support locations without requiring direct access to contact interfaces, thus reducing inspection costs. However, successful ultrasonic guided wave detection of flaws at support locations relies on the ability to distinguish between reflections produced by healthy reaction supports and reflections produced by pipe flaws. Consequently, it is essential to know how the reflections produced by healthy reaction supports behave; very little work has so far been reported on this subject. Through finite element simulations and experiments, this study develops a systematic understanding of how ultrasonic guided waves propagating along a pipe, in particular the T(0,1) mode, interact with healthy reaction supports. It is shown that, unlike the T(0,1) mode in a free pipe, the torsion-like mode in the support region has a cut-off frequency, below which it will not propagate; below this frequency the T(0,1) reflection coefficient is large, and it quickly reduces beyond the cut-off.

In-Line Corrosion Inspection Using Circumferential and Longitudinal Ultrasonic Guided Waves
---Matthew Lindsey, Penn State, Mechanical Engineering, University Park, PA 16802; Ronald Then, Cliff J. Lissenden, and Joseph L. Rose, Penn State, Engineering Science and Mechanics, University Park, PA16802; Jason Van Velsor, FBS Inc., State College, PA 16801

---Corrosion of steel casing for natural gas storage wells is a safety risk. An in-line tool capable of sending both circumferential and longitudinal ultrasonic guided waves has been designed, built, and evaluated. The heart of the tool contains sets of electromagnetic acoustic transducers (EMATs). The EMATs generate shear horizontal guided waves in the casing. The circumferential guided waves interact with the anomaly (material loss) caused by corrosion, which causes reflection and mode conversion. These reflections and converted modes can be distinguished from the incident mode based on modal group velocities. Longitudinal guided waves improve the defect characterization potential. Results from experiments on 4 inch (100 mm) diameter schedule 40 pipe are presented. Laboratory tests on pipe sections containing artificial defects that represent general corrosion and pitting corrosion are conducted. In addition, the in-line tool is tested in a gas well.
The Reflection of the Fundamental Torsional Mode from Multiple Small Circular Defects in Pipes
---Anders Lovstad\textsuperscript{1,2} and Peter Cawley\textsuperscript{1},
\textsuperscript{1}Imperial College, Mechanical Engineering, London, United Kingdom; \textsuperscript{2}Norwegian University of Science & Technology, Engineering, Trondheim, Norway

---In practice localized corrosion often occurs as clusters of pits; understanding the reflection from two and three circular holes, each of which has a diameter significantly smaller than the wavelength, is a step towards the estimation of the scattering behavior of multiple and random defects. A parametric study of the reflection from multiple circular holes in pipes with the fundamental torsional guided wave incident is presented. FE analyses of the reflection from two and three circular holes at different relative positions are presented. Most of the work deals with through-thickness defects, but part-thickness defects have also been studied in the two-hole case. The validity of employing the superposition technique in calculating reflection coefficient estimation is assessed as function of defect separation distance and orientation. Results show that the reflection coefficient for the $T(0,1)$ mode is dependent on absolute frequency and axial separation, and independent of circumferential position. Employing superposition is found to be valid down to defect centre-centre separation distances of two diameters in the worst case. The validity of superposition improves with shallower defects. Results from the FE analyses are validated experimentally.

The Effect of Complex Defect Profiles on the Reflection of Guided Waves in Pipes
---Rosalba Carandente and Peter Cawley,
Imperial College, Mechanical Engineering, London, United Kingdom

---The capacity of guided ultrasonic waves to size real corrosion defects remains challenging due to the complexity of the profiles encountered in practice. In the past many studies on the reflection from defects with relatively simple shapes have been done; the purpose of this work is to analyze the effect of complex defect profiles on the reflection coefficient. A study of the reflection of the fundamental torsional mode $T(0, 1)$ from three dimensional (3D) defects in pipes with different shapes has been carried out. Firstly, flat-bottomed defects with different surface profiles have been analyzed, and then the reflection from varying depth profile 3D defects has been studied. It is revealed that at a given maximum depth of a finite discontinuity, the peak of the reflection coefficient from this defect is linearly dependent on the circumferential extent of the defect, and is independent of its shape. The influence of the depth profile of a real corrosion defect in the axial and circumferential directions on the reflection coefficient has also been studied. The results from above analyses have been used to propose a practical approach to determine the maximum depth of a complex discontinuity from the reflection coefficient behavior.
Field Experience of Guided Wave Travel Time Tomography  
---Arno Volker and Joost Bloom, TNO, Stieltjesweg 1, P. O. Box 155, Delft, 2600 AD, The Netherlands  
---Corrosion is one of the industries major issues regarding the integrity of assets. Currently inspections are conducted at regular intervals to ensure a sufficient integrity level of these assets. Cost reduction while maintaining a high level of reliability and safety of installations is a major challenge. The concept of predictive maintenance using permanent sensors that monitor the integrity of an installation matches very well with the objective to reduce cost while maintaining a high safety level. Guided waves are very attractive for permanent monitoring systems because they can travel over large distances and therefore provide the essential large area coverage. Making use of the dispersive behavior of the guided waves, a wall thickness map over a distance of several meters can be made using only two rings of guided wave transducers. Travel time tomography is used to translate transmission travel times into a wall thickness map. This method has been applied in the field for the first time to map the wall thickness under two clearly corroded pipe supports of a 8” and 10” gas pipe line. The tomographic inversion results clearly maps the corrosion under the supports. Independent reference measurements confirm the tomographic inversion results.

Comparison of the Effects of Applied Loads and Temperature Variations on Guided Wave Propagation  
---Sang Jun Lee, Navneet Gandhi, Jennifer E. Michaels, and Thomas E. Michaels, Georgia Institute of Technology, School of Electrical and Computer Engineering, Atlanta, GA 30332-0250  
---Most guided wave-based damage detection methods for structural health monitoring rely upon detecting small damage-induced changes in ultrasonic guided wave signals. However, the structure of interest is generally exposed to variable loads and temperatures during normal usage, and received signals can be significantly affected. These signal changes are of concern because of their potential to cause false alarms during in situ monitoring. The load-induced signal changes are similar in some respects to those caused by temperature variations because both cause changes in bulk wave speeds and specimen dimensions. The result for both is a slight change in phase and group velocities and a change in separation distance between two transducers, resulting in an arrival time shift of a direct wave between a transmitter and receiver. However, load-induced changes, unlike temperature changes, can produce a slight anisotropy of the structure, causing the changes in velocities to depend on the direction of propagation. These acoustoelastic effects are well-known for bulk waves, but there are few studies that consider the effect of loading on guided waves. Here we present experimental results that show the anisotropic effect of applied loads on the direct arrivals of various Lamb wave modes and compare that to the isotropic effect of temperature. Finally, we compare theoretical and experimental results of the phase velocity changes with respect to the direction of propagation.
SESSION 26
X-RAY NDE
Trey Gordon, Chairperson
Salon D

8:30 AM  µ-Computed Tomography for Micro-Structure Characterization of CFRP
---R. Stoessel, EADS Innovation Works, Structure Engineering, Production & Aeromechanics, Structure Health Engineering (NDI&SHM), Munich, Germany; T. Guenther and T. Dierig, Volume Graphics, Heidelberg, Germany; K. Schladitz and M. Godehardt, Fraunhofer-Institut f. Techno- und Wirtschaftsmathematik (ITWM), Kaiserslautern, Germany; P.-M. Kessling, Fraunhofer-Development Center X-ray Technology (EZRT), Fuerth, Germany

8:50 AM Sparse X-Ray CT Image Reconstruction Using ECME Hard Thresholding Methods
---K. Qiu and A. Dogandzic, Iowa State University, Department of Electrical and Computer Engineering, Ames, Iowa, 50011

9:10 AM A Region of Interest X-Ray Computer Tomography Technique for Defect Characterization in Carbon-Fibre-Reinforced-Plastic Laminates
---M. Amos, S. Woods, and P. Wallace, TWI Ltd, NDT Validation Centre Wales, Port Talbot, Margam, United Kingdom; P. Withers, Materials Science Centre, University of Manchester, United Kingdom

9:30 AM Experimental Scatter Correction Methods in Industrial X-Ray Cone-Beam CT

9:50 AM Application of Micro-Focus Volumetric Computed Tomography to Characterization of Composite Materials

10:10 AM Break

10:30 AM Development of a Computed Tomography Simulator – SIM CT
---J. Gray and S. Wendt, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

10:50 AM Backscatter X-Ray Development for Space Vehicle Thermal Protection Systems
---B. B. Bartha, D. Hope, P. Vona, M. Born, and T. Corak, United Space Alliance, LLC, M/S USK-823, 8550 Astronaut Blvd., Cape Canaveral, FL 32920

11:10 AM X-Ray Backscatter Imaging for Aerospace Applications
---D. Shedlock1, T. Edwards2, C. Toh3, Nucsafe, Inc., 601 Oak Ridge Turnpike, Oak Ridge, TN 37830; 1Boeing Research & Technology, 5775 Campus Parkway, Hazelwood, MO 63042; 2Boeing Research & Technology, 5301 Bolsa Ave, Huntington Beach, CA 92647

11:30 AM Optimum Exposure Conditions for Computed Radiography Depending on Fixed Pattern Noise and Efficiency of Imaging Plate-Scanner Systems

11:50 AM Measurement and Modeling of Scatter Ratios at High Energies

12:10 PM Lunch
µ-Computed Tomography for Micro-Structure Characterization of CFRP

--- Rainer Stoessel, EADS Innovation Works, Structure Engineering, Production & Aeromechanics, Structure Health Engineering (NDI&SHM), Munich, Germany; Thomas Guenther and Tobias Dierig, Volume Graphics, Heidelberg, Germany; Katja Schladitz and Michael Godehardt, Fraunhofer-Institut f. Techno- und Wirtschaftsmathematik (ITWM), Kaiserslautern, Germany; Petra-Maria Kessling, Fraunhofer-Development Center X-ray Technology (EZRT), Fuerth, Germany

--- Non-destructive testing is of major importance for quality assurance of Carbon Fiber Reinforced Polymer (CFRP) in aerospace industry. It is of interest to obtain information of the 3D inner micro-structure of CFRP. A promising option is the usage of µ-CT inspection. So far CT methods were mainly used for metal applications. At EADS Innovation Works we operate a high resolution and high contrast µ-Computed Tomography system. It is designed and built according to our specifications especially for CFRP. State-of-the art software tools are used to characterize the 3D inner micro-structure and to obtain information about porosity, cracks and fiber orientation. In this paper the different methods, tools and results obtained with this system will be presented. This includes CFRP samples with cracks, impact damage, delaminations, porosity, and the detection of fiber orientations. The paper also discusses the potential of quantitative CT based on dual energy techniques for the characterization of CFRP. The potential of measurements for material densities is demonstrated.

Sparse X-Ray CT Image Reconstruction Using ECME Hard Thresholding Methods

--- Kun Qiu and Aleksandar Dogandzic, Iowa State University, Department of Electrical and Computer Engineering, Ames, Iowa, 50011

--- We apply our ECME hard thresholding schemes to reconstruct X-ray computed tomography (CT) images and show that they allow for faster and cheaper inspections compared with the current technology. We demonstrate that, by exploiting signal sparsity in the discrete wavelet transform (DWT) domain, it is possible to achieve good-quality reconstruction using a small number of tomographic projections, which is the scenario where the traditional reconstruction approaches (that ignore signal sparsity) fail. In particular, the traditional filtered back-projection reconstruction degrades rapidly as the number of projections is reduced; in contrast, the reconstruction performances of our schemes decrease slowly with less projections. We compare our schemes with existing methods in terms of the reconstruction accuracy and speed.---This work was supported by the NSF Industry/University Cooperative Research Program.
A Region of Interest X-Ray Computer Tomography Technique for Defect Characterization in Carbon-Fibre-Reinforced-Plastic Laminates
---Mathew Amos, Simon Woods, and Philip Wallace, TWI Ltd, NDT Validation Centre Wales, Port Talbot, Margam, United Kingdom; Philip Withers, Materials Science Centre, University of Manchester, United Kingdom

---This paper describes the development and validation of a Region-of-Interest (ROI) X-ray Computer Tomography (CT) technique for the CT inspection of Carbon-Fiber-Reinforced-Plastic (CFRP) laminates. The aim of this work was to overcome the severe artifacts associated with truncated ROI projection data and provide suitably accurate results using a simple data completion approach. Two methods were developed and implemented for use with a third generation rotate-only cone beam CT system. The performance of both methods was compared using intensity line profiles drawn across an Image Quality Indicator (IQI) fabricated into the CFRP test samples. The results proved that the developed procedures allowed highly magnified regions with improved spatial resolution to be accurately reconstructed without truncation artifacts masking large amounts of the inspected area.

Experimental Scatter Correction Methods in Industrial X-Ray Cone-Beam CT
---Karsten Schoerner, Matthias Goldammer, and Juergen Stephan, Siemens AG, Corporate Technology CT T DE HW2, Munich, Germany

---Scattered radiation presents a major source of image degradation in industrial cone-beam computed tomography systems. Scatter artifacts introduce streaks, cupping and a loss of contrast in the reconstructed CT-volumes. Artifacts become even more severe when large-scale, highly-scattering samples are inspected using a flat-panel detector system. In order to overcome scatter artifacts, we present two complementary experimental correction methods: the beam-stop array (BSA) and an inverse technique we call beam-hole array (BHA). The BSA employs a grid of lead cylinders blocking primary radiation entirely at a number of sampling points. Any signal directly detected in the cylinders’ shadows is considered to originate from one of the scatter sources, i.e. from object scatter, environmental scatter or detector-internal spread mechanisms. Alternatively, the scatter contribution can be determined indirectly with our BHA aperture mask where only primary signals are sampled. A second, open-field projection yields total signals at the corresponding points. Subtracting primary from total signals yields the scatter signals again. Both correction methods are examined in comparison measurements where it is shown that the aperture-based BHA technique has practical and scatter-reducing advantages over the BSA. The proposed BHA correction method is successfully applied to a large-scale, aluminum-based ceramic specimen from power generation technology whereby scatter artifacts are reduced and contrast is enhanced significantly.
Application of Micro-Focus Volumetric Computed Tomography to Characterization of Composite Materials

---Micro-focus volumetric computed tomography enables full volume high resolution imaging of composite materials. The size for the reconstructed data acquire is often quite large, on the order of several gigabytes. This paper discusses techniques that have been used to computationally obtain meaningful information from this data. The techniques are shown to be very useful for characterizing the changes that occur in composite materials as a result of aging. Of particular interest has been registering the volumes relative to each other. Difference between the volumes enables the visualization of subtle changes in the composite.

Development of aComputed Tomography Simulator -- SimCT
---Joe Gray and Scott Wendt, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---We report on the development of a simulation for computed tomography. The physics of the image formation process are modeled including all major x-ray sources, CAD descriptions of complex part shapes, selectable material and several detector configurations and types. Realistic flaw models are included in addition to simpler shapes. A 3D visualization tool allows for easy configuration of the set up of the CT scan in either a 2D slice or 3D cone beam configuration. The output of the program is either sinograms or reconstructed slices. Examples of the application of the CT simulation tool will be discussed illustrating the effects of energy selection of the x-ray sources, limits of detectability, both as a function of pixel size limitation and of contrast sensitivity, and optimization of the scan configuration. Comparison to experimental results will be discussed.
Backscatter X-Ray Development for Space Vehicle Thermal Protection Systems
---Bence B. Bartha,
Dale Hope, Paul Vona,
Martin Born, and Tony Corak,
United Space Alliance, LLC,
M/S USK-823, 8550 Astronaut Blvd.,
Cape Canaveral, FL 32920

---Backscatter X-Ray (BSX) imaging technique is used for various single sided inspection purposes. Previously developed BSX techniques for spray-on-foam insulation (SOFI) have been used for detecting defects in Space Shuttle External Tank foam insulation. The developed BSX hardware and techniques are currently being enhanced to advance Non-Destructive Testing (NDT) methods for future space vehicle applications. Various Thermal Protection System (TPS) materials were inspected using the BSX imaging techniques, investigating the capability of the method to detect voids at various locations within each material. Calibration standards were developed for the TPS materials in order to characterize and develop enhanced BSX inspection capabilities. The ability of the BSX technique to detect both manufactured and natural defects was also studied and compared to through-transmission x-ray techniques. The energy of the x-ray, source to object distance, angle of x-ray, focal spot size and x-ray detector configurations were parameters playing a significant role in the sensitivity of the BSX technique to image various materials and defects. The image processing of the results also showed significant increase in the sensitivity of the technique. The experimental results showed BSX to be a viable inspection technique for space vehicle TPS systems.

X-Ray Backscatter Imaging for Aerospace Applications
---Daniel Shedlock¹,
Talion Edwards², and Chin Toh³,
¹Nucsafe, Inc., 601 Oak Ridge Turnpike,
Oak Ridge, TN 37830; ²Boeing Research &
Technology, 5775 Campus Parkway,
Hazelwood, MO 63042; ³Boeing Research &
Technology, 5301 Bolsa Ave, Huntington Beach,
CA 92647

---Scatter x-ray imaging (SXI) is a real time, digital, x-ray backscatter imaging technique that allows radiographs to be taken from one side of an object. This x-ray backscatter imaging technique offers many advantages over conventional transmission radiography that include single-sided access and extremely low radiation fields compared to conventional open source industrial radiography. These features enable the use of much smaller exclusion zones for non-occupational personnel which traditionally limited the use of x-ray based imaging techniques in active production environments. Examples of some applications include the detection of corrosion, foreign object debris, water intrusion, cracking, impact damage and leak detection in a variety of material such as aluminum, composites, honeycomb structures, and titanium. This paper summarizes testing results from some of these applications and demonstrates the capabilities of x-ray backscatter imaging in offering a viable solution to some non-destructive testing application in the aerospace industry. The paper will also discuss practical limitations of applying this technique in a field environment, and lessons learned from on-aircraft testing. Scatter x-ray imaging can be used in a variety of applications where the penetrating power of x-rays is a requirement, while there is only access to one side of the object.
Optimum Exposure Conditions for Computed Radiography Depending on Fixed Pattern Noise and Efficiency of Imaging Plate-Scanner Systems
---Uwe Ewert, Uwe Zscherpel, Klara Heyne, and Mirko Jechow, BAM, Federal Institute for Materials Research and Testing, Berlin, Germany; Klaus Bavendiek, YXLON International GmbH, Hamburg, Germany

---After 5 years of experiences the presently active standards on CR need a major revision. It was observed by many users that the image quality for class B of EN 14784-2 is not achievable under the same exposure conditions as used for film exposure. A mathematical model was developed and tested, which allows the calculation of the image quality, proven by image quality indicators (IQI), depending on the fixed pattern noise and the efficiency of the used imaging plate (IP) scanner system. All tested IP scanner systems provide a fixed correlation between the measured signal/noise ratio (SNR) and the grey values in the digital images. The maximum achievable SNRmax depends on the fixed pattern noise of the plate (high dose limit). Depending on the exposure dose an optimum visibility of IQIs can be calculated and measured considering the attenuation coefficient for calculation of the contrast/noise ratio (CNR). The diameter of the just visible wire is proportional to 1/sqrt(CNR). The optimum tube voltage for best visibility of IQIs and maximum CNR depend on exposure dose. The optimum tube voltage for best visibility is achieved only at exposures with high dose. A dose dependant optimal tube voltage was not observed for film radiography.

Measurement and Modeling of Scatter Ratios at High Energies
---Gerd-Ruediger Jaenisch, Andreas Deresch, Carsten Bellon, Uwe Ewert, and Waldemar Przybilla, Federal Institute for Materials Research and Testing (BAM), Division VIII.3, Berlin, Germany

---Determining scatter ratios at high energies (>~1MeV) presents challenges not immediately obvious from measurements at conventional x-ray energies. This includes reduced attenuation even in heavy elements as well as a stronger forward bias of scattering. In order to check the reliability of different measurement setups with regard to material thicknesses, distances, and collimation, attenuation and scattering were separately simulated using the Monte Carlo code McRay. The simulation results greatly help in understanding the sources of radiation scattered into the detection area, thereby aiding in eliminating undesired contributions.
Session 27
SESSION 27
COMPOSITES AND COMPOSITE STRUCTURES
Stan I. Rokhlin, Dale E. Chimenti, and Peter B. Nagy, Co-Chairpersons
Salon E

8:30 AM  Guided Wave Phased Arrays for Defect Detection in Composite Plates
---J. P. Koduru and J. L. Rose, The Pennsylvania State University, Department of Engineering Science and Mechanics, University Park, PA 16802

8:50 AM  Use of Modal Acoustic Emission to Monitor Micromechanical Damage Progression in Carbon Fiber/Epoxy Tows and Implications for Related Composite Structures
---J. M. Waller and R. L. Saulsberry, NASA-JSC White Sands Test Facility, Laboratories Department, Las Cruces, NM 88004-0020; C. T. Nichols, New Mexico State University, Department of Mechanical and Aerospace Engineering, Las Cruces, NM 88004-0020; D. J. Wentzel, Miami University, Department of Physics, Oxford, OH 45056

9:10 AM  Fatigue Damage Identification in Composite Structures Through Ultrasonics and Wavelet Transform Signal Processing
---V. La Saponara, H.-Y. Tang, and C. Winkelmann, University of California, Mechanical and Aerospace Engineering, Davis, CA 95616-5294; W. Lestari, Embry-Riddle Aeronautical University, Aerospace Engineering, 3700 Willow Creek Road, Prescott, AZ 86301-3720

9:30 AM  Characterization of Waviness in Wind Turbine Blades Using Air Coupled Ultrasonics
---S. K. Chakrapani, V. Dayal., D. K. Hsu, and A. Gross, Iowa State University, Department of Aerospace Engineering, Ames, IA 50011; S. K. Chakrapani, V. Dayal, D. K. Hsu, and D. J. Barnard, Center for NDE, Iowa State University, 1915 Scholl Road, Ames, IA 50011

9:50 AM  Rapid Non-Contact Inspection System for Filament Wound Composite Pipe Structures: An Experimental Results and Numerical Studies
---J. M. Padiyar, K. Arun, C. V. Krishnamurthy, and K. Balasubramaniam, Indian Institute of Technology Madras, Center for Nondestructive Evaluation, Dept of Mechanical Engineering, Chennai, India

10:10 AM  Break

10:30 AM  Characterization of Material Degradation in Ceramic Matrix Composites Using Infrared Reflectance Spectroscopy
---A. T. Cooney and R. Y. Flattum-Riemers, Air Force Research Laboratory, AFRL/RXLP, 2230 10th St Bldg 655, Wright Patterson AFB, OH 45433-7817

10:50 AM  Flaw Detection in a Multi-Material Multi-Layered Composite: Using FEM and Air-Coupled UT
---R. A. Livings, V. Dayal, D. J. Barnard, and D. K. Hsu, Iowa State University, Center for NDE, Ames, IA, 50011

11:10 AM  Simulation Tools for UT Inspections of Multi-Layer Armor Panels
---N. Richter, F. Margetan, T. Gray, and R. B. Thompson, Iowa State University, Center for NDE, Ames, IA 50011

11:30 AM  Lunch (Please note: Lunch buffet lines open at 11:45 AM)
Guided Wave Phased Arrays for Defect Detection in Composite Plates
---Jaya Prakash Koduru and Joseph L. Rose, The Pennsylvania State University, Department of Engineering Science and Mechanics, University Park, PA 16802

Fiber reinforced composites are increasingly replacing metals in aerospace structures, their high strength to weight ratio and the capability to tailor their properties depending on the need makes them very desirable in comparison to metals. The development of fast and reliable non destructive inspection techniques is essential to monitor these structures during their life time. Defects like delamination, material loss due to erosion etc. are important and needs to be detected. Guided waves in plate like structures are fast emerging as the preferred choice for structural health monitoring owing to their long range propagation characteristics and multi-mode inspection capability to detect and classify defects. Recent developments in guided wave inspection technology have used phased array beamforming techniques to attain direction control over the inspection. However, the multi-mode characteristics of guided wave at any frequency complicate the beamforming procedure. Guided wave mode control techniques are developed and applied to the beamforming resulting in superior performance. Phased annular array transducers are developed to generate a desired mode omnidirectionally. Inspection is performed on a 16 layer plate like composite structure with the developed techniques and defects are imaged.

Use of Modal Acoustic Emission to Monitor Micromechanical Damage Progression in Carbon Fiber/Epoxy Tows and Implications for Related Composite Structures
---Jess M. Waller and Regor L. Saulsberry, NASA-JSC White Sands Test Facility, Laboratories Department, Las Cruces, NM 88004-0020; Charles T. Nichols, New Mexico State University, Department of Mechanical and Aerospace Engineering, Las Cruces, NM 88004-0020; Daniel J. Wentzel, Miami University, Department of Physics, Oxford, OH 45056

Broad-band modal acoustic emission (mAE) data was used to characterize micromechanical damage progression in uniaxial IM-7 and T1000 carbon fiber-epoxy tows subjected to an intermittent load hold tensile stress profile known to have demonstrated utility in activating the Felicity ratio (FR). Damage progression was followed by inspecting the Fast Fourier Transforms (FFTs) associated with individual, source locatable acoustic emission events. Detailed FFT data analysis revealed the occurrence of cooperative micromechanical damage events in a frequency range between approximately 100 kHz and 1 MHz. Further evidence of the existence of a characteristic universal damage parameter, having a measured value close to 0.96 and denoted FR*, or the critical Felicity ratio, was obtained for both IM-7 and T1000 single tow. The implications of using FR* to predict failure in carbon/epoxy composite materials is discussed, including the implications for related composite-containing components such as composite overwrapped pressure vessels (COPVs). Trends in the FFT data are also discussed; namely, the difference between the low and high energy events, the difference between early and late-life events, comparison of IM-7 and T1000 damage progression, and lastly, the similarity of events occurring at the onset of significant acoustic emission used to calculate the FR.
Fatigue Damage Identification in Composite Structures Through Ultrasonics and Wavelet Transform Signal Processing
---Valeria La Saponara, Hong-Yue Tang, and Charles Winkelmann, University of California, Mechanical and Aerospace Engineering, Davis, CA 95616-5294; Wahyu Lestari, Embry-Riddle Aeronautical University, Aerospace Engineering, 3700 Willow Creek Road, Prescott, AZ 86301-3720

---The prediction of life to failure of fiber-reinforced polymer composite structures in service is very challenging, due to factors such as the structures’ sensitivity to manufacturing defects, local stress raisers, and unforeseen loading conditions that may occur in the structure’s life. Ultrasonics with surface-bonded or embedded piezoelectric (PZT) transducers is a well-established methodology to discriminate between an intact and a damaged state. Signal processing techniques are required to interpret output voltages and correlate them with damage states and predictions of life to failure predictions. The current study investigates the damage behavior of fiberglass/epoxy specimens with surface-mounted and embedded piezoelectric (PZT) transducers, loaded under axial tensile fatigue in load control. The pitch-catch signals are acquired at certain cycle intervals, as the specimen is loaded at the mean stress in the testing machine. Thus, the specimen’s local and global damage states are complicated by the specimen’s own stretching under loading, which varies as a function of damage. We present a signal processing technique based on wavelet transforms: the denoised signal is processed with Gabor wavelet transforms, and the area of one of its contours is tracked throughout the fatigue life. Results seem to indicate the presence of a steady-state condition across different configurations, which may be used for life predictions.

Characterization of Waviness in Wind Turbine Blades Using Air Coupled Ultrasonics
---Sunil Kishore Chakrapani, Vinay Dayal, David K. Hsu, and Andrew Gross, Iowa State University, Department of Aerospace Engineering, Ames, IA 50011; Sunil Kishore Chakrapani, Vinay Dayal, David K. Hsu, and Daniel J. Barnard, Center for NDE, Iowa State University, 1915 Scholl Road, Ames, IA 50011

---Waviness in glass fiber reinforced composite is of high interest in composite research, since they result in the loss of stiffness. Several NDE techniques have been used previously to characterize waviness. This work is concerned with waves normal to the plies in a composite. Air-coupled ultrasonics was used to detect waviness in thick composites used in the manufacturing of wind turbine blades. Composite samples with different wave aspect ratios were studied. This gives us a better understanding of the effect of waviness in thick composites, and how it affects the life and performance of the composite. Finite Element model is created to understand the wave propagation in thick composite plates with waves of different aspect ratios.---TPI, Newton under the Advanced Manufacturing Innovation Initiative project to Iowa State University.
Rapid Non-Contact Inspection System for Filament Wound Composite Pipe Structures: An Experimental Results and Numerical Studies
---J. Padiyar, K. Arun, C. V. Krishnamurthy, and Krishnan Balasubramaniam, Indian Institute of Technology Madras, Center for Nondestructive Evaluation, Dept of Mechanical Engineering, Chennai, India

---Filament wound Fiber-reinforced composite structures are being widely used in pipe systems for offshore installations, pressure vessels and storage tanks. The damages that composites structures undergo are surface and sub-surface in nature. Of the various types of damages delamination in particular causes a significant reduction in compressive strength and stiffness. The NDT application proposed here relies on using Air coupled transducer to excite and receive the guided wave modes in Filament wound Pipe. The focus is on the development of rapid non-contact experimental system for finding delamination in Filament wound Fiber-reinforced composite structures. Due to high attenuation of the guided waves in the composite a preamplifier also proposed to be designed and fabricated increase the total gain of the amplifier and improve the signal to noise ratio. Furthermore commercial FEM software is used to develop a complete 3D numerical model of Filament wound pipe including the propagation through air and interaction of guided wave with delamination.

Characterization of Material Degradation in Ceramic Matrix Composites Using Infrared Reflectance Spectroscopy
---Adam T. Cooney and Richard Y. Flattum-Riemers, Air Force Research Laboratory, AFRL/RXLP, 2230 10th St Bldg 655, Wright Patterson AFB, OH 45433-7817

---Ceramic matrix composite materials for thermal protection systems are required to maintain operational performance in extreme thermal and mechanical environments. In-service inspection of materials capable of assessing the degree and extent of damage and degradation will be required to ensure the safety and readiness of future air vehicles. Infrared reflectance spectroscopy is an established material characterization technique capable of extracting information regarding the chemical composition of substances. The viability of this technique as a potentially powerful nondestructive evaluation method capable of monitoring degradation in thermal protection system materials subjected to extreme mechanical and thermal environments is analyzed. Several oxide-based and non-oxide-based ceramic matrix composite materials were stressed to failure in a high temperature environment and subsequently measured using infrared reflectance spectroscopy. Spectral signatures at locations along the length of the samples were compared resulting in distinct and monotonic reflectance peak changes while approaching the fracture point. The chemical significance of the observed signatures and the feasibility of infrared reflectance nondestructive evaluation techniques are discussed.
Flaw Detection in a Multi-Material Multi-Layered Composite: Using FEM and Air-Coupled UT

---Richard A. Livings, Vinay Dayal, Dan J. Barnard, and Dave K. Hsu, Iowa State University, Center for NDE, Ames, IA, 50011

---Ceramic tiles are the main ingredient of a multi-layer multi-material composite being considered for the modernization of tank armors. The high stiffness, low attenuation, and precise dimensions of these uniform tiles make them remarkable resonators when driven to vibrate. This study is aimed at modeling the vibration modes of the tiles and the composite lay-up with finite element analysis and comparing the results with the resonance modes observed in air-coupled ultrasonic excitation of the tiles and amour samples. Defects in the tile, during manufacturing or after usage, are expected to change the resonance modes. The comparison of a pristine tile/lay-up and a defective tile/lay-up will thus be a quantitative damage metric. The understanding of the vibration behavior of the tile, both by itself and in the composite lay-up, can provide useful guidance to the nondestructive evaluation of armor panels containing ceramic tiles.---This work is supported by the Army Research Laboratory.

Simulation Tools for UT Inspections of Multi-Layer Armor Panels

---Nate Richter, Frank Margetan, Tim Gray, and R. Bruce Thompson, Iowa State University, Center for NDE, Ames, IA 50011

---Some armor panels are fabricated from several layers of material including ceramics, graphite and/or glass composites, and rubber. This multi-layer makeup can complicate UT inspection, since many possible sound paths (including intra-layer reverberations) can contribute to observed UT signals. At last year’s QNDE conference we reported on baseline property measurements (density, sound speed, attenuation, etc.) for the constituents of one prototype panel, and we discussed how that information was used to choose an appropriate inspection frequency. We now report on progress to develop better simulation tools for armor panel inspections. In particular we consider normal-incidence pulse/echo inspections and use a paraxial beam model to predict time-domain signals for unflawed panels and those containing delaminations. The model uses the frequency-dependent baseline property data as inputs, and treats beam spread and focusing effects. We present comparisons of model predictions to experimental data, and we discuss the use of the model in inspection design.---Research was sponsored by the Army Research Laboratory and was accomplished under Cooperative Agreement Number W911NF-08-2-0036. The views and conclusions contained in this document are those of the authors and should not be interpreted as representing the official policies, either expressed or implied, of the Army Research Laboratory or the U.S. Government. The U.S. Government is authorized to reproduce and distribute reprints for Government purposes notwithstanding any copyright notation hereon.
Session 28
### SESSION 28

**NDE IN CIVIL ENGINEERING**  
Herbert Wiggenhauser, Chairperson  
Salons F-H

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<th>Time</th>
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<th>Authors</th>
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<tr>
<td>8:30 AM</td>
<td><strong>Ultrasonic and Seismic Imaging for Concrete Elements</strong></td>
<td>J. S. Popovics, K. S. Hall, T. Oh, and Suyun Ham, University of Illinois, Civil and Environmental Engineering, Urbana, IL 61801</td>
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<tr>
<td>8:50 AM</td>
<td><strong>Basic Study and Application for Ultrasonic Dispersion in Concrete Structures</strong></td>
<td>T. Mihara, M. Maruta, T. Hamajima, and H. Tashiro, University of Toyama, Graduate School of Engineering, Toyama, Japan; Y. Udagawa, ISL Co. Ltd., Nara, Japan</td>
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<tr>
<td>9:10 AM</td>
<td><strong>NDT Validation Facility at the Florida Department of Transportation</strong></td>
<td>D. Algernon, D. R. Hiltunen, and C. C. Ferraro, University of Florida, Civil &amp; Coastal Engineering Department, Gainesville, FL; C. Ishee, Florida Department of Transportation, State Materials Office, 5007 NE 39th Avenue, Gainesville, FL 32609</td>
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<tr>
<td>9:30 AM</td>
<td><strong>Monitoring of Reinforced Concrete Corrosion and Deterioration by Periodic Multi-Sensor Non-Destructive Evaluation</strong></td>
<td>R. W. Arndt, F. Jalinoos, J. Cui, and D. Huston, 1NRC Associate, NDE Center, Federal Highway Administration, McLean, VA 22101; Program Manager, NDE Center, Federal Highway Administration, McLean, VA 22101; University of Vermont, Burlington, VT 05405</td>
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<tr>
<td>9:50 AM</td>
<td><strong>Quantitative Solution for Active Thermography with Square Pulse Heating</strong></td>
<td>R. W. Arndt, Ch. Maierhofer, M. Röllig, and H. Wiggenhauser, NDE Center, Federal Highway Administration, McLean, VA 22101; Department of NDT, Federal Institute for Materials Research and Testing (BAM), 12205 Berlin, Germany</td>
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<td><strong>Break</strong></td>
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<td>10:30 AM</td>
<td><strong>Modification to the Zero Group Velocity (Impact Echo) Resonance Frequency in the Presence of Voids for the Inspection of Tendon Ducts</strong></td>
<td>O. Abraham and L.-M. Cottineau, Laboratoire Central des Ponts et Chaussées, Mesure Auscultation et Calcul Scientifique Department, Route de Bouaye, Bouguenais Cedex, 44341, France; J. S. Popovics, The University of Illinois, 205 N. Mathews Ave. MC 250, Urbana, IL 61801</td>
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<td>10:50 AM</td>
<td><strong>NDE of Steel Bridges for Fatigue Crack Detection and Monitoring</strong></td>
<td>P. Haldipur and F. Jalinoos, Federal Highway Administration, Escinc, 6300 Georgetown Pike, Mclean, VA 22101</td>
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<tr>
<td>11:10 AM</td>
<td><strong>Acoustic Emission Monitoring for Assessment of Steel Bridge Details</strong></td>
<td>D. E. Kosnik, Northwestern University, Infrastructure Technology Institute, Evanston, IL 60208; T. Hopwood, University of Kentucky, Kentucky Transportation Center, Lexington, KY 40506</td>
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<tr>
<td>11:30 AM</td>
<td><strong>Imaging Laser Analysis of Building Materials – Practical Examples</strong></td>
<td>G. Wilsch, A. Molkenthin, and D. Schaurich, Federal Institute for Materials Research and Testing (BAM), Berlin, Germany, H. Wiggenhauser to present</td>
</tr>
<tr>
<td>11:50 AM</td>
<td><strong>Use of Non-Linear Vibration Responses to Characterize Material Properties</strong></td>
<td>J. S. Popovics, University of Illinois, Civil and Environmental Engineering, Urbana, IL 61801; A. Lecunff, ENTPE, 3 rue Maurice Audin - 69518 Vaulx en Velin, France</td>
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<tr>
<td>12:10 PM</td>
<td><strong>Changes in the Propagation Characteristics of Elastic Wave in Concrete Under Compression</strong></td>
<td>P. Shokouhi, A. Zeoga, and H. Wiggenhauser, Federal Institute for Materials Research &amp; Testing, Uter den Eichen 87, Berlin D-12205, Germany</td>
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<td>12:30 PM</td>
<td><strong>Lunch</strong></td>
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Ultrasonic and Seismic Imaging for Concrete Elements  
---John S. Popovics, Kerry S. Hall, Taekeun Oh, and Suyun Ham, University of Illinois, Civil and Environmental Engineering, Urbana, IL 61801  

---Ongoing work toward contactless, air-coupled sensing of seismic and ultrasonic waves in concrete is presented. The ultrasonic equipment and sensors that are employed are described. Then two applications for concrete are discussed: (i) scanning impact-echo tests applied to bridge deck scanning and (ii) internal material reconstruction using ultrasonic tomography. The first application aims to locate and characterize defects within concrete bridge deck elements using impact-echo data that are collected continuously from a moving platform. The data are presented in the form of 3-dimensional “cloud” images, which indicate the presence of subsurface delamination defects. Next, ultrasonic tomography is applied to concrete elements using both fully contactless and semi-contact testing configurations. Various solutions for tomographic inversion and improvement of signal SNR are evaluated. Experimental ultrasonic tomography images are presented for concrete and other solid elements that locate high velocity (steel) and low velocity (voids) internal defects. These results demonstrate that contactless imaging and scanning can provide enhanced evaluation of unseen internal material defects within concrete structures.

Basic Study and Application for Ultrasonic Dispersion in Concrete Structures  
---Tsuyoshi Mihara, Masayuki Maruta, Takumi Hamajima, and Hatsuzo Tashiro, University of Toyama, Graduate School of Engineering, Toyama, Japan; Yoshio Udagawa, ISL Co. Ltd., Nara, Japan  

---The ultrasonic method is expected as a quantitative evaluation method of the damage for concrete structures. However conventional ultrasonic measurement systems for steel structures are difficult to apply for industrial concrete structures due to the large noise which considered as the ultrasonic scattering of aggregate in mortars. Thus applied frequency is lowered to 20 kHz for example and only the first traveling echo of penetration layout is used until now. However ultrasonic measurement is still difficult and have not recognized as a common evaluation method for concrete structure. In this research, after the simulation of the three dimensional concrete model by large-scale FEM, we focused on the large dispersion of the transmitted echo due to the velocity difference between aggregate and mortal. Then the super-broad band ultrasonic measurement system using step function pulser for the frequency of 500 kHz or less was applied for the penetration and reflective measurement of the concrete specimen with a thickness of 200 mm. Furthermore, waveform treatment procedures for improving the S/N ratio were applied as a basic research of the ultrasonic evaluation for a industrial concrete structure.
NDT Validation Facility at the Florida Department of Transportation
---Daniel Algernon, Dennis R. Hiltunen, and Christopher C. Ferraro, University of Florida, Civil & Coastal Engineering Department, Gainesville, FL; Charles Ishee, Florida Department of Transportation, State Materials Office, 5007 NE 39th Avenue, Gainesville, FL 32609

---Acoustic as well as electromagnetic methods can provide a valuable tool for the quality assessment of concrete bridges. For the efficient application in the field, the capabilities of the different methods in solving a specific testing problem have to be known. In a research project funded by the Florida Department of Transportation (FDOT) a first stage facility for the calibration and validation of NDT methods has been established. A test frame with two automated scanners has been designed and built, in which concrete blocks with artificial defects or testing problems can be tested by NDT methods like ultrasonic-echo, impact-echo, covermeter or Ground Penetrating Radar. The most relevant testing problems dealt with in this project are the location of reinforcement steel, tendon duct inspections and thickness measurements, but the capabilities and limitations of NDT methods in determining elastic parameters have also been investigated. 2D and 3D imaging techniques as well as signal processing such as the Synthetic Aperture Focusing Technique (SAFT) applied to the data provide a vivid representation of the results and make the interpretation easier and more intuitive. The capabilities and limitations of the different methods regarding the different testing problems are discussed.

Monitoring of Reinforced Concrete Corrosion and Deterioration by Periodic Multi-Sensor Non-Destructive Evaluation
---R. W. Arndt¹, F. Jalinoos², J. Cui³, and D. Huston⁴, ¹NRC Associate, NDE Center, Federal Highway Administration, McLean, VA 22101; ²Program Manager, NDE Center, Federal Highway Administration, McLean, VA 22101; ³University of Vermont, Burlington, VT 05405

---This paper describes the concept of periodic non-destructive evaluation (NDE) surveys as a means for structural health monitoring (SHM) and provides results from a benchmark project set up in Federal Highway Administration’s NDE Center. The focus of this collaborative effort is to design and build concrete test specimens, artificially induce and monitor corrosion, periodically perform multi-sensor NDE inspections, and conduct 3D imaging. The aim is to devise a test protocol for structural health monitoring of reinforced concrete structures by performing periodic baseline NDE measurements as a strategy for bridge maintenance and preservation. The monitoring system consists of corrosion sensors supported by periodic half-cell potential measurements. The NDE methods utilized are an ultrasonic shear wave tomography system, impact echo, ground penetrating radar and induction infrared thermography. Since the periodic multi-sensor NDE for SHM requires a high standard of repeatability an automated scanning system and data fusion is utilized in the laboratory experiment.
Quantitative Solution for Active Thermography With Square Pulse Heating
---R. W. Arndt¹, Ch. Maierhofer², M. Röllig², and Herbert Wiggenhauser², ¹NRC Associate, NDE Center, Federal Highway Administration, McLean, VA 22101; ²Department of NDT, Federal Institute for Materials Research and Testing (BAM), 12205 Berlin, Germany

---A quantitative solution for active thermography in the frequency domain with square pulse heating and long observation times is presented. It aims at complementing the established approaches for defects depth calculation for measurements with long heating and observation times quite common in some applications of active thermography in civil engineering (CE) and cultural heritage. The quantitative approach is based on the thermal diffusivity of the material and the characteristic frequency of the negative maximum of phase and amplitude contrast and might be understood as an amplitude expended pulsed phase thermography or a square pulse thermography in frequency domain. The solution was developed in the Federal Institute for Materials Research and Testing (BAM), in the frame of a research project funded by the German Research Foundatin (DFG) in cooperation with the Technical University of Berlin especially for applications in CE but should be easily extendable to other fields of application. The main focus of the paper is the description of the concept and its application at concrete test specimens of BAM to determine the concrete cover of artificially manufactured defects.

Modification to the Zero Group Velocity (Impact Echo) Resonance Frequency in the Presence of Voids for the Inspection of Tendon Ducts
---Odile Abraham and Louis-Marie Cottineau, Laboratoire Central des Ponts et Chaussées, Mesure Auscultation et Calcul Scientifique Department, Route de Bouaye, Bouguenais Cedex, 44341, France; John Sandor Popovics, The University of Illinois, 205 N. Mathews Ave. MC 250, Urbana, IL 61801

---Non-destructive testing of civil engineering infrastructure is becoming of primary importance for their diagnosis, residual service life estimation and/or structural health monitoring. Post-tensioned concrete bridges may be subject to sudden collapse due to tendon breakage. In France, tendon ducts are currently investigated with the gamma ray radiometry method, but alternative non ionizing techniques are currently sought. Since the mid nineties, the impact echo method has been proposed to detect voids in tendon ducts, where a void indicates a possible location for tendon corrosion and rupture. The impact echo method is currently used in civil engineering to determine thicknesses or depths by measuring the resonance frequency of the S1 Lamb mode associated to its zero group velocity (ZGV frequency). A downward shift of the ZGV frequency is commonly associated to the presence of an internal void, but limited evidence of such phenomena in case of fully filled ducts calls for deeper physical insight. In this paper we show impact-echo results obtained with a laser interferometer on a 0.25m thick concrete test wall including filled and partially of fully empty ducts (either thin or thick) and corroborate the ZGV frequency to the modification of the local stiffness of the wall. Numerical results with the finite element method, together with a schematic semi analytical model, are also presented.
NDE of Steel Bridges for Fatigue Crack Detection and Monitoring
---Pranaam Haldipur and Frank Jalinoos, Federal Highway Administration, Escinc, 6300 Georgetown Pike, Mclean, VA 22101

---Four bridge sites in the states of Maryland, Virginia, and Florida have been selected to be part of a study to assess the inspection capabilities of NDE technologies for inspection and long-term monitoring of steel bridge components. This study is a part of the Steel Bridge Testing Program (SBTP) carried out by the Federal Highway Administration NDE Center. The objective of the program is to assess suitable advanced NDE technologies to detect and monitor fatigue cracks in steel bridges. The study includes the approaches (visual and magnetic particle inspection) that most state departments of transportation (DOT) follow during a biennial bridge inspection. In addition, advanced NDE technologies such as Phased Array Ultrasonics, Meandering Winding Magnetometer (MWM) Eddy Current Arrays, conventional Eddy Current, Acoustic Emission Sensors and Electrochemical Fatigue Sensors will be assessed and their capability in providing specific information on the geometry and the state (active/in-active) of the fatigue cracks will be evaluated. This paper describes the results of this ongoing study at the four bridge sites.

Acoustic Emission Monitoring for Assessment of Steel Bridge Details
---David E. Kosnik, Northwestern University, Infrastructure Technology Institute, Evanston, IL 60208; Theodore Hopwood, University of Kentucky, Kentucky Transportation Center, Lexington, KY 40506

---Acoustic emission (AE) testing is a method by which specialized transducers are used to “listen” for the ultrasonic noises made by engineering materials under stress. AE is traditionally associated with testing of pressure vessels; however, a similar release of stress waves occurs near the tips of cracks in steel bridge details. Applications of AE to testing of steel bridge details show promise in answering two important questions in steel bridge preservation by 1) determining if a known crack is actively propagating or extinguished, and 2) locating crack tips or other flaws in a high-stress or other area suspected to contain flaws. Quantitative measurements may be obtained by deploying an array of AE transducers around the area of interest, using array geometry and post-processing filters to reject noise from other parts of the bridge. This paper will summarize several AE monitoring deployments on two large Interstate highway bridges. In one case, AE data were used to evaluate proposed retrofit designs on a steel box girder bridge; in the other, AE was used along with conventional non-destructive testing methods to characterize a crack and additional defect in a fracture-critical member of a steel truss bridge. The paper will also discuss best practices for AE work on highway bridges and the limitations – including potential misuses – of the technique.
Imaging Laser Analysis of Building Materials – Practical Examples
---G. Wilsch, A. Molkenthin, and D. Schaurich, Federal Institute for Materials Research and Testing (BAM), Berlin, Germany
NOTE: H. Wiggenhauser to present this work

---The Laser induced Breakdown Spectroscopy (LIBS) is supplement and extension of standard chemical methods and SEM- or Micro-RFA-applications. As a laboratory method LIBS is used to gain color coded images of composition, distribution of characteristic ions and/or ingress characteristic of damaging substances. To create a depth profile of element concentration a core has to be taken and split along the core axis. The main advantages are spatial resolution in mm-scale, measurement direct on the sample surface with minor preparation, online results, detection of all elements, quantitative results, fast and automated analysis. LIBS can measure many elements at a time with high dynamic range. Different damage mechanisms like corrosion of reinforcement (Chloride), corrosion of concrete (Sulfate), alkali-silica-reaction or weathering of concrete can be investigated. Examples for quantitative measurements of chlorine and sulfur concentrations on real samples are demonstrated. The potential of LIBS for the evaluation of composition during removal on a micrometer-scale is shown. At BAM also a mobile system for on-site use is developed. Results of mobile LIBS-System to evaluate the chloride concentration are presented.

Use of Non-Linear Vibration Responses to Characterize Material Properties
---John S. Popovics, University of Illinois, Civil and Environmental Engineering, Urbana, IL 61801; Alexandre Lecunff, ENTPE, 3 rue Maurice Audin - 69518 Vaulx en Velin, France

---The non-linear response of a specimen to applied load may yield useful information about the material. For dynamic cases such as vibration, a non-linear material response manifests as strain softening (decreasing stiffness or modulus with increasing dynamic strain amplitude), the generation of additional higher harmonics at integer multiples above the fundamental excitation response, and generation of harmonic side bands in the case a two-frequency dynamic input. These non-linear dynamic responses have been applied as sensitive indicators to porous, ceramic-like materials (such as rock and concrete), where additional constitutive parameters, beyond the two elastic non-linear coefficients, are considered in the analysis. The aim of this work is develop specific links between changes in the non-linear constitutive parameters to the identified vibration response characteristics of standard prismatic concrete elements. Numerical simulation (FEM) data are employed to establish this link, where various vibration mode families of vibration (flexural and longitudinal), support conditions (cantelever and simply supported) and constitutive models (linear, 2nd order nonlinear and nonlinear hysteretic) are considered. Experimental data are presented to verify the results. The results illustrate the promise of the method to characterize nonlinear constitutive parameters from vibration responses, which may lead to sensitive detection of internal damage in cement-based materials at early stages.
Changes in the Propagation Characteristics of Elastic Wave in Concrete Under Compression
---Parisa Shokouhi, Andreas Zeöga, and Herbert Wiggenhauser, Federal Institute for Materials Research & Testing, Uter den Eichen 87, Berlin D-12205, Germany

---Stress- and damage-induced changes in the propagation velocities and frequency content of elastic waves in concrete were experimentally evaluated. A large prismatic concrete column having a cross section of 0.5 x 0.6 m² and length of 1.5m was gradually loaded in very small steps (0.67 MPa) until reaching failure. At each step, the load was held constant long enough to allow taking ultrasonic and surface wave velocity measurements. Ultrasonic measurements (100 KHz) were taken in four different directions/polarizations: parallel to the loading (longitudinal waves) and perpendicular to the loading (longitudinal waves and shear waves in two different polarizations). Surface wave velocities were measured using two different measurement techniques: sensor array and laser vibrometer. An eight-sensor linear array was mounted on one of the two largest sides (0.6 x 1.5 m²) of the specimen. Two hammers were glued on either side of the array (top and bottom). This setup allowed the surface wave velocity measurements parallel to the loading on top and middle of the specimen. Laser vibrometer was used to measure the surface wave velocities on the opposite side of the specimen. The velocities were measured on the surface of the specimen along different directions. Using both measurement setups, the surface wave velocities were measured in the sonic frequency range (< 20 KHz). Surface deformations as well as the changes in the dimensions of the specimen were also recorded using a number of strain gauges and LDVTs. A concise summary of the findings of this experiment is presented in this paper. Stress-dependency of elastic wave velocities was observed in both ultrasonic and sonic surface wave velocity measurements. Sonic surface wave velocities exhibited however a greater sensitivity. A gradual shift of frequency content was observed in surface wave velocity measurements. The largest effects were measured parallel to the loading.
Session 29
SESSION 29 – POSTERS
NONLINEAR UT TECHNIQUES, SIGNAL PROCESSING,
MATERIALS AND MATERIAL PROPERTIES, COMPOSITE MATERIALS,
NDE FOR CIVIL STRUCTURES, NEW TECHNIQUES AND SYSTEMS, RELIABILITY
Cabrillo Salons 1 and 2

1:30 PM

**Nonlinear UT Techniques**

**Measurements of Nonlinear Harmonic Waves at Cracked Interfaces**
---H. Jeong, Wonkwang University, Division of Mechanical and Automotive Engineering, Iksan, Heonbuk 570-749, Korea; D. Barnard, Iowa State University, Center for Nondestructive Evaluation, 1915 Scholl Road, Ames, IA 50011

**Strongly Nonlinear Vibration Phenomena in Plates Excited by High-Intensive Ultrasonic Pulses**
---Z.-J. Chen, K. Zheng, and S.-Y. Zhang, Nanjing University, Lab of Modern Acoustics, Institute of Acoustics, Nanjing, China

**Assessment of Damage in Thermally Degraded 2250 Duplex Stainless Steel Using Nonlinear Resonance Ultrasound Spectroscopy Technique**
---S. Kim, Department of System Dynamics, Korea Institute of Machinery and Materials, Daejeon, 305-343, Republic of Korea; J.-Y. Kim and L. J. Jacobs, Georgia Institute of Technology, School of Civil and Environmental Engineering, Atlanta, GA 30332; A. Ruiz, Instituto de Investigaciones Metalúrgicas, Universidad Michoacana de San Nicolás de Hidalgo, Morelia, Michoacán, C.P. 58000, México

**Signal Processing**

**Improving Synthetic Aperture Image by Image Compounding in Beamforming Process**
---O. Martinez-Graullera, C. J. Martin, L. G. Ullate, D. Romero, M. Perez, and M. Parrilla, Centro de Acústica Aplicada y Evaluación No Destructiva (UPM-CSIC), ctra. Campo Real 0,200 (La Poveda) Arganda del Rey (Madrid) 28500 Spain; R. T. Higuti, Universidade Estadual Paulista, Department of Electrical Engineering, Av. Brasil, 56, Ilha Solteira, SP, 15385-000, Brazil

**Characterization of Cast Iron Microstructure Through the Statistical Fluctuation and Fractal Analyses of Ultrasonic Backscattered Signals**
---E. P. de Moura, P. G. Normando, and L. L. Gonçalves, Universidade Federal do Ceará, Departamento de Engenharia Metalúrgica e de Materiais, Fortaleza, Ceará, Brazil; S. E. Kruger, Institut des Matériaux Industriels, Conseil National des Recherche, Boucherville, Quebec, Canada

**Intelligent System for Radiogram Analysis**
---R. Sikora, T. Chady, P. Baniukiewicz, P. Lopato, L. Napierala, and T. Pietrusewicz; West Pomeranian University of Technology in Szczecin, Faculty of Electrical Engineering, Szczecin, Poland
Materials and Material Properties

Piezoelectric Material for Use in Harsh Environments
---D. A. Parks and B. R. Tittmann, Penn State University, Engineering Science and Mechanics Department, University Park, PA 16802

The Fatigue Evaluation Method for Structural Stainless Steels Using the Magnetic Sensor Composed of Three Pancake Type Coils
---M. Oka and T. Yakushiji, Oita National College of Technology, 1666 Maki, Oita; Y. Tsuchida, and M. Enokizono, Oita University, 700 Danno-haru, Oita 870-1192, Japan

Evaluation of Stress Effect to Vector Magnetic Properties on Electrical Steel Sheets
---Y. Kai, Y. Tsuchida, T. Todaka, and M. Enokizono, Oita University, Faculty of Engineering, Oita 870-1192, Japan

Characterization of Residual Stresses in Ferrous Components by Magnetic Anisotropy Measurements Using a Hall Sensor Array Probe
---C. C. H. Lo, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

Evaluation of Surface Hardening by Measuring Magnetic Properties
---Y. Tsuchida, T. Matsuda, and M. Enokizono, Oita University, Faculty of Engineering, Oita 870-1192, Japan

Search of the Order of Passes of an Austenitic Weld by Optimization of an Inversion Process of Ultrasound Data
---C. Gueudre, M. Checkroun, J. Moysan, and G. Corneloup, LCND, Laboratoire de Caractérisation Non Destructive (lcnd.fr), Université de la Méditerranée, 13625 Aix en Provence, France; L. Le Marrec, IRMAR, Institut de Recherche Mathématique de Rennes, UMR 6625 du CNRS, Campus de Beaulieu, 35042 Rennes, France; B. Chassignole, EDF R&D, Les Renardières, Département MMC, Avenue des Renardières, 77818 Moret sur Loing, France

Composite Materials

Porosity Detection in Ceramic Armor Tiles Via UT Time-of-Flight
---F. J. Margetan, N. Richter, and T. Jensen, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

Ultrasonic Velocity Measurements in Chopped Carbon Fiber Composites
---T. N. Claytor, M. L. Steinzig, and J. F. Hunter, Los Alamos National Laboratory, Los Alamos, NM 87545

Ultrasonic Pitch-Catch Study for Evaluating Fiber Orientation and Porosity Distribution in CF/Epoxy Composites
---K.-H. Im, Woosuk University 490, Department of Automotive Eng., Hujung-ri, Samrae-up, Wanjungun, Chonbuk, 565-701, Korea; D. K. Hsu and D. Barnard, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, Iowa 50011; I.-Y. Yang, Chosun University, Department of Mechanical Design Engineering, 375 Seosuk-dong, Dong-gu, Kwangju 501-759, Korea; J.-W. Park, Chosun University, Department of Naval Architecture and Ocean Eng., Gwangju 501-759, Korea

Guided Wave Scattering by Anisotropic Layer Delamination
---R. A. Roberts, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

Guided Wave Sensing of Structural Defects in Composite Vehicle Armor
---J. Stilley, P. Clayton, D. E. Chimenti, and R. A. Roberts, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011
NDE for Civil Structures

Nondestructive Evaluation of Prestressed Concrete Cylinder Pipe by Resonance Acoustic Spectroscopy
---J. C. Lesage and A. N. Sinclair, University of Toronto, Department of Mechanical and Industrial Engineering, Toronto, Ontario, Canada; F. Honarvar, K. N. Toosi University of Technology, Faculty of Mechanical Engineering, Tehran, Iran

NDT Data Fusion for Evaluating Concrete Structure
---M.-A. Ploix, V. Garnier, and J. Moysan, LCND, Aix-en-Provence, France; D. Breysse, GHYMAC, Bordeaux, France

Following Modifications of the Stress Level of Concrete Structures with CODA Wave Interferometry: Estimation of the Investigated Zone
---Y. Zhang, O. Abraham, L.-M. Cottineau, and O. Durand, Laboratoire Central des Ponts et Chaussées, Department Mesure Auscultation & Calcul Scientifique, BP 4129 44 341 Bouguenais Cedex, France; E. Larose and T. Planes, Laboratoire de Geophysique et de tecthonophysique, Université Joseph Fourier, BP 53 38041 Grenoble Cedex 9, France; A. Le Duff, Ecole Supérieure d'Electronique de l'Ouest, 4 rue Merlet de la Boulaye - BP 30926 49009 Angers Cedex 01, France; B. Lascoup, Ecole Supérieure des Techniques Aéronautiques et de Construction Automobile, Parc Universitaire de Laval Changé Rue Georges Charpak, BP 76121 53061 Laval Cedex 9, France; V. Tournat and R. El Guerjouma, Laboratoire d'Acoustique de l'Université du Maine, Avenue Olivier Messiaen 72085 LE MANS Cedex 9, France

Ultrasonic Guided Wave for Non Destructive Testing in High Speed Railways: Preliminary Results
---B. Rubio, N. Galarza, and E. Moreno, Fundación LEIA, C.D.T., 01510 Miñano, Álava, Spain; R. González, DASEL, S.L., 28500 Arganda del Rey, Madrid, Spain; J. A. Otero, Instituto de Cibernética, Matemática y Física - ICIMAF, 10400 Havana, Cuba

Investigation of EMAT Technique Evaluation of Axial Flaws in Gas Pipelines

Development of Ultrasonic Flaw Imaging Techniques for Detection of Flaws in Plate-Like Structure Using EMAT

Monitoring and Evaluation of Damages in Steel Beams by Using Electro-Mechanical Impedance Method
---Z. Liu, N. Wang, G. Song, J. Jiao, C. He, and B. Wu, College of Mechanical Engineering and Applied Electronics Technology, Beijing University of Technology, Beijing, 100124, China

New Techniques and Systems

Structural Damage Identification in Wind Turbine Blades Using Piezoelectric Active Sensing with Ultrasonic Validation
Plate Wave Transmission/Reflection at Geometric Obstructions
---R. A. Roberts, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

Evolutionary Technique for Designing Optimized Arrays
---J. R. Villazón and A. Ibáñez, Centro de Acústica Aplicada y Evaluación No Destructiva, CAEND (UPM - CSIC), Madrid, Spain

A Data-Driven Correction Method for Phase Array Element Sensitivity
---A. Volker and R. van Vossen, TNO, P. O. Box 155, 2600 AD Delft; P. van Capel, Universiteit Utrecht

Automatic Magnetic Particle Inspection System for the Bracket’s Welds of Atucha I Nuclear Power Plant’s Pressure Vessel

Potential of Ultrasounds for NDT of a Structure Located Behind Parallel Immersed Plates
---G. Corneloup, M.-A. Ploix, J.-F. Chaix, and I. Lillamand, LCND, Université de la Méditerranée, Aix-en-Provence, France; F. Baque, CEA Cadarache, DEN/DTN/STPA/LIET, St Paul lez Durance, France

Extremely Short Impulse Eddy Current Testing System for Ti Samples
---T. Chady and P. Frankowski, West Pomeranian University of Technology in Szczecin, Faculty of Electrical Engineering, Szczecin, Poland

Microwave Broadband One-Port Portable Vector Network Analyzer Used for a Multitude of NDT Application
---M. T. Ghasr, M. A. Baumgartner, and R. Zoughi, Missouri University of Science and Technology (S&T), Applied Microwave Nondestructive Testing Laboratory (amntl), Electrical and Computer Engineering Department, Rolla, MO 65409

Signal Modeling in the Far-Infrared Region for Nondestructive Evaluation Applications
---C.-P. Chiou, D. K. Hsu, D. Barnard, and K.-H. Im, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

Comparison of Novel Non-Destructive Evaluation Techniques for the Analysis of Biodiesel Fuel Quality
---K. Boudreau, R. Johnson, M. Kropf, and B. R. Tittmann, Penn State, Department of Engineering Science and Mechanics, 212 EES Building, University Park, PA 16802

Reliability

Classification Procedure in Limited Angle Tomography System
---P. Baniukiewicz, W. Chlewicki, A. Brykalski, and T. Chady, West Pomeranian University of Technology in Szczecin, Faculty of Electrical Engineering, Szczecin, Poland

3:10 PM Break
Nonlinear Harmonic Waves at Cracked Interfaces

Hyunjo Jeong, Wonkwang University, Division of Mechanical and Automotive Engineering, Iksan, Heonbuk 570-749, Korea; Dan Barnard, Iowa State University, Center for Nondestructive Evaluation, 1915 Scholl Road Ames, IA 50011

Nonlinear harmonic waves generated at cracked interfaces are investigated both experimentally and theoretically. A compact tension specimen is fabricated and the amplitude of transmitted wave is analyzed as a function of position along the fatigued crack surface. In order to measure as many nonlinear harmonic components as possible a broadband Lithium Niobate (LiNbO3) transducers are employed together with a calibration technique for making absolute amplitude measurements with fluid-coupled receiving transducers. Cracked interfaces are shown to generate high acoustic nonlinearities which are manifested as harmonics in the power spectrum of the received signal. The first subharmonic (f/2) and the second harmonic (2f) waves are found to be dominant nonlinear components for an incident toneburst signal of frequency f. To explain the observed nonlinear behavior a partially closed crack is modeled by planar half interfaces that can account for crack parameters such as crack opening displacement and crack surface conditions. The simulation results show reasonable agreements with the experimental results.

Strongly Nonlinear Vibration Phenomena in Plates Excited by High-Intensive Ultrasonic Pulses

Zhao-jiang Chen, Kai Zheng, and Shu-yi Zhang, Nanjing University, Lab of Modern Acoustics, Institute of Acoustics, Nanjing, China

It is well known that the ultrasonic infrared (UIR) imaging technique has been widely applied in NDE/T, in which it is found that the detection sensitivity is improved greatly as the sample vibration in chaos compared with that in non-chaos. In this paper, to study the mechanism of the complicated phenomena, the strongly nonlinear vibration phenomena including superharmonics, subharmonics, quasi-subharmonics and chaos in metal plates excited by intensive ultrasonic pulses are studied experimentally and theoretically. In the experiments, the nonlinear vibrations are excited by high-intensive ultrasonic pulses via an ultrasonic horn and measured by a laser vibrometer in different conditions. Based on the experimental results, a vibro-impact model with nonlinear contact damping is presented to explore the generation mechanism of the complicated nonlinear vibrations in the plates. In the dynamic model, the intermittent impact between the ultrasonic transducer horn and plate are considered as the main source for generating the nonlinear vibration. The numerical calculation results are in good agreement with that of the experimental measurements, which illustrate that the amplitude of the chaotic vibration is larger than that of non-chaotic vibration and the chaotic waveform is more complex. Therefore, the theoretical results can explain suitably the experimentally observed phenomena.
Nonlinear UT Techniques

Assessment of Damage in Thermally Degraded 2205 Duplex Stainless Steel Using Nonlinear Resonance Ultrasound Spectroscopy Technique
---SangRyul Kim, Department of System Dynamics, Korea Institute of Machinery and Materials, Daejeon, 305-343, Republic of Korea; Jin-Yeon Kim and Laurence J. Jacobs, School of Civil and Environmental Engineering, Georgia Institute of Technology, Atlanta, GA 30332; Alberto Ruiz, Instituto de Investigaciones Metalúrgicas, Universidad Michoacana de San Nicolás de Hidalgo, Morelia, Michoacán, C.P. 58000, México

---Previous studies show that the nonlinear resonance ultrasound spectroscopy (NRUS) technique has high sensitivity to the microstructural damage in various materials. In this paper, the NRUS technique is applied to the assessment of damage in thermally degraded 2205 duplex stainless steel samples that have been aged isothermally at 700°C for different time intervals. Nonlinear response near the fundamental resonance frequency of each sample is measured using swept-sine signals with increasing excitation amplitude, and then the amount of resonance frequency shift versus the input amplitude is evaluated. The comparison of the results shows that the change in the resonance frequency increases largely with the degradation time and thus the level of thermal damage. The main cause of the thermal degradation and the increase in nonlinearity is attributed to the production of carbide precipitates and the changes in grain boundary structure. These are supported with micrographs. This work suggests using the NRUS technique to evaluate thermal damage in this material and to investigate the changes in microstructure.

Signal Processing

Improving Synthetic Aperture Image by Image Compounding in Beamforming Process
---Oscar Martinez-Graullera, Carlos J. Martin, Luis G. Ullate, David Romero, Manuel Perez, and Montserrat Parrilla, Centro de Acústica Aplicada y Evaluación No Destructiva (UPM-CSIC), ctra. Campo Real 0,200 (La Poveda) Arganda del Rey (Madrid) 28500 Spain; Ricardo T. Higuti, Universidade Estadual Paulista, Department of Electrical Engineering, Av. Brasil, 56, Ilha Solteira, SP, 15385-000, Brazil

---In this work, signal processing techniques are used to improve the quality of images based on multi-element synthetic aperture techniques. Dividing the array into partial segments, two images with different apodization functions are composed per segment, which result in different resolution and contrast. Afterwards, following a criterion of image polarity coincidence and order statistics, image compounding between all segments is performed in order to reduce noise and artifacts. Experimental results are presented, reinforcing our conclusions. Thus, this method is applied to steel or carbon fiber pieces, with good improvements of resolution and image contrast. Finally, a real time implementation integrated in the beamforming process and based on GPGPU techniques is also presented.
Signal Processing

Characterization of Cast Iron Microstructure Through the Statistical Fluctuation and Fractal Analyses of Ultrasonic Backscattered Signals
---Elineudo P. de Moura, Paulo G. Normando, and Lindberg L. Gonçalves, Universidade Federal do Ceará, Departamento de Engenharia Metalúrgica e de Materiais, Fortaleza, Ceará, Brazil; Silvio E. Kruger, Institut des Matériaux Industriels, Conseil National des Recherche, Boucherville, Quebec, Canada

---This work aims to identify the different microstructures presented by cast iron, namely, lamellar, vermicular and spheroidal microstructures, through the statistical fluctuation and fractal analyses of backscattered ultrasonic signals. The signals were obtained by using a broad band ultrasonic probe with a central frequency of 5 MHz. The statistical fluctuations of the ultrasonic signals were analyzed by means of Hurst (RSA) and detrended-fluctuation analyses (DFA), and the fractal analyses were carried out by applying the minimal cover and box-counting techniques to the signals. The curves obtained for the statistical fluctuations and fractal analyses, as functions of the time window, were processed by using two pattern classification techniques, namely, principal-component analysis (PCA) and Karhunen-Loève expansion. For the Karhunen-Loève expansion, an approximately 100% success rate has been reached for the classification of the different microstructures, for the training and the testing sets of events, and the results presented correspond to an average taken over a 100 randomly chosen sets of events. These results indicate that the statistical fluctuation and fractal analyses are effective additional tools for recognition of the different cast iron microstructures.

Signal Processing

Intelligent System for Radiogram Analysis
---Ryszard Sikora, Tomasz Chady, Piotr Baniukiewicz, Przemystaw Lopato, Lech Napierala, and Tomasz Pietrusewicz; West Pomeranian University of Technology in Szczecin, Faculty of Electrical Engineering, Szczecin, Poland

---In this paper a concept of an Intelligent System for Radiogram Analysis (ISAR) for welds quality inspection is presented. ISAR is created in order to support radiologist in his work. It consists of hardware and software solutions. The hardware side of the system contains digital radiography scanner and dedicated computer. The software is based on the application, which supports variety of sources: selected radiogram scanners, imaging plate scanners and digital flat panels. Software modules contains preliminary image processing (linear and nonlinear filtering algorithms) as well as histogram equalization. It includes also some specialized functions, like IQI detection, that automatically detects and removes image quality indicators according to the EN-462-1 norm. Methods of defects extraction and tresholding (Sauvola, Niblack, Otsu, Iteretive etc.) are also implemented. All functions are prepared for parallel images processing in order to increase calculation speed. After the preliminary signal processing the original and proceeded images can be visualized. Then ISAR evaluates welds quality with aid of fuzzy logic standards and returns information about welding defects to the data base. This work was supported by the Ministry of Education and Science, Poland, under grant N R01 0037 06 (2009–2012).
Materials and Material Properties

**Piezoelectric Material for Use in Harsh Environments**
---David A. Parks and Bernhard R Tittmann, Penn State University, Engineering Science and Mechanics Department, University Park, PA 16802

---Ultrasonic transducers for use in high temperature environments are the focus of our research. We have tested aluminum nitride up to 1000°Celsius. We utilized a variety of ultrasonic systems to operate the aluminum nitride in pulse echo mode, including a 13 MHz tone burst and a spike pulse. It has been found that commercially available aluminum nitride has a widely varying resistivity. It has been suggested that this variation in the resistivity is due to residual impurities. We report a strong correlation between low resistivity and low temperature failure as an ultrasonic transducer. Several ultrasonic couplants were investigated, including MgO or Al₂O₃ based adhesives and thin foils. Although the adhesives have been shown to work excellently, thermal expansion mismatch can become problematic with this technique. Additionally, a future aim of our research is to develop a transducer for use in a nuclear reactor. Therefore, foil coupling was considered due to the fact that Al₂O₃ based adhesives have been said, by Kazys, to become porous and brittle in a radiation environment.

Materials and Material Properties

**The Fatigue Evaluation Method for Structural Stainless Steels Using the Magnetic Sensor Composed of Three Pancake Type Coils**
---M. Oka and T. Yakushiji, Oita National College of Technology, 1666 Maki, Oita; Y. Tsuchida, and M. Enokizono, Oita University, 700 Dannoharu, Oita 870-1192, Japan

---A lot of metallic structure materials like the stainless steels are used in our surroundings now. If the external force is repeatedly added for many years, it is thought that fatigue damage accumulates in the stainless steels. When excessive fatigue damage accumulates in them, there is a possibility that they are destroyed by fatigue damage accumulation. Therefore, it is important to know the amount of the fatigue in them to prevent them from doing the fatigue destruction. There is an eddy current method in one of the methods of evaluating the amount of the fatigue damage of them by the non-destructive testing. We are developing the method of the fatigue evaluation of the stainless steels with a magnetic sensor composed of three pancake type coils. In this research, the inspection objects were the stainless steels such as SUS304 and SUS430. The method of the fatigue evaluation for the stainless steels had the good correlation between the accumulative amount of fatigue damage in the stainless steels and the output signal of the sensor. This paper describes the evaluation method of fatigue damage in the stainless steels that uses the magnetic sensor composed of three pancake type coils.
Materials and Material Properties

Evaluation of Stress Effect to Vector Magnetic Properties on Electrical Steel Sheets
---Yuichiro Kai, Yuji Tsuchida, Takashi Todaka, and Masato Enokizono, Oita University, Faculty of Engineering, Oita 870-1192, Japan

---Electrical steel sheets and permanent magnets are used for an electrical machine. It is important for effective use of those materials to evaluate the magnetic properties in the electrical steel sheet. Specially, the electrical steel sheets are used as main materials in the electrical machine. The magnetic properties in the electrical steel sheet are changed complicatedly due to alternating and rotating magnetic flux in the rotating machine. In general, the magnetic property parallel to the applied magnetic field is evaluated by a single sheet testing or an Epstein testing. A measurement method for measuring B and H as the vector quantities has been developed, and some different magnetic properties in the electrical steel sheet under the alternating and the rotating magnetic flux conditions have been made clear. In addition, it is well known that the residual stress, which is occurred during the manufacturing process, is considered as one of the factors to the deterioration of the magnetic properties. Therefore, it is important to clarify the relationship between the magnetic properties and the stress in the electrical steel sheet. In this paper, the vector magnetic properties under stress condition are examined by using a newly developed vector magnetic measurement system.

Materials and Material Properties

Characterization of Residual Stresses in Ferrous Components by Magnetic Anisotropy Measurements Using a Hall Sensor Array Probe
---Chester C. H. Lo, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---This paper reports on a recent study aimed at improving a novel measurement technique for characterization of residual stresses in ferrous components. The technique is based on the fact that stresses, including applied and residual stresses, induce an anisotropy in magnetic properties via the magnetomechanical effect. In this work, a surface sensor probe comprising an angular array of Hall effect sensors was developed to determine the orientations and magnitudes of principal residual stresses. The performance of the sensor probe was evaluated using a series of heat treated AISI 1018 steel plates with different residual stresses measured by the conventional XRD sine-square-psi method. The sensor array outputs were found to vary as a sinusoidal function of the angular position of the sensors with a period of 180 degree for all samples. The maximum and minimum signals were detected along the principle stress axes of the samples, indicating the presence of a stress-induced, uniaxial magnetic anisotropy. The amplitude of signal variations increases approximately linearly with the residual stress level, indicating the feasibility of the technique for characterization of residual stresses in ferrous components using the sensor array probe.---This work was supported by the NSF Industry/University Cooperative Research Program.
**Materials and Material Properties**

**Evaluation of Surface Hardening by Measuring Magnetic Properties**

---Yuji Tsuchida, Taisuke Matsuda, and Masato Enokizono, Oita University, Faculty of Engineering, Oita 870-1192, Japan

---The steel materials are used for main parts of the structure, and they are requested that they have a high quality and high strength. Therefore, it is very important to develop the evaluation system that can examine the properties of the steel materials. As for a current material evaluation, the destruction evaluation that should cut out the specimen has been done. However, it is required for industry to establish the non-destructive evaluation system that might not destroy the specimen. The hardening that is one of the heat-treatment to improve strength is made on a lot of parts now. This heat-treatment can harden only the surface of steel materials. However, as problems of hardening, there are unevenness and lack of hardness. Therefore, establishment of control and evaluation of the hardening becomes important. As for non-destructive evaluation of the hardening, various methods have been studied till now. In this paper, we present that the numerical analysis by the two-dimensional finite element method to develop an evaluation system for hardening by a magnetic sensor, which can distinguish the change of magnetic properties of hardened steels. Moreover, some measured results are discussed to confirm the numerical results and realize the measurement system.

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**Materials and Material Properties**

**Search of the Order of Passes of an Austenitic Weld by Optimization of an Inversion Process of Ultrasound Data**

---C. Gueudre, M. Checkroun, J. Moysan, and G. Corneloup, LCND, Laboratoire de Caractérisation Non Destructive (lcnd.fr), Université de la Méditerranée, 13625 Aix en Provence, France; L. LeMarrec, IRMAR, Institut de Recherche Mathématique de Rennes, UMR 6625 du CNRS, Campus de Beaulieu, 35042 Rennes, France; B. Chassignole, EDF R&D, Les Renardières, Département MMC, Avenue des Renardières, 77818 Moret sur Loing, France

---The ultrasonic testing of austenitic stainless steel welds found in the primary system of nuclear power stations is difficult due to their heterogeneous and anisotropic structures. It leads to the deviation and splitting of the ultrasonic beam which can limit the performances of the control. Currently, several simulation tools aimed at modeling the wave propagation in this type of structure. The efficiency of the tool will mostly depend on the weld description used for the propagation simulation. Unfortunately, this description is not always accessible. To overcome this difficulty the MINA code has been developed. It provides the grain orientation inside the weld taking into account the characteristic of the welding process (number and the order of passes). Combined in the knowledge of the elastic constants and attenuation coefficients of the material, these data can be injected in an FE code like ATHENA 2D to simulate the ultrasonic propagation. As the welding process is often poorly documented, an approach coupling a MINA modeling and an optimization of an inversion process of ultrasound data is proposed in order to better estimate the grain orientation in the weld. In particular, the passes order determination, which is a first-order parameter, is discussed.
**Composite Materials**

**Porosity Detection in Ceramic Armor Tiles Via UT Time-of-Flight**  
---Frank J. Margetan, Nate Richter, and Terrence Jensen, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---Some multilayer armor panels contain ceramic tiles as one constituent, and porosity in the tiles can affect armor performance. It is well known that porosity in ceramic materials leads to a decrease in ultrasonic velocity. We report on a feasibility study exploring the use of ultrasonic time-of-flight (TOF) to locate and characterize porous regions in armor tiles. The tiles in question typically have well-controlled thickness, thus simplifying the translation of TOF data into velocity data. By combining UT velocity measurements and X-ray absorption measurements on selected specimens, one can construct a calibration curve relating velocity to porosity. That relationship can then be used to translate typical ultrasonic C-scans of TOF-versus-position into C-scans of porosity-versus-position. This procedure is demonstrated for pulse/echo, focused-transducer inspections of silicon carbide (SiC) ceramic tiles.---This material is based on work supported by the Army Research Laboratory as part of cooperative agreement number W911NF0820036 at the Center for Nondestructive Evaluation at Iowa State University. The views and conclusions contained in this document are those of the authors and should not be interpreted as representing the official policies, either expressed or implied, of the Army Research Laboratory or the U.S. Government. The U.S. Government is authorized to reproduce and distribute reprints for Government purposes notwithstanding any copyright notation hereon.

**Composite Materials**

**Ultrasonic Velocity Measurements in Chopped Carbon Fiber Composites**  
---Thomas N. Claytor, Michael L. Steinzig, and James F. Hunter, Los Alamos National Laboratory, Los Alamos, NM 87545

---A dry couplant method incorporating vinyl pads was used to measure longitudinal sound speed in several samples of resins and chopped carbon fiber composites taken from a pressed part. These samples were highly cut from a manufactured (pressed part) and were highly attenuative to ultrasound propagation so several different types of transducers and techniques were used in an attempt to achieve consistent sound velocity data. The results indicate an unexpected anisotropy in the material and also that the fabricated material is non uniform with respect to elastic properties by ~10 % in a given direction. Microfocus radiography and computed tomography was used to image the fiber orientation and homogeneity in the samples.
Composite Materials

**Ultrasonic Pitch-Catch Study for Evaluating Fiber Orientation and Porosity Distribution in CF/Epoxy Composites**

---Kwang-Hee Im, Woosuk University 490, Department of Automotive Eng., Hujung-ri, Samrae-up, Wanju-kun, Chonbuk, 565-701, Korea; David K. Hsu and Dan Barnard, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, Iowa 50011; In-Young Yang, Chosun University, Department of Mechanical Design Engineering, 375 Seosuk-dong, Dong-gu, Kwangju 501-759, Korea; Je-Woong Park, Chosun University, Department of Naval Architecture and Ocean Eng., 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. It is very important to detect fiber orientation and porosity distribution in composite laminates because the layup orientation and the porosity content of a composite structure is critical to the overall strength and performance of the structure. As well known for ultrasonic technique for evaluating the flaws of CFRP composite laminates, a pitch-catch technique was found to be more practical than normal incidence backwall echo of longitudinal wave to arbitrary flaws in the composite, including fiber layup and low level porosity. The measurement depth using Rayleigh probes can be increased by increasing the separation distance of the transmitting and receiving probes. Especially beam profile was characterized in unidirectional CFRPs with using pitch-catch Rayleigh probes and the one-sided and two-sided pitch-catch technique was utilized to produce C-scan images with the aid of the automatic scanner. Also, a method was utilized to determine the porosity content of a composite lay-up by processing micrograph images of the laminate. A free software package was utilized to process micrograph images of the test sample.---Authors appreciated experimental and technical help of Center for NDE, Iowa State University.

**Guided Wave Scattering by Anisotropic Layer Delamination**

---R. A. Roberts, Iowa State University, Center for NDE, 1915 Scholl Road, Ames IA 50011

---This paper reports on work to determine the guided wave scattering behavior of a delaminated region in an anisotropic layer adhered to an isotropic substrate. The motivating problem is a ballistic armor system consisting of a graphite epoxy composite adhered to a ceramic substrate. Freely propagating guided modes are noted to exist for this laminated system, which are not supported in the unadhered constituents, thereby providing a possible means of detecting constituent delamination. The effectiveness of such an inspection will be determined by the efficiency of mode conversion of an incident guided mode into modes supported by the delaminated constituents when the delamination is encountered, along with the reciprocal conversion into the original incident mode at the far end of the delamination. The scattering problem is studied using a boundary integral formulation employing the Green function for the anisotropic layer/substrate system. Numerical methods will be summarized for evaluating the Green function, and for extracting small argument asymptotic behaviors required in solving the governing hyper-singular integral equation. Results will be presented showing delamination transmission/reflection characteristics as a function of delamination length.---This work is based on work supported by the Army Research Laboratory as part of cooperative agreement number W911NF0820036 at the Center for Nondestructive Evaluation at Iowa State University.
Guided Wave Sensing of Structural Defects in Composite Vehicle Armor
---J. Stilley, P. Clayton, D. E. Chimenti, and R. A. Roberts, Iowa State University, Center for NDE and Department of Aerospace Engineering, 1915 Scholl Road, Ames, IA 50011

---This project is designed to test composite vehicle armor panels for subsurface damage induced by variations in the manufacturing process. In the experimental work we have designed and constructed an apparatus to make precision guided wave measurements using an optical breadboard and related components. Measurements have been made on a variety of specimens, both with and without, simulated defects. The structural features of the armor are quite complicated. At the top is a layer of carbon-epoxy, followed by the ceramic tile, another layer of carbon-epoxy, then a 1/8-inch rubber separator, and a layer of glass-epoxy at the bottom. We find that spectra acquired in long-range inspection change with the presence or absence of defects at either the upper or lower rubber surface. The calculations of guided wave behavior in the multilayer plate show similar spectral changes when a delamination (slip boundary condition) exists at one of the rubber interfaces. A novel feature of this work is the development of a means to couple sound into the composite laminate from low frequency transducers at only a single location on the plate. (The measurements are not done in immersion.) The transducers are on the ends of search tubes and encased in water-filled bladders designed specifically for this purpose. A unique feature of the bladder coupling is the presence of a rigid ring that holds the bladder surface planar and in direct contact with the surface to be inspected. Additional measurements and calculations will be reported.

Nondestructive Evaluation of Prestressed Concrete Cylinder Pipe by Resonance Acoustic Spectroscopy
---Jonathan C. Lesage and Anthony N. Sinclair, University of Toronto, Department of Mechanical and Industrial Engineering, Toronto, Ontario, Canada; Farhang Honarvar, K. N. Toosi University of Technology, Faculty of Mechanical Engineering, Tehran, Iran

---A new nondestructive evaluation technique is proposed to assess the condition of Prestressed Concrete Cylinder Pipe (PCCP), a reinforced concrete pipe commonly used for high pressure water transmission. The technique is based on the principles of Resonance Acoustic Spectroscopy (RAS) and involves comparing the forced vibration response of a healthy section of pipe to that of a damaged section. Failure of PCCP is typically initiated by corrosion of the pipe's outermost layer causing a localized reduction in flexural stiffness. This reduction in stiffness leads to changes in the resonant spectrum of the pipe. An approximate numerical model based on linear elasticity is developed in order to quantify the effect of external corrosion on the resonance characteristics of PCCP. Modes of vibration found to be most sensitive to damage are identified. The response of a healthy section of pipe determined experimentally is presented to validate the numerical model.
NDT Data Fusion for Evaluating Concrete Structure
---Marie-Aude Ploix, Vincent Garnier, and Joseph Moysan, LCND, Aix-en-Provence, France; Denys Breysse, GHYMAC, Bordeaux, France

---Increasing needs involving pathological diagnosis of concrete structures imply the necessity of non destructive evaluation methods. The major problem with concrete structures is the sensitivity of NDE techniques to numerous parameters. Thus reliable information is often difficult to extract. French project ANR named “SENSO” aims at improving the assessment of in situ structures by providing quantitative evaluation of indicators like porosity rate, water saturation, modulus of elasticity, mechanical strength, chloride content and carbonatization degree, by combining different NDE methods. We present here the study regarding simultaneous estimation of porosity rate and water saturation, for sane concrete. A large measurement campaign in laboratory was achieved on a representative range of concretes to establish empirical relationships linking many non destructive measures (radar, electrical resistivity and capacity, infrared thermography, impact echo and ultrasounds) and indicators. Data fusion based on possibility theory is selected to deal with imprecise and uncertain available data, and with the need of quantitative estimation of indicators. Applications provide a good agreement between predicted and expected values of porosity and saturation. Moreover results show that the selection of complementary techniques to be combined is essential for a better estimation of indicators and so to improve diagnosis.

Following Modifications of the Stress Level of Concrete Structures with CODA Wave Interferometry: Estimation of the Investigated Zone
---Yuxiang Zhang, Odile Abraham, Louis-Marie Cottineau, and Olivier Durand, Lab Central des Ponts et Chaussées, Dept. Mesure Auscultation & Calcul Scientifique, BP 4129 44 341 Bouguenais Cedex, France; Eric Larose and Thomas Planes, Lab. de Geophysique et de techtonophysics, Université Joseph Fourier, BP 53 38041 Grenoble Cedex 9, France; Alain Le Duff, Ecole Supérieure d'Electronique de l'Ouest, 4 rue Merlet de la Boulaye - BP 30926 49009 Angers Cedex 01, France; Bertrand Lascoup, Ecole Supérieure des Techniques Aéronautiques et de Construction Automobile, Parc Universitaire de Laval Changé Rue Georges Charpak, BP 76121 53061 Laval Cedex 9, France; Vincent Tournat and Rachid El Guerjouma, Lab. d'Acoustique de l'Université du Maine, Avenue Olivier Messiaen 72085 LE MANS Cedex 9, France

---The determination of the stress level in situ concrete structure is of paramount importance for the engineers. CODA wave interferometry (CWI) has been recently propose to monitor non destructively stress level in pre-stress concrete structures. The idea is to follow very small change of the ultrasonic wave velocity linked to stress level modifications through Murnaghan's theory. The velocity change which is of the order of 0.1% for 1MPa for classical concrete can be measured taking advantage of the heterogeneity of concrete. Indeed a source generating a wave train having wavelengths sizes comparable to that of aggregates will produce a very long signal due to multiple diffusion of the wave field. The energy arriving at late times in the signal has been travelling a large distance making possible travel time delay measurement with sufficient accuracy in case of small modification of the medium mechanical properties. In this paper we tackle the question of the estimation of the size the investigation zone of a source-receiver pair positioned at the surface of concrete. This is perform through an experiment on a rectangular beam (0.8 m x 0.2 m x 0.1 m) coupled to diffusion theory. An experiment on a real size concrete structures having numerous embedded sensors (mainly strain gauges and Raman optic fibers used as reference) submitted to time varying loading is also commented.
Ultrasonic Guided Waves for Non-Destructive Testing in High Speed Railways: Preliminary Results
---Benjamín Rubio, Nekane Galarza, and Eduardo Moreno, Fundación LEIA, C.D.T., 01510 Miñano, Álava, Spain; Ricardo González, DASEL, S.L., 28500 Arganda del Rey, Madrid, Spain; José Antonio Otero, Instituto de Ciencias Matemáticas y Físicas - ICIMAF, 10400 Havana, Cuba

---Preliminary results of ultrasonic guided waves application in High Speed Railways (HSR) are presented. New software, based on SAFEM-method, has been developed to obtain the theoretical dispersion curves and the vibration modes simulations. A compact electronics have been developed to excite and receive up to 32 channels (35KHz - 1MHz). FPGAs-technology has been implemented to process the multichannel signal in real time. Ultrasonic transducers have been also developed to work out of resonance frequencies. Experimental have been carried out in industrial environment, where a customizable array transducer have been used and different propagation modes have been excited. The obtained echoes are presented showing the capability of this method for the flaw detection in HSR.

Investigation of EMAT Technique Evaluation of Axial Flaws in Gas Pipelines
---Sung-Ho Cho, Hui-Ryong Yoo, Dae-Jin Park, and Yong-Woo Rho, Korea Gas Corporation, Intelligent Pig R&D Group, R&D Division, Incheon, Korea; Hak-Joon Kim and Sung-Jin Song, Sungkyunkwan University, School of Mechanical Engineering, Suwon, Gyeonggi-do, Korea; Seung-Hyun Cho, Korea Research Institute of Standard and Science, Safety Metrology Center, Division of Quality of Life, Daejon, Korea

---As increasing operation time of gas pipelines, possibility of initiating and generating flaws due to erosion and corrosion, fatigue and etc in pipelines increases significantly. So, insurance of integrity of degraded gas pipelines becomes one of major issues in the gas industry. To secure integrity of the gas pipelines, in-line inspection (ILI) system based on various nondestructive methods, such as magnetic flux leakage (MFL), ultrasonic testing (UT), eddy current testing (ECT) and etc, are applied for inspecting flaws in the pipelines. In the most cases, ILI systems based on axial MFL are used for inspection of the gas pipelines. But, the axial MFL based system has relatively low probability of detection (POD) for axial flaws such as axial cracks, axial grooves and etc. For increasing POD for axial flaws in the pipelines, electromagnetic acoustic transducer (EMAT) could be one of strong candidates. Also, some companies have developed ILI system based on EMAT. However, investigation of performance of EMAT method for detection and evaluation flaws in the gas pipelines is needed in order to develop EMAT based ILI system. For that purpose, EMA sensors that can generating receiving SH-Wave in the pipelines were designed and fabricated. Using the EMA sensor, detection and evaluation of artificial flaws including axial crack and axial grooves with various depth and/or width in the gas pipeline specimens will be performed. And, based on acquired EMAT signals, signal analysis and interpretation methods to find relation between EMAT signals and flaws depth and/or width will be developed. In this presentation, brief description of developed EMA sensors and signal interpretation methods and performance of the developed EMA sensor and the methods will be presented.
NDE for Civil Structures

Development of Ultrasonic Flaw Imaging Techniques for Detection of Flaws in Plate-Like Structure Using EMAT

---Dong-Kyu Kim, Sung-Ja Koo, and Yong-Woo Rho, Korea Gas Corporation, Intelligent Pig R&D Group, Incheon, Korea; Hak-Joon Kim, Dae-Kwang Kim, and Sung-Jin Song, Sungkyunkwan University, School of Mechanical Engineering, Suwon, Gyeonggi-do, Korea; Seung-Hyun Cho, Korea Research Institute of Standard and Science, Safety Metrology Center, Daejon, Korea

---Structural health monitoring (SHM) techniques for monitoring and improving structural integrity of various types of systems and/or facilities such as gas plants, nuclear power plants, aircraft and space shuttle, and etc. Especially, SHM for gas plants including gas storage tanks, pipelines and etc require methods that can cover large area plate-like structure and pipes. For large area SHM, ultrasonic guided waves considered as one of strong candidate and electromagnetic acoustic transducer (EMAT) methods can generate SH0 mode of guided waves which is non-dispersive and low attenuated waves. Thus, in this study, to develop SHM techniques for gas storage tanks, ultrasonic flaw imaging techniques for detecting flaw in plate-like structure using EMAT methods will be developed. For developing EMAT based flaw imaging techniques, EMAT sensors generating SH0 wave and low mode of Lamb waves in plate efficiently will be designed and fabricated. Also, ultrasonic flaw imaging techniques for detecting and determining location of flaws in large area of plates will be invested and developed. Furthermore, performance of the developed EMAT sensor and the ultrasonic flaw imaging techniques will be investigated by detecting standard type of flaw in plate-like structure specimens. In this presentation, developed EMAT sensors and ultrasonic flaw imaging techniques applied in this study will be presented. And, performance of the developed EMAT sensor and methods will be discussed.

---Monitoring and Evaluation of Damages in Steel Beams by Using Electro-Mechanical Impedance Method

---Zenghua Liu, Na Wang, Guorong Song, Jingpin Jiao, Cunfu He, and Bin Wu, College of Mechanical Engineering and Applied Electronics Technology, Beijing University of Technology, Beijing, 100124, China

---Because of some advantages such as high sensitivity to small local damages and no consideration of the original model of the structure monitored, electro-mechanical impedance method has gained increasing attention. This paper presents a study on monitoring and evaluation of damages in a steel beam using the electro-mechanical impedance method. Two piezoelectric patches are pasted on two beam ends respectively, and the experiments are carried out to study the damage propagation and defect severity by drilling holes in sequence along the length direction of the steel beam. PZT impedance signatures are recorded for each damage state and compared with the signature of the pristine state in several selected frequency domains though root mean squared deviation (RMSD). The results show that the change of the PZT impedance signatures gradually increases with the increase in the number of holes, however, the degree of change differs due to different measurement frequencies. Also, the damage near the PZT induces a greater change in impedance signatures. What's more, hole expansion causes greatly the increase in change of the PZT impedance signatures. The results demonstrate the capability of the electro-mechanical impedance method for monitoring and evaluation of damages in steel beams.
**New Techniques and Systems**

**Structural Damage Identification in Wind Turbine Blades Using Piezoelectric Active Sensing with Ultrasonic Validation**
---*Thomas N. Claytor*, Curtt N. Ammerman, Gyuhae Park, Kevin M. Farinholt, Charles R. Farrar, and Emily Tencate, Los Alamos National Laboratory, Los Alamos, NM 87545

---This paper gives a brief overview of a new project at LANL in structural damage identification for wind turbines. This project makes use of modeling capabilities and sensing technology to understand realistic blade loading on large turbine blades, with the goal of developing the technology needed to automatically detect early damage. Several structural health monitoring (SHM) techniques using piezoelectric active materials are being investigated for the development of wireless, low power sensors that interrogate sections of the wind turbine blade using Lamb wave propagation data, frequency response functions (FRFs), and time-series analysis methods. The modeling and sensor research will be compared with extensive experimental testing, including wind tunnel experiments, load and fatigue tests, and ultrasonic scans – on small- to mid-scale turbine blades. Furthermore, this study will investigate the effect of local damage on the global response of the blade by monitoring low-frequency response changes.

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

---This paper reports on work to model the transmission characteristics of arbitrarily shaped geometric obstructions in problems of plate wave propagation, such as joints, stiffeners, thickness transitions, and bends. The motivation for this work is noise source location in structures, the specific application being the location of air leaks in spacecraft skins, funded by NASA. The approach applies the boundary element method (BEM) to the geometric obstruction, using impedance boundary conditions over the regions where the plate(s) join to the obstructing feature. A simple BEM analysis over a semi-infinite plate is used to determine the traction/displacement impedance relation over the joining regions, in which the Green function for an infinite plate is used to confine the analysis to the joining edge of the plate. Transmission and reflection coefficients are extracted from the far-field analysis of displacements in the plate using the computed displacements/tractions on the plate edge. Extension of the model to three dimensions to enable consideration of non-perpendicular plate wave incidence will be reported. Results will be presented showing the transmission and reflection characteristics of various geometric features of interest.---This material is based on work supported by NASA under award NNX07AM15A.
New Techniques and Systems

Evolutionary Technique for Designing Optimized Arrays

---Javier R. Villazón and Alberto Ibáñez, Centro de Acústica Aplicada y Evaluación No Destructiva, CAEND (UPM - CSIC), Madrid, Spain

---Performance of many ultrasonic inspection applications in industry can be improved if phased array transducers with specifically designed characteristics are used for them. In order to support and promote the development of these transducers new methods, techniques and tools are needed. In this paper we present a novel method that allows the design of a wide kind of ultrasonic arrays (whether 1D or 2D array). The proposed method uses Evolutionary Algorithms for refining the design using the results supplied by a fast continuous wave field simulation method to evaluate the match between the characteristics of the current design and these of the desired target. The Non-dominated Sorting Genetic Algorithm version II (NSGA-II) has been selected as the optimizing tool because it provides multi objective capabilities that are needed to simultaneously considerer variables as number of elements, its shape, size, distribution, etc. in the design. The continuous wave simulator is based in a matrix formulation of a discrete version of Rayleigh - Sommerfeld monochromatic solution of the wave equation. Several examples of 1D and 2D array are presented, where we apply the proposed design method to find different array configurations radiating in homogeneous media.

New Techniques and Systems

A Data-Driven Correction Method for Phased Array Element Sensitivity

---Arno Volker and Robbert van Vossen, TNO, Stieltjesweg 1, P. O. Box 155, Delft, 2600 AD, The Netherlands; Peter van Capel, Universiteit Utrecht, 3508 TC Utrecht, The Netherlands

---The application of phased arrays is growing for NDT applications. State of the art ultrasonic arrays consist of many small piezo-electric elements that can be excited separately to synthesize a desired wave front. This may vary from simple plane waves to complex-shaped focusing wave fields. An implicit requirement is that the source strength (sensitivity) of all elements is equal, to prevent artifacts in the generated wave front. The same holds for the detection of ultrasonic waves. In typical commercial ultrasonic arrays, however, the sensitivity variations can be significant: amplitude variations of +/- 3 dB are not uncommon. Pulse-echo data can be used for calibration of element strengths, but has some limitations. Pulse-echo corrections can only be implemented accurately when the sensitivity in transmission is equal to the sensitivity in detection. For ultrasonic measurements this is not necessarily true when separate transmit and receiver arrays are used, but is also not evident when the same array is used. A new data-drive method is demonstrated that can be used to determine the frequency dependent sensitivity of each element in a phase array in emission and detection separately.
New Techniques and Systems

Automatic Magnetic Particle Inspection System for the Bracket’s Welds of Atucha I Nuclear Power Plant’s Pressure Vessel
---Pablo Katchadjian, Carlos Desimone, and Alejandro D. Garcia, Comision Nacional de Energia Atomica, Unidad de Actividad de Ensayos No Destructivos, Buenos Aires, Argentina; Carlos Antonaccio, Fernando Schroeter, and Pablo Mastroleonardo, Nucleoelectrica Argentina Sociedad Anonima, Ingenieria, Buenos Aires, Argentina

---The present work refers to the welding inspection of the brackets of Atucha I Nuclear Power Plant’s Pressure Vessel (RPV) using the wet fluorescent magnetic particles technique (MPT). Due to limited access and high radiation levels in the inspection area, it was necessary to automate the testing and use non conventional magnetization techniques. This paper describes the design and implementation of an automated inspection device and the tests carried out on the mock-up to set up the system. Also, magnetization techniques used are described, explaining in detail the non conventional technique of magnetization by current plates and the use of magnetic field concentrators to increase the field values in the area of interest. Finally, the device mounted on the RPV, used to inspect the bracket’s weld, and the results achieved from the inspection are shown.

Potential of Ultrasounds for NDT of a Structure Located Behind Parallel Immersed Plates
---Gilles Corneloup, Marie-Aude Ploix, Jean-François Chaix, and Ivan Lillamand, LCND, Université de la Méditerranée, Aix-en-Provence, France; François Baque, CEA Cadarache, DEN/DTN/STPA/LIET, St Paul lez Durance, France

---The In Service Inspection of internal structures of future liquid sodium cooled fast reactors is highly studied by the CEA (French Atomic Institute). Among different options, ultrasounds from the outside of sodium circuit can face this challenge. In these conditions, ultrasounds have to propagate through the metallic envelope of main vessel, then other immersed plates. Thus the study aims at mastering ultrasonic propagation in these multilayered structures in order to determine the best conditions allowing NDT of a plate behind n screens. The necessity of propagating a maximum of energy through bounded media orientated the study towards Lamb waves. Those are often employed for singles plates or solid layers but they are less usual for liquid/solid alternations. Theoretical results are obtained using transfer matrix method. They are compared to in water experimental measurements. Cases with one, two and three parallel plates without then with an artificial defect are presented for identical and different thicknesses of plates. Results show that an artificial crack defect is obviously detected in a plate located behind one and two screens. Measured attenuation is compatible with industrial NDT conditions. Thus a promising potential is shown for this inspection technique.
THURSDAY, SESSION 29

New Techniques and Systems

Extremely Short Impulse Eddy Current Testing System for Ti Samples
---Tomasz Chady and Pawel Frankowski, West Pomeranian University of Technology in Szczecin, Faculty of Electrical Engineering, Szczecin, Poland

---This paper presents a new system for eddy current testing. The system enables to carry on tests with very short currents impulses. Therefore, the frequency spectrum of the excitation signal is very wide. It creates opportunity to achieve similar advantages as in case of the multi-frequency system. A main component of the measuring system is a dedicated short impulse current generator which is powered by regulated power supply. Generator can be triggered by internal or external trigger source with 1Hz…100Hz frequency. Duration of the current impulses can be from several hundreds of nanoseconds to several microseconds. In order to achieve high reliability, current pulse width is always inspected by microcontroller. The system is controlled by the computer and it is possible to set up the impulse amplitude (up to 100A), impulse duration and repetition frequency. The generator supplies a newly developed differential eddy current transducer manufactured on the thin film. The probe consists of two search coils fabricated on the top of the thin film and one excitation coil wound on the bottom side. This construction is aimed at probe’s miniaturization and improved spatial resolution. Test specimens used for the experiments are titanium plates with EDM notches. Results of preliminary experiments confirmed usability of the ESIECT system and the transducer. This work was supported in part by Polish Ministry of Science and Higher Education and by European Commission sponsored project QualiTi which is a collaboration between the following organizations: I.S.O.TEST Engineering s.r.l, Technical University of Szczecin (PUZ), Tecnitest Ingenieros S.L., TIMET UK Ltd, TWI Ltd and Vernon SA. The project is co-ordinated and managed by TWI Ltd and is partly funded by the EC under the Research for the Benefit of Specific Groups Project (ref: FP7-SME-2007-1-GA-222476).

New Techniques and Systems

Microwave Broadband One-Port Portable Vector Network Analyzer Used for a Multitude of NDT Application
---Mohammad T. Ghasr, Mark A. Baumgartner, and Reza Zoughi, Missouri University of Science and Technology (S&T), Applied Microwave Nondestructive Testing Laboratory (amntL), Electrical and Computer Engineering Department, Rolla, MO 65409

---An accurate one-port vector network analyzer (VNA) that is capable of performing coherent reflection coefficient measurement is an essential tool in many microwave nondestructive testing (NDT) applications. This paper presents an X-band one port VNA that is capable of performing calibrated vector (magnitude and phase) measurements of reflection coefficient over the frequency range of 8.2 to 12.4 GHz. This device is built upon a recently developed and novel design approach that makes it low-cost, handheld, portable and furthermore customizable for a number of critical NDT applications. One of these applications involves material characterization in which utilizing this VNA along with one of several well-established dielectric measurement techniques, accurate property characterization of various material types is possible. Another application involves measurement and evaluation of layered composite structures for example for disbond thickness evaluation where measuring vector reflection coefficient over a bandwidth results in accurate estimation of the disbond thickness. Furthermore, given the broadband nature of this versatile VNA, it may be used to produce A-scan of many structures for NDT purposes to localize boundaries and defects. Another utility of this small VNA is its incorporation into commercial raster scanners to provide a magnitude and phase image of a structure under test which can subsequently be transformed into high-resolution 3D microwave images of its interior. In addition, this VNA will be demonstrated as part of the interactive Poster Session.
New Techniques and Systems

Signal Modeling in the Far-Infrared Region for Nondestructive Evaluation Applications
---Chien-Ping Chiou, David K. Hsu, Dan Barnard, and Kwang-Hee Im, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---Terahertz radiation (a.k.a. T-ray) has emerged as a powerful inspection technique in recent years. It nicely extends into the lower region of far-infrared in the electromagnetic spectrum, and has been proven very effective in many NDE applications. T-ray is particularly useful in some areas where accessibility is difficult or even not possible for other conventional NDE methods. In these areas, modeling has become a necessity, which allows us to assess those problematic situations that may be otherwise experimentally unfeasible and to do so much more cost-effectively. Here we report a modeling effort of T-ray signal of “hidden delaminations”, a special case that some delamination shadowed by the others. This special case was experimentally simulated by a double saw-cut slot in fiber-glass composites. T-ray has also shown great potential in assessing the conditions of thin coating or paints. In this paper, we will also explore the feasibility of combing T-ray and Fourier transform infrared spectroscopy using a unified least-squares scheme for one such application.

---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 Nondestructive Evaluation.

New Techniques and Systems

Comparison of Novel Non-Destructive Evaluation Techniques for the Analysis of Biodiesel Fuel Quality
---K. Boudreau, R. Johnson, M. Kropf, and B. R. Tittmann, Penn State, Department of Engineering Science and Mechanics, 212 EES Building, University Park, PA 16802

---Several techniques to determine the quality of biodiesel have been examined and select methods involving light diffraction and ultrasonic wave propagation have been identified for comparison. The comparison will include calibration aspects, accuracy and precision in reference current ASTM specification techniques, cost, and ease of integration into fuel processing plants. With ultrasound, both non-linear analysis and time of flight diffraction techniques have been compared. Light amplitude measurements near the cloud point of biodiesel samples utilizing simple electronics are also included in the technique analysis.
Reliability

Classification Procedure in Limited Angle Tomography System
---Piotr Baniukiewicz, Wojciech Chlewicki, Andrzej Brykalski, and Tomasz Chady, West Pomeranian University of Technology in Szczecin, Faculty of Electrical Engineering, Szczecin, Poland

---Due to high complications, welding process mostly relies on the experience of human being. Defects and discontinuities in the weld can reduce the strength of the joint and can lead to catastrophic failure. Therefore, the advanced computerized systems for radiogram analysis are the subject of intensive research. In this work limited angle reconstruction algorithms combined with procedure for defect detection in three dimensions to enhance contrast and visibility of potential defects is proposed. The procedure consists of the following steps: acquisition of the X-ray projections, approximated limited angle 3D image reconstruction, image preprocessing and classification. As a result of the first two steps we obtain discreet volume from which we extract plains of interest. The basic operation in the classification process is recognition of shape of the object what is related with evaluation of object's features. 3D reconstruction makes possible to gain additional information on defect location and dimension deep into material, in opposition to traditional radiography. The advantage of this approach is better description of defect by features and hence more reliable classification. The evaluation was carried out with the X-ray projections obtained by digital radiography system based on flat panel. This work was supported by the Polish Ministry of Science and Higher Education Grant no. 1141/B/T02/2009/36 (2009-2012).
Session 30
Thursday, July 22, 2010

SESSION 30
GUIDED WAVES II
Mike Lowe, Chairperson
Salons A-C

3:30 PM  Lamb Wave Mode Selection Algorithm for Multilayer Plate NDE
---C. Lissenden and H. Kannajosyula, Penn State, Engineering Science and Mechanics, University Park, PA 16802

3:50 PM  SH Guided Waves to Infer the Shear Stiffness of Adhesive Bonds
---M. Castaings, University of Bordeaux, UMR CNRS 5469 – LMP, 351 cours de la Liberation, Talence, 33405 Cedex, France

4:10 PM  Experimental Measurement and Numerical Simulation of Lamb Wave Scattering in Composites
---M. Veidt and C.-T. Ng, School of Mechanical and Mining Engineering, The University of Queensland, Brisbane, Queensland, Australia

4:30 PM  Monitoring Fatigue Cracks in Aluminum Joints with Ultrasonic Guided Waves
---C. Lissenden and H. Cho, Penn State, Engineering Science and Mechanics, University Park, PA 16802

4:50 PM  Defect Detection in Multi-Layered Structures Using High Frequency Guided Waves
---B. Masserey, University of Applied Sciences, Department of Industrial Technologies, Fribourg, Switzerland; E. Kostson and P. Fromme, University College London, Mechanical Engineering, London, United Kingdom

5:10 PM  Scattering of Weld Guided Modes from Defect Located Around the Weld
---Z. Fan and M. J. S. Lowe, Imperial College, Mechanical Engineering, London, United Kingdom
Lamb Wave Mode Selection Algorithm for Multilayer Plate NDE
---Cliff Lissenden and Haraprasad Kannajosyula, Penn State, Engineering Science and Mechanics, University Park, PA 16802

---The need for nondestructive evaluation and/or structural health monitoring of adhesively bonded joints has motivated the study of Lamb waves in multilayered plates. The objective of the study is to select modes and frequencies that are most sensitive to defects within the adhesive layer or at the adhesive-adherend interface. Such modes exhibit wave structures with peaks within the adhesive layer. We recently reported work on adhesively bonded joints indicating that dispersion curves for some Lamb waves actually coincide with interface waves. This work leads to the proposition that the Lamb wave modes coincident with interface waves are invariant with respect to the bounding layer thickness. Here, invariant modes have dispersion curves and wave structures that are insensitive to an increase in the thickness of the two bounding layers. An algorithm is implemented to systematically identify all modes that are thickness insensitive. These modes are shown through their wave structures to exhibit peak displacement components in the bounded center layer. The algorithm avoids the need to compute dispersion curves which would be time consuming. It also avoids explicit computation of wave structures as a means for mode selection, which can be unreliable due to inaccuracies in computing the dispersion curves (or roots) and inadequate sampling frequency in space during computation of the wave structure. Results are presented for aluminum plates bonded by epoxy.

SH Guided Waves to Infer the Shear Stiffness of Adhesive Bonds
---Michel Castaings, University of Bordeaux, UMR CNRS 5469 – LMP, 351 cours de la Liberation, Talence, 33405 Cedex, France

---Composite patches adhesively bonded onto metallic components are more and more used for repairing Aeronautical structures. The shear resistance of such adhesive bonds is of great importance to guarantee the efficiency of the repair. To non-destructively assess the shear stiffness of bonds, which is necessarily linked to their shear resistance, shear-horizontally polarized (SH), ultrasonic, wave modes are investigated. Numerical simulations are first run for selecting the most appropriate SH modes, i.e. with higher sensitivity to the bond than to other components. Then, experiments are made for generating-detecting pre-selected SH wave modes, and for measuring their phase velocities. An inverse problem is finally solved, consisting of the evaluation of the shear stiffness modulus of a bond layer at different curing times between an aluminum plate and a Carbon-Epoxy patch.
Experimental Measurement and Numerical Simulation of Lamb Wave Scattering in Composites
--- Martin Veidt and Ching-Tai Ng, The University of Queensland, School of Mechanical and Mining Engineering, Brisbane, Queensland, Australia

--- One critical factor affecting the performance of Lamb wave based damage detection and characterization techniques is the angular amplitude distribution of the interrogating wave scattered at defects and structural features. Analytical solutions for this problem do not exist for composite laminates due to the anisotropic nature and multilayer characteristics of the material. This paper reports on the scattering characteristics of the fundamental antisymmetric Lamb wave at delaminations and structural features in composite laminates. Experimental measurements and finite element simulations are employed to quantify the A0 mode Lamb wave scattering characteristics at delaminations, through holes and stiffeners. Good agreement is found between the simulations and experimental measurements. Extended parameter studies provide improved physical insight into the phenomena and show that the angular distributions of the scattered wave amplitudes depend on the damage size to wavelength ratio, the stacking sequence of the laminate and, in the case of delamination damage, the through thickness location of the delamination.

Monitoring Fatigue Cracks in Aluminum Joints with Ultrasonic Guided Waves
--- Cliff Lissenden and Hwanjeong Cho, Penn State, Engineering Science and Mechanics, University Park, PA 16802

--- The aging of aircraft fleets is a significant reliability and maintenance concern. The longer the legacy fleet remains in service, the more likely fatigue cracks are to initiate and grow. Structural health monitoring (SHM) provides an economical way to maintain airworthiness of aging fleets. A network of surface mounted piezoelectric disk transducers is investigated to monitor fatigue crack initiation and growth in planar aluminum alloy structures representative of aircraft wing and fuselage structures. Finite element analysis of ultrasonic guided wave propagation in a plate with multiple open fastener holes and a crack enables identification of a superior transducer network pattern. In-plane cyclic loading of an aluminum plate causes fatigue crack initiation and growth that is monitored with a network of piezoelectric transducers. The transducers generate the fundamental Lamb wave modes, which interact with the fatigue crack. Data analysis of the received signals to date focuses on two basics. First, the transmission coefficient is calculated for a transmitter-receiver pair with a fastener hole directly in the line of sight of the transducers. Second, a tomography algorithm that uses all transducers in the network is implemented to enable visualization of the crack location. Results are presented for two types of specimens: a plate with multiple open fastener holes, and a plate containing a double lap joint connection.
Defect Detection in Multi-Layered Structures Using High Frequency Guided Waves
---Bernard Masserey, University of Applied Sciences, Department of Industrial Technologies, Fribourg, Switzerland; Erik Kostson and Paul Fromme, University College London, Mechanical Engineering, London, United Kingdom

Aircraft structures contain multi-layered components connected by fasteners, where fatigue cracks and disbonds can develop due to cyclic loading conditions. High frequency guided waves propagating along the structure allow for the efficient non-destructive testing of large components, such as aircraft wings. However, the sensitivity for the detection of small defects has to be ascertained. The type of multi-layered model structure investigated consists of two adhesively bonded aluminum plate-strips. High frequency ultrasonic wave propagation along the structure and the sensitivity to disbonds was investigated from simulations and verified experimentally. Fatigue experiments were carried out and the sensitivity of the guided wave modes to monitor fatigue crack growth at a fastener hole during cyclic loading was investigated. The sensitivity and repeatability of the measurements were ascertained, having the potential for fatigue crack growth monitoring at critical and difficult to access fastener locations from a stand-off distance. Good agreement was observed between the experimental results and predictions from numerical simulations of the wave propagation along the structure and scattering at the fastener hole and crack.

Scattering of Weld Guided Modes from Defects Located Around the Weld
---Zheng Fan and Michael J. S. Lowe, Imperial College, Mechanical Engineering, London, United Kingdom

The inspection of large areas of complex structures is a growing interest for industry. An experimental observation on a large welded plate found that the weld can concentrate and guide the energy of a guided wave traveling along the direction of the weld. A modal study of the welded plate geometry has previously been published by the authors; this examined the compression weld-guided mode which had been observed, and also revealed an attractive shear weld guided mode, which is non-attenuative and almost non-dispersive. These weld guided waves may be reflected by some defects when they are located on the path of the propagation. Thus it is possible to use a simple pulse-echo arrangement with a single transducer which is aligned to generate waves along the weld then receive reflections from any defects in or around the weld. In this new study, further investigation of the properties of both compression and shear weld-guided modes has been carried out. The interaction of weld-guided modes with different type of defects, including cracks perpendicular or parallel to the weld and circular holes, in the heat affected zone next to the weld has been studied. The results are obtained from both Finite Element simulations and experimental measurements, showing good agreement. The sensitivity of the two welded-guided modes to different defects has been discussed and suitable choices of frequency to detect these defects have been suggested.
Session 31
SESSION 31
NDE FOR CONCRETE
Jin-Yeon Kim, Chairperson
Salon D

3:30 PM Effect of Air Voids on Ultrasonic Wave Propagation in Cement Pastes
---J. Zhu, S.-H. Kee, and D. Han, The University of Texas at Austin, Department of Civil,
Architectural and Environmental Engineering, Austin, TX 78681

3:50 PM NDT Techniques for Characterizing Alkali-Silica Reaction in Standard Concrete Specimens
---J. Chen, A. Jayapalan, K. E. Kurtis, J.-Y. Kim, and L. J. Jacobs, Georgia Institute of Technology,
School of Civil and Environmental Engineering, Atlanta, GA 30332; K. J. Lesnicki and L. J. Jacobs,
Georgia Institute of Technology, GWW School of Mechanical Engineering, Atlanta, GA 30332

4:10 PM Transmission Measurement of Air-Coupled Surface Waves Across a Partially Closed
Surface-Breaking Crack in Concrete
---S.-H. Kee and J. Zhu, The University of Texas at Austin, Department of Civil, Architectural, and
Environmental Engineering, 1 University Station, C1748, Austin, TX 78712-0273
Effect of Air Voids on Ultrasonic Wave Propagation in Cement Pastes
---Jinying Zhu, Seong-Hoon Kee, and Dongyeop Han, The University of Texas at Austin, Department of Civil, Architectural and Environmental Engineering, Austin, TX 78681

---Ultrasonic waves have been used to monitor early age microstructure development in cementitious materials since 1980s. However, application of this research has been limited because the propagation of P waves is strongly affected by the air voids in fresh cement paste. The objective of this study is to investigate the effects of air contents on ultrasonic wave measurements in early age cement paste and mortar. First, experimental study is performed to measure P and S wave velocities in cement pastes containing various amount of air-entraining agent. Test results indicate that the shear wave velocity is closely related to the setting time of cement pastes and less affected by air contents than the P wave velocity. Then, Biot’s theory is used to analyze the wave propagation behavior in multi-phase media with air voids. Finally, embedded piezo bender elements are proposed to reliably measure shear modulus of cementitious materials at very early ages. The embedded sensors provide a possibility for long term health monitoring and damage detection.

NDT Techniques for Characterizing Alkali-Silica Reaction in Standard Concrete Specimens
---Jun Chen, Amal Jayapalan, Kimberly E. Kurtis, Jim-Yeon Kim, and Laurence J. Jacobs, Georgia Institute of Technology, School of Civil and Environmental Engineering, Atlanta, GA 30332; Krzysztof J. Lesnicki and Laurence J. Jacobs, Georgia Institute of Technology, GWW School of Mechanical Engineering, Atlanta, GA 30332

---Alkali-silica reaction (ASR) is a chemical reaction between amorphous siliceous minerals in aggregates and alkaline solution in the micro pores of concrete, during which high expansive internal pressure is produced. These high pressures eventually lead to cracking of aggregates and interfaces, and thus ASR is considered a serious cause of damage in concrete structures. Aggregate with an unknown level of reactivity is subjected to a screening process according to one or more standards (ASTM C1293, ASTM C1260, AASHTO T303, etc.) before its field application. The current standard testing methods are either time-consuming or sometimes unable to distinguish between moderate and marginal levels of reactivity. In addition, they may not accurately predict field performance. This paper presents a review of our past and on-going effort to develop NDT techniques for rapid and more reliable screening of ASR in concrete specimens. These techniques are tied to the standard testing methods (expansion-based) to provide relevant information that will help the tester assess the aggregate reactivity in a timely and accurate manner. Developed techniques are based on the use of nonlinear acoustic and diffuse field characteristics of concrete materials. A simple model to explain observed nonlinear behavior of ASR-suffering concrete specimens is also presented.
Transmission Measurement of Air-Coupled Surface Waves Across a Partially Closed Surface-Breaking Crack in Concrete

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

---Previous researchers have demonstrated that transmission coefficients of surface waves are effective to estimate the depth of a surface-breaking crack in solids. However, most of the results were obtained using a well-defined crack (or notch) in laboratory. In facts, there is a critical gap to apply the theory to surface-breaking cracks in concrete structures subjected to external loading where the crack is generally ill-defined, and partially closed. In this study, the authors investigate the transmission coefficients of surface waves across a partially closed surface-breaking crack in concrete. First, concrete beams (1.5 X 0.4 X 0.2 m3) are prepared in laboratory, and flexural cracks are generated by applying two pointed load on the middle of simply supported beams. Crack width is measured using crack-width gauge, and strain gauge attached on concrete surface. Simultaneously transmission coefficients of impact-induced surface waves are measured in a wide frequency ranges. Second, transmission is measured again across a crack subjected to various compressive stress levels. For this purpose, external post-tensioning is applied at the end of concrete beams. As a result, the effects of a crack width, and average compressive stresses on transmission measurements are investigated.
Session 32
SESSION 32
NONLINEAR UT MEASUREMENTS
Jeong-Kwan Na, Chairperson
Salon E

3:30 PM  Measuring Acoustic Nonlinearity by Collinear Mixing Waves
---M. Liu and J. Qu, Northwestern University, Department of Civil and Environmental Engineering, Evanston, IL 60208; G. Tang and J. Qu, Northwestern University, Department of Mechanical Engineering, Evanston, IL 60208; L. Jacobs, Georgia Institute of Technology, School of Civil and Environmental Engineering, Atlanta, GA 30332-0360

3:50 PM  Nonlinear Ultrasonic Characterization Using the Noncollinear Method
---A. J. Croxford, B. W. Drinkwater, P. D. Wilcox, University of Bristol, Department of Mechanical Engineering, Bristol, United Kingdom

4:10 PM  Surface-Wave Nonlinearity Measured with EMAT for Crept Cr-Mo-V Steel
---T. Ohtani, T. Ogawa, M. Kobayashi, and X. Bao, Shonan Institute of Technology, Department of Mechanical Engineering, Fujisawa, Kanagawa, Japan

4:30 PM  Nonlinear Acoustic Characteristics for Micro-Crack Detection in a SA508 Gr. B Reactor Pressure Vessel Material
---Y.-M. Cheong and H.-K. Jung, Korea Atomic Energy Research Institute, Nuclear Materials Research Division, Yusong, P. O. Box 105, Daejon, 305-600, Korea

4:50 PM  Ultrasonic Properties of Low Solvus High Refractory (LSHR) Super Alloy Disk Material
---J.-K. Na, University of Dayton Research Institute, 300 College Park, Dayton, OH 45469; M. Blodgett, Air Force Research Laboratory, Wright Patterson Air Force Base, OH 45433
Measuring Acoustic Nonlinearity by Collinear Mixing Waves
---Minghe Liu and Jianmin Qu, Northwestern University, Department of Civil and Environmental Engineering, Evanston, IL 60208; Guangxin Tang and Jianmin Qu, Northwestern University, Department of Mechanical Engineering, Evanston, IL 60208; Laurence Jacobs, Georgia Institute of Technology, School of Civil and Environmental Engineering, Atlanta, GA 30332-0360

---It is well known that the acoustic nonlinearity parameter beta is correlated to fatigue damage in metallic materials. Various methods have been developed to measure beta. One of the most often used methods is the harmonic generation technique, in which beta is obtained by measuring the magnitude of the second order harmonic waves. An inherent weakness of this method is the difficulty in distinguishing material nonlinearity from the nonlinearity of the measurement system. In this paper, we demonstrate the possibility of using collinear mixing waves to measure beta. The wave mixing method is based on the interaction between two incident waves in a nonlinear medium. Under certain conditions, such interaction generates a third wave of different frequency. This generated third wave is also called resonant wave, because its amplitude is unbounded, if the medium has no attenuation. Such resonant waves are less sensitive to the nonlinearity of the measurement system, and have the potential to identify the source location of the nonlinearity. In this work, we used a longitudinal wave and a shear wave as the incident waves. The resonant shear wave is measured experimentally on samples made of aluminum and steel, respectively. Numerical simulations of the tests were also performed using a finite difference method. Results from numerical simulations and experimental measurement show good agreement. The measured beta values are also consistent with those given in the literature.

Nonlinear Ultrasonic Characterization Using the Noncollinear Method
---Anthony J. Croxford, Bruce W. Drinkwater, Paul D. Wilcox, University of Bristol, Department of Mechanical Engineering, Bristol, United Kingdom

---The measurement of material non-linearity using ultrasound is an attractive concept, offering the potential to detect fatigue damage earlier than is possible with conventional techniques. Despite this advantage and much work in the field the currently developed approaches are primarily limited to the lab environment. This is due to the difficulty in separating the material nonlinearity from that generated by equipment. This paper reports on an approach that eliminates this problem. When two shear waves interact a third wave is generated due to the material nonlinearity. This paper shows how this interaction can be used to measure material properties in damaged specimens. It goes on to show that this approach can be used to make measurements of material non-linearity both across a specimen and at different specimen depths.
Surface-Wave Nonlinearity Measured with EMAT for Crept Cr-Mo-V Steel
---Toshihiro Ohtani, Tomonori Ogawa, Munenori Kobayashi, and Xuesong Bao,
Shonan Institute of Technology, Department of Mechanical Engineering, Fujisawa, Kanagawa, Japan

---The microstructural evaluation of Cr-Mo-V steel during creep test, subjected to tensile creep at 923K, was studied by monitoring an acoustic nonlinearity using electromagnetic acoustic resonance (EMAR). EMAR is the technique applied non-contacting electromagnetic acoustic transducer to ultrasonic resonance method. We used an EMAT which is consisted of a solenoid coil to supply the biasing magnetic field along the axial direction and meander-line coil surrounding the cylindrical surface to induce the dynamic field in the circumferential direction. The total field oscillates in the axial direction at the same frequency as the driving currents and produces a shearing vibration through the magnetostrictive effect, resulting in the axial-shear-wave excitation. The ultrasound is transmitted to the sample by exciting EMAT by high power rf bursts and propagates along the circumferential surface. With the super-heterodyne spectrometer, a resonant spectrum is obtained by sweeping the frequency of the rf burst. Excitation of the EMAT at half or one-third of the resonance frequencies caused the standing waves to contain only the second-harmonic or third-harmonic components, which was received by the same EMAT to determine the second-harmonic or third-harmonic components amplitude to calculate the nonlinearity. This measured second-harmonic nonlinearity showed the peaks at 40% of the total life. The trend corresponded to the dislocation mobility by microstructural observation of TEM and SEM. This noncontact resonance-EMAT measurement can monitor the evolution of acoustic nonlinearity throughout the creep life and has a potential to assess the damage advance and to predict the creep life of metals.

Nonlinear Acoustic Characteristics for Micro-Crack Detection in a SA508 Gr. B Reactor Pressure Vessel Material
---Yong-Moo Cheong and Hyun-Kyu Jung,
Korea Atomic Energy Research Institute,
Nuclear Materials Research Division, Yusong, P. O. Box 105, Daejon, 305-600, Korea

---Micro-cracks in a CT specimen after fatigue test were related to the nonlinear acoustic properties by a resonant spectroscopy technique. Information on the amplitude and resonance frequency was analyzed to quantify the degree of nonlinearity and diagnose the micro-cracks. The damage produces a nonlinear stress-strain relationship and the nonlinearity can be measured by increasing excitation amplitudes. The amount of non-linearity is highly correlated to the damaged state of the material. A shift of resonance frequency as a function of driving voltage or strain is chosen as a nonlinear parameter to correlate the micro-cracks or damage. In addition a normalized resonance pattern also reflects the nonlinearity and the normalized patterns of intact sample and cracked CT specimen were compared.
Ultrasonic Properties of Low Solvus High Refractory (LSHR) Super Alloy Disk Material
---Jeong-Kwan Na, University of Dayton Research Institute, 300 College Park, Dayton, OH 45469; Mark Blodgett, Air Force Research Laboratory, Wright Patterson Air Force Base, OH 45433

---Measurements are made for ultrasonic linear and nonlinear properties of the powder metallurgy disk alloy LSHR material designed with a relatively low y' precipitate solvus temperature and high refractory element content. This allows versatile heat treatment processing which results in high tensile, creep and fatigue properties depending on the grain size controlled through proper selection of solution heat treatment temperatures relative to the y' precipitate solvus temperature. Sound velocity and attenuation for both longitudinal and shear modes at various frequencies from 5 to 20 MHz help to identify and quantify the size of transition zone nondestructively between the small grain (~10 micron) and the large grain (~100 micron) zones. Acoustic nonlinearity parameter data shows a similar trend. In addition, the result of shear wave velocity measurements taken by aligning the transducer polarization direction parallel and perpendicular to the grain transition direction reveals the acoustoelastic birefringence effect, indicating an existence of a preferred microstructure orientation (texture) or residual stress in the material.
SESSION 33
ELECTROMAGNETIC MODELING AND DEFECT SIZING
Harold A. Sabbagh, Chairperson
Salons F-H

3:30 PM  Modeling Direct and Inverse Problems in Ferritic Heat-Exchanger Tubes
---H. A. Sabbagh, R. K. Murphy, and E. H. Sabbagh, Victor Technologies, LLC, Bloomington, IN 47407-7706

3:50 PM  Low Frequency Eddy Current Benchmark Study for Model Validation
---R. D. Mooers and T. R. Boehnlein, University of Dayton Research Institute, Structural Integrity Division, Dayton, OH 45433; J. S. Knopp and M. R. Cherry, Air Force Research Lab, RXLP (NDE Branch), Wright Patterson, OH 45433; J. C. Aldrin, Computational Tools, Gurnee, IL 60031; H. A. Sabbagh, Victor Technologies LLC, Bloomington, IN 47407

4:10 PM  Simulation for the Eddy Current Method Measurement of Pipe-Wall Thinning
---W. Cheng and I. Komura, NDE Center, Japan Power Engineering and Inspection Corporation, Yokohama, Kanagawa, Japan

4:30 PM  Automatic Thickness Detection by Pulsed Eddy Current Method Using Time-Frequency Analysis in Double Layer Structures
---S. Hosseini and A. A. Lakis, Ecole Polytechnique de Montreal, Department de Mecanique Appliquee, Montreal, Quebec, Canada

4:50 PM  Flux Leakage Measurements for Defect Characterization Using a 3-Axial GMR Magnetic Sensor
---M. Kreutzbruck, M. Pelkner, M. Blome, and V. Reimund, Federal Institute for Materials Research and Testing, Division VIII-4, Berlin, Germany

5:10 PM  ECT Inspection of Interacting Flaws in a Planar Specimen: Modeling with the Volume Integral Method and Comparisons with Experimental Data
---A. Dubois, C. Reboud, J. M. Decitre, and G. Pichenot, CEA, LIST, CEA Saclay, F-91191 Gif-sur-Yvette Cedex, France
Modeling Direct and Inverse Problems in Ferritic Heat-Exchanger Tubes
---Harold A. Sabbagh, R. Kim Murphy, and Elias H. Sabbagh, Victor Technologies, LLC, Bloomington, IN 47407-7706

---Ferritic stainless steels, such as Type 439 or SEACURE, are being increasingly used in heat-exchanger tubes because of the increased resistance to chloride stress corrosion and intergranular attack when compared to older alloys, such as Type 304. This presents interesting modeling opportunities for the eddy-current nondestructive evaluation of these tubes because their magnetic permeability is quite large. For Type 439, the relative permeability is quite sensitive to the stress state of the material, being of the order of 950 for low stress, decreasing to 500 for a state of shear stress. In this paper we present examples of direct and inverse problems involving such tubes, using the proprietary eddy-current code, VIC-3D(c). We demonstrate conditions that are peculiar to ferritic tubes, and give insight into the optimum methods for characterizing the tubes and flaws within them.

Low Frequency Eddy Current Benchmark Study for Model Validation
---Ryan D. Mooers and Thomas R. Boehnlein, University of Dayton Research Institute, Structural Integrity Division, Dayton, OH 45433; Jeremy S. Knopp and Matthew R. Cherry, Air Force Research Lab, RXLP (NDE Branch), Wright Patterson, OH 45433; John C. Aldrin, Computational Tools, Gurnee, IL 60031; Harold A. Sabbagh, Victor Technologies LLC, Bloomington, IN 47407

---This paper presents results of eddy current measurements performed with an impedance analyzer to validate numerical models. The eddy current impedance spectroscopy system was used to make precise absolute measurements on thick aluminum plates with EDM notches similar to previous high quality benchmark studies. The change in impedance due to the presence of notches was measured on samples with rectangular notches (0 degree) and notches with tilted angles 10, 20, 30 with respect to surface of the plates. The measurements were made with the eddy current probe parallel to the length of the notch and perpendicular to the length of the notch. The eddy current signatures of angled notches are compared with signatures of the zero degree notches. In previous studies, computational models have been validated for rectangular notches. Angular notches present an additional computational complexity for some numerical methods, and the advantages and disadvantages of the different methods are discussed. The sensitivity of the eddy current signature to the notch angle in the experimental measurements and computational models is also presented.
Simulation for the Eddy Current Method Measurement of Pipe-Wall Thinning
---Weiying Cheng and Ichiro Komura, NDE Center, Japan Power Engineering and Inspection Corporation, Yokohama, Kanagawa, Japan

---The failure in pipelines in power plants, chemical plants, and other related industry systems accounts for enormous economic loss. In order to ensure the integration of piping system, pipe-wall thinning needs to be monitored appropriately. The pipes are usually made of carbon steel which is thermal insulated and protected by aluminum, stainless steel, or galvanized steel cladding. It remains a challenge for NDE on how to measure the pipe-wall thickness efficiently without removal of insulation and cladding. In this study, the application of eddy current method for the pipe-wall thinning monitoring is investigated based on numerical simulation. The piping system is modeled as a multilayer structure, and analytical solutions for sinusoidal and pulse excitation are deduced. The possibility and limitation of low frequency eddy current method and pulse eddy current method on wall thickness measurement are discussed based on the simulation results.

Automatic Thickness Detection by Pulsed Eddy Current Method Using Time-Frequency Analysis in Double Layer Structures
---S. Hosseini and A. A. Lakis, Ecole Polytechnique de Montreal, Department de Mecanique Appliquee, Montreal, Quebec, Canada

---Thickness loss due to corrosive factors is the major cause of most of the failures in aircraft fuselages. Pulsed Eddy Current testing (PEC) is an effective method to measure the thickness and material thickness reduction. This paper describes an automatic method to measure thickness of material in double layer structure. The purpose of this paper is to present a technique which applies time-frequency methods to show the thickness variations of thin plate in Aluminum double layer system. Rihaczek Distribution and Short Time Fourier Transform (STFT) were used as time-frequency methods. The time–frequency presentation of PEC signals provides three dimensional patterns which were treated by Principal Component Analysis (PCA) and Complex Wavelet Transform (CWT). PCA and CWT were applied for data compression and classification. To design a decision algorithm, neural network method was used to gather weight of all the treated and compressed data. In this paper, synthetic metal loss was measured by PEC method and treated data by related programs. Combination of all programs for time-frequency analysis methods, feature extraction and neural network training constitutes software to detect and estimate amount and place of metal loss in double layer structure.
Flux Leakage Measurements for Defect Characterization Using a 3-Axial GMR Magnetic Sensor

---Marc Kreutzbruck, Matthias Pelkner, Mark Blome, and Verena Reimund, Federal Institute for Materials Research and Testing, Division VIII.4, Berlin, Germany

---Recently, Giant Magnetoresistive (GMR) sensors are becoming increasingly popular for a number of MFL inspection problems demanding high sensitivity, high signal-to-noise ratio and small sensing area. In this work we detect three field-components simultaneously to increase the amount of information and to improve the reconstruction conditions. For this purpose, we employ a planar 3D GMR sensor that can be placed at very close to the surface of the test piece and that features small sensing areas with edge lengths in the range of a few tens micrometer. We investigate the defect detection capabilities of the employed GMR sensor by means of measurements on a test specimen that includes a series of artificial defects. It is demonstrated that thanks to the high signal-to-noise ratio and the high spatial sampling rate offered by the employed GMR sensor, defects with a depth of only 50 µm can be detected reliably. Our experimental results show that a determination of the defect's length, depth and width is feasible also for defects not aligned perpendicular to the applied magnetic field. The experimental findings are verified by extensive finite-element simulations of 3D magnetic leakage fields for various defect geometries.

ECT Inspection of Interacting Flaws in a Planar Specimen: Modeling with the Volume Integral Method and Comparisons with Experimental Data

---A. Dubois, C. Reboud, J. M. Decitre, and G. Pichenot, CEA, LIST, CEA Saclay, F-91191 Gif-sur-Yvette Cedex, France

---The ECT module of the multi-technique simulation software CIVA is able since recently to address configurations with several interacting flaws located in a planar specimen. The model which has been developed is based on the volume integral method. Applications of this new feature include the ECT modeling of more complex 3D flaws and the study of the shading between neighboring flaws, which constitute problems of interest in several industrial fields. This communication presents comparisons between simulation results and experimental data in the case of L shape, T shape or cross shape flaws. After a presentation of the theoretical formulation of the problem, results obtained with coils functioning in absolute and transmit/receive modes will be discussed and compared with corresponding experimental data obtained at the laboratory.
Session 34 – Laser Ultrasonics ..........................192
Session 35 – Material Properties Measurements........198
Session 36 – Probes, Sensors, and Instruments ........202
Session 37 – New Techniques and Systems .............208
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Session 34
8:30 AM Characteristics of Laser-Generated Viscoelastic (Like-) Rayleigh Waves in the Stratified Half Space Structures
---H. Qingbang¹,² L. Jian¹,⁴, Q. Menglu³, and Z. Changping¹, ¹Department of Computer and Engineering information, Hehai University, Changzhou 213032, PR China; ²Department of Information Technology, Technology Institute of Changzhou, Changzhou 213004, China; ³Institute of Acoustics, Tongji University, Shanghai 200092, China; ⁴Institute of Acoustics, The Chinese Academy of Science, Beijing 100080, China

8:50 AM Detection of Shear and Pressure Waves in Metals by Dynamic Wavelet Fingerprinting Techniques in Laser Ultrasonic NDT
---N. N. Kishore, A. Gajendragonkar, P. Gupta, and V. Raghuram, Indian Institute of Technology Kanpur, Department of Mechanical Engineering, Kanpur, UP, India

9:10 AM Defect Detection Using a Scanning Laser Source
---S. Burrows and S. Dixon, University of Warwick, Department of Physics, CV4 7AL, United Kingdom

9:30 AM Non-Contact Ultrasonic Characterization of Angled Surface Defects
---R. S. Edwards, B. Dutton, M. H. Rosli, and A. R. Clough, University of Warwick, Department of Physics, Coventry, United Kingdom

9:50 AM Determination of Crystallographic Texture in Steel Plates Using Laser-Generated Surface Waves
---D. Levesque, C. Padioleau, and A. Blouin, Industrial Materials Institute, National Research Council Canada, Boucherville, Qc, Canada; C. S. Lim, POSCO Technical Research Laboratories, Instrumentation & Control Research Group, Pohang City, Gyeongbuk, Korea

10:10 AM Break

10:30 AM Melting Point Measurement Using Pulsed Laser Thermal Pyrometry and Laser Ultrasonics
---Z. N. Utegulov, S. J. Reese, R. S. Schley, and D. H. Hurley, Idaho National Laboratory, Department of Materials Science and Engineering, Idaho Falls, ID 83415-2211

10:50 AM Laser-Ultrasonics on Composite Fibre Reinforced Plastics (CFRP)
---P. Huke, O. Focke, A. Hildebrand, C. von Kopylow, and R. B. Bergmann, BIAS Bremer Institute für Angewante Strahltechnik GmbH, 25359 Bremen, Germany

11:10 AM Non-Destructive Testing Using Two-Component/Two-Wave Mixing Interferometer
---A. Wartelle, B. Pouet, and S. Breugnot, Bossa Nova Technologies, Venice, CA 90291

11:30 AM New Industrial Laser-Ultrasonic Systems for the Inspection of Large Composite Aeronautic Structures
---M. Dubois and T. E. Drake, iPhoton Solutions, Fort Worth, TX 76111

11:50 AM Adjourn
Characteristics of Laser-Generated Viscoelastic (Like-) Rayleigh Waves in the Stratified Half Space Structures
---Han Qingbang,1,2 Li Jian,1,4 M. Qian,3 and Zhu Changping1, 1Department of Computer and Engineering Information, Hehai University, Changzhou 213032, PR China; 2Department of Information Technology; Technology Institute of Changzhou, Changzhou 213004, China; 3Institute of Acoustics, Tongji University, Shanghai 200092, China; 4Institute of Acoustics, The Chinese Academy of Science, Beijing 100080, China

---This research has been conducted to study the propagation characteristics of the viscoelastic (Like-) Rayleigh waves in the stratified half space structures. By means of Laplace and Hankel inversion transform and Kelvin model, the frequency equation and the normal displacement of viscoelastic Rayleigh in stratified half space wave were derived; the influence of the viscoelastic modulus on dispersion and attenuation were discussed. It shows that the attenuation-frequency perfectly match with phase-frequency curves. The effect of viscoelasticity on the attenuation of the (Like-) Rayleigh wave is more than that on its dispersion. In the presence of a weak viscosity, the attenuation of viscoelastic (Like-) Rayleigh wave is directly proportional to viscosity modulus, the shear viscosity impacted more on dispersion curves than the bulk viscosity. The transient response of viscoelastic Rayleigh wave was also simulated, which are showed in good agreement with the theoretic predictions. It was sure that the calculated results and conclusion of this simulation could provide some theoretical instruction and guidance for estimation of viscoelastic parameters.

Detection of Shear and Pressure Waves in Metals by Dynamic Wavelet Fingerprinting Techniques in Laser Ultrasonic NDT
---N. N. Kishore, Aparna Gajendragadkar, Pankaj Gupta, and V. Raghuram, Indian Institute of Technology Kanpur, Department of Mechanical Engineering, Kanpur, UP, India

---A dynamic wavelet fingerprinting and visual pattern recognition method has been developed for characterization of Bulk Ultrasonic Waves. Signals are generated in thick stepped samples of Aluminum, steel, Inconel and Brass using Laser Based Ultrasonics. The pulsed wave Nd-YAG laser is used to generate the ultrasonic signal in the material and continuous wave He-Ne laser heterodyne interferometry to record surface(out of plane) waves at the detection end. The ultrasonic signals thus obtained are quite complicated to analyze due to simultaneous presence of bulk, surface, Rayleigh waves. A suitable stepped geometry is used to keep the length of travel same for all angles of laser incidence. The ultrasonic signals are analyzed with Continuous Wavelet Transform using Morlet wavelet and pattern recognition is applied using moment invariants. Comparative study of Hu and Zernike moments proved that Zernike moments work better in pattern recognition. Shear and pressure waves are correctly identified with pattern similarity by windowing of the ultrasonic signal. The velocities calculated lie within theoretical limits. The accurate time of arrival of waves can be used in tomographic inversion techniques to obtain a precise reconstruction of the defects and inhomogeneities in the material. The technique brings out utility of wavelet transform based pattern recognition in analysis of transient signals.
Defect Detection Using a Scanning Laser Source
---Susan Burrows and Steve Dixon, University of Warwick, Department of Physics, CV4 7AL, United Kingdom

---Surface breaking defects are identified using a scanning laser source. A Q-switched Nd-YAG laser is used as a non-contact source of ultrasound and an electromagnetic acoustic transducer (EMAT) employed as detector. For a thin plate, an increase in frequency content of the received wave is observed when the laser spot is situated directly over the defect. Time-frequency analysis using a Wigner transform has enabled individual Lamb wave modes to be identified, while propagation of Lamb waves through aluminum sheet is studied by finite element analysis.

Non-Contact Ultrasonic Characterization of Angled Surface Defects
---Rachel S. Edwards, Ben Dutton, Mohd H. Rosli, and A. R. Clough, University of Warwick, Department of Physics, Coventry, United Kingdom

---Surface ultrasonic waves have been shown to have many uses in non-destructive testing, in particular for gauging the depth of surface defects. Much of the previous work has assumed that these defects are oriented normal to the surface. However, this is not always the case; for example, rolling contact fatigue in rails propagates at an angle of around 25° to the surface, and this will affect the characterization. We present results using non-contact ultrasonic methods to generate and detect ultrasound for a range of defect angles, and compare these with finite element method models. We use both electromagnetic acoustic transducers (EMATs) and laser ultrasound, where our laser system consists of laser generation and a two-wave mixer interferometer for detection. We consider the depth calibration using far-field measurements and show that the angle must be considered. The benefits of measuring the in-plane and out-of-plane components of the ultrasound separately are discussed, including looking at near-field signal enhancement. Finally, moving towards characterization of fatigue cracking we consider branched defects, and how these affect further the crack characterization using Rayleigh waves.
**Determination of Crystallographic Texture in Steel Plates Using Laser-Generated Surface Waves**

---Daniel Levesque, Christian Padieoleau, and Alain Blouin, Industrial Materials Institute, National Research Council Canada, Boucherville, Qc, Canada; Choongsoo S. Lim, POSCO Technical Research Laboratories, Instrumentation & Control Research Group, Pohang City, Gyeongbuk, Korea

---A laser-ultrasonic approach based on the propagation of surface skimming longitudinal wave (P-wave) and Rayleigh wave (SAW) is proposed for the measurement of crystallographic texture on moderately thick steel plates. The angular dependence of the P-wave and SAW velocity variations presents different patterns. Both velocity variations have amplitude of about 2% attributed to texture. Results obtained from fitting the angular profiles using relevant expressions for both P-wave and SAW confirm that texture coefficients may accurately be measured by this approach. Moreover, the difference of the P-wave and SAW profiles is shown to be very robust against small path length changes or other detrimental effects such as surface roughness. For measurements on large plates, a solution based on the rotation of a generation line using an axicon lens is tested. Profiles of texture variations across the width of steel plates are presented and the influence of residual stress is discussed.

**Melting Point Measurement Using Pulsed Laser Thermal Pyrometry and Laser Ultrasonics**

---Zhandos N. Utegulov, Stephen J. Reese, Robert S. Schley, and David H. Hurley, Idaho National Laboratory, Department of Materials Science and Engineering, Idaho Falls, ID 83415-2211

---Laser-based, containerless melting point measurements are of great utility for the development of advanced nuclear fuels. We present results on temperature measurements up to a melting point of pure tungsten heated by single and multiple nanosecond laser pulses. The combination of two in-situ techniques were used to detect surface melting: pulsed thermal IR radiometry and pulsed laser acoustics. In the first method, the melting point was detected by monitoring the blackbody thermal emission signals at two infrared wavelengths. In the second method, pulsed laser ultrasonics was used to measure the onset of melting by carefully analyzing the resulting epicentral waveform. Both methods were then compared with expected results using a thermal conduction model. Nanosecond pulse laser heating results of melting point determination are also compared with previous millisecond radiation pyrometry results.
Laser-Ultrasonics on Composite Fibre Reinforced Plastics (CFRP)
---P. Huke, O. Focke, A. Hildebrand, C. von Kopylow, and R. Bergmann, BIAS Bremer Institute für Angewante Strahltechnik GmbH, 25359 Bremen, Germany

--Laser-ultrasonics has significant advantages over standard ultrasound methods due to the contactless measurement technology and high accessibility even to complex parts with high curvature. In addition to non-destructive evaluation (NdE) with body waves, we show that NdE can be expanded to using two-dimensional surface (Lamb) waves for detection of delaminations close to the surface or small deteriorations caused by e.g., impacts. We excite Lamb waves by a single transducer as well as by a short-pulse Laser which additionally produces A0- and S0-Lamb waves. The waves are detected with a shearography setup that allows for measuring two-dimensionally the displacement of a surface. Short integration times of the camera are realized using a pulsed ruby laser for illumination. The propagation in different directions exhibit individual characteristics like amplitude, damping and velocity. This has motivated to build up models for the propagation of Lamb waves which we use for comparison with experimental results.

Non-Destructive Testing Using Two-Component/Two-Wave Mixing Interferometer
---Alexis Wartelle, Bruno Pouet, and Sebastien Breugnot, Bossa Nova Technologies, Venice, CA 90291

--A new laser-based ultrasonic (LBU) receiver, capable of simultaneous detection of both out-of-plane and in-plane displacements, was recently introduced. The novel architecture is based on the classic setup using two-wave mixing (TWM) in photorefractive materials. We kept the same compact architecture as the standard interferometer used for detection of out-of-plane ultrasonic displacements and took advantage of recent developments in parallel electronic processing in order to also extract the information about the in-plane displacements. This technique is well suited for high-sensitivity and high-frequency laboratory measurements as the TWM scheme can easily accommodate collecting optics with high numerical aperture (NA) and has no high-frequency limit. Only the detector electronic limits the high frequency of the system. By using a single collecting aperture and a single laser probe beam, this two-component interferometer is simple to operate and allows automated surface mapping. We will characterize the system performances and present experimental results demonstrating the capability for this compact two-component interferometer.
New Industrial Laser-Ultrasonic Systems for the Inspection of Large Composite Aeronautic Structures
---Marc Dubois and Thomas E. Drake, iPhoton Solutions, Fort Worth, TX 76111

---Laser-ultrasonics has demonstrated a huge potential to reduce the cost of composites inspection for aerospace industry. Until now, large acquisition cost and lack of reliability have prevented the introduction of this technology on a large scale in aeronautic manufacturing. In this paper, a new industrial implementation of laser-ultrasonics is presented. This new approach uses articulated robots to position the laser-ultrasonic system for the inspection of large composite aeronautic structures. In addition to the new robotic approach, other improvements were introduced to increase reliability and decrease cost. The details of this new implementation will be described and results will be presented. A specific application will also be presented and discussed.
Session 35
SESSION 35
MATERIAL PROPERTIES MEASUREMENTS
Nicola Bowler, Chairperson
Salon D

8:30 AM  In-Situ Creep Monitoring Using the Potential Drop Method
---E. Madhi and P. B. Nagy, University of Cincinnati, Department of Aerospace
Engineering & Engineering Mechanics, Cincinnati, OH, 45221; G. Sposito, C. M. Davies,
and P. Cawley, Imperial College, UK Research Centre in NDE, London, United Kingdom

8:50 AM  Material Gauge Factor of Directional Electric Potential Drop Sensors for Creep
Monitoring
---P. B. Nagy and E. Madhi, University of Cincinnati, Department of Aerospace
Engineering and Engineering Mechanics, Cincinnati, OH, 45221-0070

9:10 AM  A New Way of Determining Residual Stress in Steels Using the Magnetic
Barkhausen Effect
---L. Mierczak, E. Melikhov, and D. Jiles, Cardiff University, School of Engineering,
Cardiff, United Kingdom

9:30 AM  Complementary Electromagnetic Method for NDE
---G. Y. Tian, J. Wilson, and M. Morozov, Newcastle University, School of Electrical,
Electronic and Computer Engineering, Newcastle Upon Tyne, England

9:50 AM  Nondestructive Evaluation of Dual Microstructure Turbine Engine Disk Material
---E. A. Medina and M. P. Blodgett, Air Force Research Laboratory, Nondestructive
Evaluation Branch, Materials and Manufacturing Directorate, Wright-Patterson Air Force
Base, OH 45433-7817; R. W. Martin, J.-K. Na, and S. Sathish, University of Dayton
Research Institute, Dayton, OH 45469

10:10 AM  Break

10:30 AM  Non-Destructive Evaluation of Elastic Properties and Ultrasonic Attenuation of
Shear Waves of Anisotropic Media
---P. A. Bodian, P. Guy, and J. Courbon, MATEIS, INSA Lyon, Villeurbanne, France;
B. Chassignole, F. Rupin, and O. Dupond, EDF R&D, Moret-sur-Loing, France

10:50 AM  Adjourn
In-Situ Creep Monitoring Using the Potential Drop Method
---Elhoucine Madhi and Peter B. Nagy, University of Cincinnati, Department of Aerospace Engineering & Engineering Mechanics, Cincinnati, OH, 45221; Giuseppe Sposito, Catrin M. Davies, and Peter Cawley, Imperial College, UK Research Centre in NDE, London, United Kingdom

---A directional low-frequency Alternating Current Potential Drop (ACPD) sensor was developed for in-situ monitoring of creep in metals. The sensor relies on a modified ACPD technique that measures simultaneously both values of resistance in the axial and lateral directions using a square electrode configuration. As compared to the more commonly used in-line electrode configuration, the square arrangement used in this sensor is much more directional and thus allows the detection of creep-induced anisotropy and texture. The sensor essentially monitors the variation in the ratio of the measured axial and lateral resistances, therefore can efficiently separate the mostly isotropic common part of the resistivity variation caused by reversible temperature variations from the mostly anisotropic differential part caused by direct geometrical (size and shape) and indirect material (resistivity) effects of creep. Initially, this ratio is roughly proportional to the applied axial creep strain, while at later stages, the resistance ratio increases even faster with creep strain because of the formation of directional discontinuities such as preferentially oriented grain boundary cavities and multiple-site cracks in the material.

Material Gauge Factor of Directional Electric Potential Drop Sensors for Creep Monitoring
---Peter B. Nagy and Elhoucine Madhi, University of Cincinnati, Department of Aerospace Engineering and Engineering Mechanics, Cincinnati, OH, 45221-0070

---Directional electric potential drop measurements can be exploited for in-situ monitoring of creep in metals. The sensor monitors the variation in the ratio of the resistances measured simultaneously in the axial and lateral directions using a square-electrode configuration. This method can efficiently separate the mostly isotropic common part of the resistivity variation caused by reversible temperature variations from the mostly anisotropic differential part caused by direct geometrical (size and shape) and indirect material (resistivity) effects of creep. Similarly to ordinary strain gauges, the relative sensitivity of the sensor is defined as a gauge factor that can be approximated as a sum of geometrical and material parts. Initially, subtle material changes produce weak electric anisotropy via reversible and irreversible piezoresistivity due to elastic and plastic strains, respectively. At high temperature, much stronger irreversible resistivity changes also occur with time due to cavities developing along grain boundaries approximately perpendicular to the applied stress and subsequent cracks forming between these cavities. The ensuing electric anisotropy is detected by the directional sensor. Although the material effects remained smaller than the geometrical ones up to the initiation of preferentially oriented cracks, later the material gauge factor sharply increases and close to rupture can reach a value of more than 10.
A New Way of Determining Residual Stress in Steels Using the Magnetic Barkhausen Effect
---Lukasz Mierczak, Eugene Melikhov, and David Jiles, Cardiff University, School of Engineering, Cardiff, United Kingdom

---A new procedure for detecting stress in the surface of high strength steels has been devised based on the measurement of magnetic Barkhausen emissions. Magnetic Barkhausen measurements were carried out and residual stress was determined independently using X-ray diffraction. A linear calibration curve has been developed based on theoretical considerations that provides an explanation of the rather surprisingly simple dependence of Barkhausen signal amplitude on stress. The relationship between stress dependence of the maximum differential susceptibility and Barkhausen peak amplitude was observed. Plots of reciprocal values $1/\chi'_m$ and $1/V_{MBN}$ max against stress showed a linear relationship providing a convenient method for detecting stress levels in near-surface regions from Barkhausen measurements. The linear calibration has the advantage that realistic extrapolations as well as interpolations can be made from a set of data. The peak amplitude of the Barkhausen emissions was found to correlate with residual and applied stress, showing a clear rising trend for transition from compressive to tensile stress. The location of the peak was found to correlate with the mechanical hardness of the material. This is caused by a change in coercivity arising from a change in microstructure. Therefore a combination of Barkhausen peak height and position can be used to evaluate residual stress and mechanical hardness in high strength steels.

Complementary Electromagnetic Methods for NDE
---G. Y. Tian, J. Wilson, and M. Morozov, Newcastle University, School of Electrical, Electronic and Computer Engineering, Newcastle Upon Tyne, England

---This paper reports recent developments in the field of electromagnetic NDE at Newcastle University. The principal applications pursued at Newcastle encompass pulsed eddy currents for residual stress measurement and pulse eddy current stimulated thermography for defect detection and eddy current distribution mapping, as well as Magnetic Barkhausen Noise and Magneto-Acoustic Emission for microstructural characterization of ferromagnetic materials. The respective research involves the development of eddy current sensors and arrays for advanced material characterization and early defect detection. Experimental case studies looking at pulsed eddy currents for residual stress measurement and pulsed eddy current thermography for eddy current mapping are presented in the paper. The complementary characters of electromagnetic techniques for NDE are discussed.
Nondestructive Evaluation of Dual Microstructure Turbine Engine Disk Material
---Enrique A. Medina and Mark P. Blodgett, Air Force Research Laboratory, Nondestructive Evaluation Branch, Materials and Manufacturing Directorate, Wright-Patterson Air Force Base, OH 45433-7817; Richard W. Martin, Jeong-Kwan Na, and Shamachary Sethish, University of Dayton Research Institute, Dayton, OH 45469

---We present development status and plans for NDE of graded material microstructures such as those found in dual microstructure turbine engine disks. These hybrid disks typically feature coarse grain microstructures in the rim for increased creep resistance and fine grain microstructures in the bore for optimal fracture toughness and fatigue resistance. NDE methods are necessary for estimating microscopic materials property changes throughout the disk life. Key NDE goals include identifying the transition zone between the coarse and fine grain regions and developing approaches for nondestructively characterizing grain structure and size distributions and a range of damage size scales from low-level/precursor damage to mid-level microcracking. Initial eddy current measurements showed lower conductivity in the coarse grain region, a modest conductivity variation between the fine and coarse grain zones, and a band of increasing conductivity corresponding to the transition zone. Initial ultrasonic measurements, including longitudinal, shear, and Rayleigh wave velocity, and frequency dependent attenuation, resulted in clear identification of the coarse grain, transition, and fine grain regions. Grain noise increased with grain size, possibly posing difficulties for nondestructively estimating material features. Future work will target practical NDE measurement tools for grain size, texture, and elastic constants, and tools to assess damage accumulation.

Non-Destructive Evaluation of Elastic Properties and Ultrasonic Attenuation of Shear Waves of Anisotropic Media
---P. A. Bodian, P. Guy, and J. Courbon, MATEIS, INSA Lyon, Villeurbanne, France; B. Chassignole, F. Rupin, and O.Dupond, EDF R&D, Moret-sur-Loing, France

---An experimental device has been developed in order to measure the stiffness constants and attenuation in oblique incidence on a single specimen. Its originality, is that it allows us to work beyond the first critical angle and therefore to measure the attenuation properties of shear waves. Elastic constants are assessed from experimental data thanks to a genetic algorithm based on an optimization method, while attenuation is evaluated from the angular spectrum analysis of transmitted beam.
Session 36
SESSION 36
PROBES, SENSORS, AND INSTRUMENTS
Ke Wang, Chairperson
Salon E

8:30 AM Characterizing T/R Arrays Via N-Port Theory
---H. A. Sabbagh, R. K. Murphy, and E. H. Sabbagh, Victor Technologies, LLC, Bloomington, IN 47407-7706; J. C. Aldrin, Computational Tools, Gurnee, IL 60031; M. Johnson, EM Sensors, Inc., Ames, IA 50012

8:50 AM Development and Application of Wide Bandwidth Magneto-Resistive Sensor Based Eddy Current Probe
---B. A. Wincheski, NASA Langley Research Center, Hampton, VA 23681; J. Simpson, Lockheed Martin, Hampton, VA 23681

9:10 AM Real Time Electromagnetic Inspection of Composite Joining Process

9:30 AM Measurement of the Effect of Temperature on the Acoustic Properties of a Modified BS-PT Piezoelectric Material
---S. Roa Prada, H. A. Scarton, and K. R. Wilt, Rensselaer Polytechnic Institute, Department of Mechanical, Aerospace & Nuclear Engineering, Troy, NY 12180; G. J. Saulnier, J. D. Ashdown, and T. J. Lawry, Rensselaer Polytechnic Institute, Department of Electrical, Computer & Systems Engineering, Troy, NY 12180; P. J. Das, University of California, Electrical and Computer Engineering, La Jolla, CA 92093; A. J. Gavens, Bechtel Marine Propulsion Corporation, Schenectady, NY 12308

9:50 AM Measurements to Characterize Acoustic Distribution Properties of Ultrasonic Transducer
---T. Kong, D. Xiao, and C. Xu, Key Laboratory of Fundamental Science for Advanced Machining, Beijing Institute of Technology, Beijing, China

10:10 AM Break

10:30 AM Liquid Steel Cleanliness Measurement: Numerical Analysis of Probe Design
---H. Cui, J. Trevelyan, and S. Johnstone, University of Durham, School of Engineering and Computing Sciences, Durham, United Kingdom; S. Millman, Corus UK Ltd, Corus Research Development & Technology, Middlesbrough, United Kingdom

10:50 AM Ultrasonic Wall Thickness Monitoring at High Temperatures (>500°C)
---F. Cegla and P. Cawley, Imperial College, Mechanical Engineering, London, United Kingdom; J. Allin and J. Davies, Permasense Ltd, Horsham, United Kingdom

11:10 AM Development of a Novel Ultrasonic Waveguide Transducer for Under-Sodium Viewing
---H. T. Chien, K. Wang, and S. H. Sheen, Argonne National Laboratory, Nuclear Engineering Division, Building 308, Argonne, IL 60439

11:30 AM Defect Monitoring at Elevated Temperatures (>500°C) Using an Array of Ultrasonic Waveguides
---A. Jarvis and F. Cegla, Imperial College, Mech. Engineering, London, United Kingdom

11:50 AM Microwave Interferometer for Shockwave Induced Displacement Measurement
---J. Choi and T. Itoh, University of California, Los Angeles, Department of Electrical Engineering, Los Angeles, CA 90095; G. Youssef, University of California, Los Angeles, Department of Mechanical Engineering, Los Angeles, CA 90095; S. Breugnot, Bossa Nova Technologies, Venice, CA 90291

12:10 PM Adjourn
Characterizing T/R Arrays Via N-Port Theory
---Harold A. Sabbagh, R. Kim Murphy, and Elias H. Sabbagh, Victor Technologies, LLC, Bloomington, IN 47407-7706; John M. Aldrin, Computational Tools, Gurnee, IL 60031; Marcus Johnson, EM Sensors, Inc., Ames, IA 50012

---Accurate models of the subsystems that go into eddy-current nondestructive evaluation (NDE) are required if progress is to be made through the disciplines of model-assisted probability of detection (MAPOD) and model-assisted inversion (MBI). Perhaps the most crucial subsystem in eddy-current NDE is the probe, and in this paper we apply electrical network N-port theory to accurately and carefully characterize a transmit-receive array of coils. The characterization starts with the development of a model that can be executed using the proprietary volume-integral code, VIC-3D(c), and then the model is fitted to measured scattering-parameter data taken with the HP3577A network analyzer, with the array in free space. Excellent results are achieved, and will be discussed.

Development and Application of Wide Bandwidth Magneto-Resistive Sensor Based Eddy Current Probe
---Buzz A. Wincheski, NASA Langley Research Center, Hampton, VA 23681; John Simpson, Lockheed Martin, Hampton, VA 23681

---The integration of magneto-resistive sensors into eddy current probes can significantly expand the capabilities of conventional eddy current nondestructive evaluation techniques. The room temperature solid-state sensors have typical bandwidths in the megahertz range and resolutions of tens of microgauss. The low frequency sensitivity of magneto-resistive sensors has been capitalized upon in previous research to fabricate very low frequency eddy current sensors for deep flaw detection in multilayer conductors. In this work a modified probe design is presented to expand the capabilities of the device. The new probe design incorporates a switchable induction source enabling a change in operation from low frequency deep flaw detection to high frequency high resolution near surface material characterization. Applications of the probe for the detection of both deep flaws and localized near surface conductivity anomalies are presented. Finite element modeling of the probe is shown to be in good agreement with experimental measurements.
Real Time Electromagnetic Inspection of Composite Joining Process
---Changting Wang, Waseem Faidi, Aparna Vadde, Nilesh Tralshawala, Manda Godbole, Andrew May, and Thomas Mieback, Nondestructive Technologies Laboratory, General Electric Global Research, Niskayuna, NY12309

---Composite materials are increasingly being used to meet strength and weight requirements in new aeronautical designs for infrastructure such as airplanes and windmills. Quality control of these new materials during manufacturing and in service is an active area of research and development. Ultrasonic inspection is widely used for inspection of internal structures, however, false calls related to normal variation in material porosity and anisotropy can lead to higher inspection and repair costs and increases the chance of in-service failures from missed defects. This paper will present an electromagnetic approach for NDE of adhesive bonds between composites that does not suffer from the limitations of ultrasonic methods. A real-time imaging system was developed using a 2-D electromagnetic sensor array and computer interface. Sensor designs were evaluated and optimized with finite element modeling and empirical measurements for imaging ferrite-doped adhesives used during the manufacturing of wind blade components.

Measurement of the Effect of Temperature on the Acoustic Properties of a Modified BS-PT Piezoelectric Material
---Sebastian Roa Prada, Henry A. Scarton, Kyle R. Wilt, Rensselaer Polytechnic Institute, Department of Mechanical, Aerospace & Nuclear Engineering, Troy, NY 12180; Gary J. Saulnier, Jonathan D. Ashdown, and Tristan J. Lawry, Rensselaer Polytechnic Institute, Department of Electrical, Computer & Systems Engineering, Troy, NY12180; Pankaj J. Das, University of California, Electrical and Computer Engineering, La Jolla, CA 92093; Andrew J. Gavens, Bechtel Marine Propulsion Corporation, Schenectady, NY 12308

---The effect of temperature up to 315°C (600°F) on the properties of a piezoelectric material used for nondestructive testing, or in an ultrasonic through-wall communication system (UTWC), is presented. A modified BS-PT (BiScO3–PbTiO3) material was selected from commercially available piezoelectric materials for evaluation due to its strong piezoelectric activity and properties. Potential changes in acoustic properties with increasing temperature could impact performance and data interpretation. Therefore, the temperature dependence of the properties of this piezoelectric material must be characterized so that performance changes can be predicted and compensated for. Two electroded disk-shaped BS-PT samples were placed inside an oven. The temperature was gradually increased from room temperature to 315°C and the impedance at the electrical terminals of the samples was measured over a frequency range that included the planar and the longitudinal resonance frequencies of the disks. The acoustic and piezoelectric properties were extracted from the impedance measurements as a function of frequency. The potential effects of these temperature dependent properties are discussed.
Measurements to Characterize Acoustic Distribution Properties of Ultrasonic Transducer
---Tao Kong, D. Xiao, and Chunguang Xu, Key Laboratory of Fundamental Science for Advanced Machining, Beijing Institute of Technology, Beijing, China

---A reflection method is developed to characterize the sound field distribution. Instead of a point-like target (rigid sphere) or thin wires (line-like targets), a line response function (LRF) of experimental knife-edge distribution (KED) combined the inverse Abel transforms is used to estimate the beam distributions of ultrasonic transducers, and this approach is simpler and more cost-effective. There are two major steps in this method, first step, a rigid block with knife-edge is used, and transducers driven by the positioning system scan the knife-edge to obtain the reflective distribution, then the line response function of this distribution is solved, which is similar the wire-target distribution in essence. Second step, inverse Abel transform of line response function is employed to obtain the transverse beam pattern of transducer. An additional experiment with a small-aperture hydrophone was performed to compare with this method. Results of compared experiments will demonstrate the effectiveness of this method.

Liquid Steel Cleanliness Measurement: Numerical Analysis of Probe Design
---Hanyin Cui, Jon Trevelyan, and Sherri Johnstone, University of Durham, School of Engineering and Computing Sciences, Durham, United Kingdom; Stuart Millman, Corus UK Ltd, Corus Research Development & Technology, Middlesbrough, United Kingdom

---This paper presents the results from a numerical analysis of propagating modes along a transmission rod to aid in the design of a probe used in a liquid steel inclusion measurement system. The probe has been designed to function as a waveguide in temperatures in excess of 1500°C; it consists of a steel rod surrounded by a ceramic sheath. This study investigates the effect of signal bandwidth and mode selection related to probe diameter and length on the number and types of propagating modes. The aim is to reduce dispersion and increase the signal to noise ratio of the transmitted ultrasonic signal. The numerical simulations for a variety of rod geometries have shown that a large number of guided modes exist for practical dimensions; all the modes are dispersive and cause the signal to extend in time; and the energy is distributed over several modes with different phase and group velocities. It is suggested that a suitable mode at the excitation centre frequency should have high amplitude, minimal dispersion with a distinguishable group velocity and the excitation signal should have a narrow bandwidth. Increasing the length of the rod aids in separating modes in time and thus facilitates mode selection.
Ultrasonic Wall Thickness Monitoring at High Temperatures (>500°C)
---Frederic Cegla and Peter Cawley, Imperial College, Mechanical Engineering, London, United Kingdom; Jonathan Allin and Jacob Davies, Permasense Ltd, Horsham, United Kingdom

---Corrosion and erosion shorten the life of components that are used in the petrochemical industry. In order to mitigate the safety and financial risks posed by the degradation mechanisms, plant operators monitor wall thicknesses at regular inspection intervals. In high temperature locations inspections have to be carried out at plant shut downs because conventional ultrasonic sensors cannot withstand the high operating temperatures. The authors have developed a waveguide based high temperature thickness gauge for monitoring of wall thicknesses in high temperature areas. The waveguide allows the use of conventional transduction systems (max temp. 60°C) at one end and guides ultrasonic waves into the high temperature region where the inspection is to be carried out. Slender stainless steel waveguides allow a temperature drop of ~500-600°C per 200mm length to be sustained simply by natural convection cooling. This paper describes the technical challenges that had to be overcome (dispersion and source/receiver characteristics) in order to implement this “acoustic cable”. A range of experimental results of thickness measurements on components of different thickness, and furnace tests at different temperatures are presented. An accelerated corrosion test that demonstrates the feasibility of the monitoring for corrosion is also presented, together with results from site trials.

Development of a Novel Ultrasonic Waveguide Transducer for Under-Sodium Viewing
---H. T. Chien, K. Wang, and S. H. Sheen, Argonne National Laboratory, Nuclear Engineering Division, Building 308, Argonne, IL 60439

---A novel ultrasonic waveguide transducer (UWT) has been developed for under-sodium ultrasonic visual inspection of sodium-cooled fast reactor (SFR). As the critical component of the under-sodium ultrasonic imaging system, UWT transmits signal and provides thermal isolation. In the present work, a prototype UWT was designed and tested for under-sodium imaging. The performance was evaluated and compared with other four types of waveguide designs. Our design shows a great improvement of signal transmission efficiency and enhancement of detection sensitivity than others. Under-sodium imaging facility was designed and fabricated and experiments were carried out in sodium. Our preliminary results demonstrate that our novel ultrasonic waveguide transducer (UWT) is able to achieve 1 mm lateral resolution in molten sodium with temperature ranged from 300°F to 500°F.
Defect Monitoring at Elevated Temperatures (>500°C) Using an Array of Ultrasonic Waveguides

---Andrew Jarvis and Frederic Cegla, Imperial College, Mechanical Engineering, London, United Kingdom

---This paper describes the development of an array of ultrasonic waveguides that can be permanently installed on high temperature pipe work. The work was motivated by the need for monitoring of thermal fatigue cracks in power station boiler outlet pipes. The defect monitoring concept is described and simulated results are presented for the operating envelope of the array. The effects of component geometry, array location and signal to noise ratios on measured defect size were investigated. Results show that the array is capable of measuring defects ranging from the size of an ultrasonic wavelength to half the thickness of the component to within 0.2mm of the defect length. Experimental tests using a prototype array attached to a 30mm thick steel plate containing a 5mm deep and 0.3mm wide notch in a furnace at 550°C showed that monitoring at elevated temperatures is possible. A mean defect length of 5.09mm with standard deviation of 0.13mm was measured over a 2.5 weeks period. Further tests at even higher temperatures (up to 730°C) were used to accelerate creep in the attachment mechanism and showed that long-term exposure to temperatures at 550°C should not have a detrimental effect on the system.

Microwave Interferometer for Shockwave Induced Displacement Measurements

---Jun Choi and Tatsuo Itoh, University of California, Los Angeles, Department of Electrical Engineering, Los Angeles, CA 90095; George Youssef, University of California, Los Angeles, Department of Mechanical Engineering, Los Angeles, CA 90095; Sebastien Breugnot, Bossa Nova Technologies, Venice, CA 90291

---A microwave interferometer for detecting shockwave induced displacement is demonstrated. Displacement of the target by laser induced shockwave has been widely used for material characterization and interfacial strength testing. In optical interferometers, the surface velocity related to the input stress is measured by counting the number of fringes which requires additional post-processing steps. Longer wavelength in microwave interferometer allows direct reading of the surface displacement. Detection of the shockwave induced displacement on plastic targets using microwave interferometer are measured and then compared with the optical interferometer measurements.
SESSION 37
NEW TECHNIQUES AND SYSTEMS
Marc Genest, Chairperson
Salons F-H

8:30 AM  A Secure Method for Enterprise Wide Digital Inspection and Maintenance Records in Aviation Industry
---P. Pisupati and S. Dewangan, Infosys Technologies Limited, SETLabs, Bangalore, Karnataka, India; A. Saxena, Infosys Technologies Limited, SETLabs, Hyderabad, Andhra Pradesh, India

8:50 AM  Laser and LED Hybrid Source for Scanning White Light Interferometry Based MEMS Quality Control
---V. Heikkinen, B. Wälchli, H. Räikkönen, I. Kassamakov, and E. Hæggström, University of Helsinki, Department of Physics, Helsinki, Finland; J. Aaltonen and I. Kassamakov, Helsinki Institute of Physics, Helsinki, Finland

9:10 AM  Graphics Processing Unit Based NDE Modeling and Imaging Sensors Development for Cracks and Corrosion Detection
---Y. J. Deng, University of Colorado Denver, Departments of Electrical Engineering, Bioengineering and Radiology, Denver, CO 80217; X. Liu and D. Connors, University of Colorado Denver, Department of Electrical Engineering, Denver, CO 80217

9:30 AM  Use of Microwaves for the Detection of Corrosion Under Insulation: A Sensitivity Study
---R. Jones, F. Simonetti, and M. J. S. Lowe, Imperial College, Mechanical Engineering, London, United Kingdom; I. Bradley, BP, Sunbury on Thames, United Kingdom

9:50 AM  High Frequency Ultrasonic Vibration Modal Analysis Technique (UMAT) for Defect Detection
---F. Yan and J. L. Rose, FBS, Inc, State College, PA 16802; Y. Liang, C. Borigo, 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  Multi-Skip Tomographic Inversion
---A. Volker and J. Bloom, TNO, Stieltjesweg 1, P. O. Box 155, Delft, 2600 AD, The Netherlands

10:50 AM  Crack Detection Using Induction Thermography for TMF Tests
---M. Genest, D. Dudzinski, and S. Bulmer, Institute for Aerospace Research, National Research Council Canada, Ottawa, ON, K1A 0R6 Canada

11:10 AM  Super-Resolution Imaging with Elastic Waves
---T. Hutt and F. Simonetti, Imperial College, Mechanical Engineering, London, United Kingdom

11:30 AM  Development of a Volumetric EC Solution for the Orion OME Injector
---L. A. Schaefer, Aerojet, Highway 50 and Aerojet Road, Sacramento, CA 95813

11:50 AM  Adjourn
A Secure Method for Enterprise Wide Digital Inspection and Maintenance Records in Aviation Industry
---Preeti Pisupati and Sandeep Dewangan, Infosys Technologies Limited, SETLabs, Bangalore, Karnataka, India; Ashutosh Saxena, Infosys Technologies Limited, SETLabs, Hyderabad, Andhra Pradesh, India

---Structural health related inspection and maintenance records, of the cost and safety critical engineering components in aviation industry, are securely preserved and monitored. Various Non-Destructive Testing (NDT) methods which include, ultrasound, radiography, computed tomography, eddy current testing, visual inspection, infra-red imaging etc. are used to generate the inspection data. These are generated in the form of 1-dimensional signals or 2 or 3-dimensional images in conjunction with annotations, interpretations and conclusions made by the inspector. Regulatory requirements mandate that the records must be tamper proof in order to safeguard their integrity and authenticity. Digital signature is one of the mechanisms for demonstrating data integrity and performing source authentication. Timestamps are useful for confirming data existence at a particular point in time. The value of timestamp pertaining to digital signatures is limited due to lack of tools and techniques that address the problems which accrue over the period of time, like expiration, revocation, cryptanalytic and computational advances. We present a secure schema for enterprise wide digital information, related to inspection and maintenance of engineering parts and components, throughout manufacturing and service usage life-cycle. The proposed method covers the source authentication, integrity of information during transactions and secured archiving of data.

Laser and LED Hybrid Source for Scanning White Light Interferometry Based MEMS Quality Control
---Ville Heikkinen, Ben Wälchli, Heikki Räikkönen, Ivan Kassamakov, and Edward Häggström, University of Helsinki, Department of Physics, Helsinki, Finland; Juha Aaltonen and Ivan Kassamakov, Helsinki Institute of Physics, Helsinki, Finland

---We apply a novel hybrid light source with adjustable spectrum to Scanning White Light Interferometry (SWLI) for MEMS device characterization. The source combines light from a blue laser, a red LED and a fluorescent material to cover the visible wavelengths. The light source decreases interference ringing and improves surface localization especially of diffuse surfaces or while measuring both surfaces of a transparent sample. To test the light source we measured samples with known step heights. The results were compared to those measured using a halogen lamp (h = 7.025 ± 0.020 µm) with a coherence length of 0.83 ± 0.02 µm. The new light source is more versatile than earlier light sources used with SWLI. It allows both stroboscopic illumination and spectrum shaping during a measurement to maximize the reflection from the sample surface.
Graphics Processing Unit Based NDE Modeling and Imaging Sensors Development for Cracks and Corrosion Detection
---Yiming J. Deng, University of Colorado Denver, Departments of Electrical Engineering, Bioengineering and Radiology, Denver, CO 80217; Xin Liu and Daniel Connors, University of Colorado Denver, Department of Electrical Engineering, Denver, CO 80217

---Rocket propulsion testing facilities must operate in extreme condition including very low or high temperatures, vacuum or pressures up to 15,000 psi and other perfect environment for the formation of cracks and corrosion. To ensure the integrity and safety of these facilities is critical. There is a tremendous need to track and detect hidden tight cracks and corrosion at earlier stage using automatic and reliable imaging technologies, which can also help to identify and optimize the factors that affect subjective human performance in maintenance and inspection. To better understand the imaging physics and to guide the sensor design, the graphics processing unit (GPU) based NDE modeling of cracks and corrosion interacting with multi-frequency electromagnetic energy is presented. An innovative numerical solver based on meshless method is adopted over conventional finite element method (FEM) and implemented in parallel computing. This paper also presents the prototype of an innovative automated imaging array system for near real time highlighting, tracking and classifying cracking and corrosion issues for rocket propulsion testing facilities, e.g. A3 Vacuum chamber. The system can enhance the maintainer’s ability in the prevention, inspection, removal and treatment of corrosion and/or tight cracks and information management. Variability due to human factors is minimized by introducing automated quantification and classification algorithms associated with the imaging components. Substantial decreases in maintenance costs associated with detecting, repairing, and tracking defective/corrosive areas can be achieved.

Use of Microwaves for the Detection of Corrosion Under Insulation: A Sensitivity Study
---Robin Jones, Francesco Simonetti, and Michael J.S. Lowe, Imperial College, Mechanical Engineering, London, United Kingdom; Ian Bradley, BP, Sunbury on Thames, United Kingdom

---Corrosion Under Insulation (CUI) is a significant cause of pipeline failure in the oil and gas industry. When water breaches the external cladding used to protect the insulation, it starts to corrode the external surface of the pipe. Inspection of the pipe by removal of the insulation is expensive and time consuming. This paper explores the possibility of detecting CUI with an indirect approach aimed at inspecting the insulation for the presence of water, which is a necessary precursor to CUI. In particular, it is observed that the pipe and the cladding form a coaxial waveguide which can be used to propagate microwaves within the insulation along the length of the pipe. An accumulation of water in the insulation will act as an impedance discontinuity within the waveguide, causing a reflection of the microwave signal. These reflections can be used to detect and locate water accumulations, and hence locate the regions of the pipe at risk of CUI. An antenna array is used to achieve pure TEM (Transverse Electromagnetic) mode excitation in a coaxial waveguide of realistic pipeline dimensions, with a signal-to-coherent-noise ratio of 40dB readily obtained. The sensitivity of the technique to the presence of water within the waveguide is demonstrated by introducing discrete volumes of water into a plastic tank within the waveguide. Water volumes presenting a cross-sectional extent of only 5% of the area corresponding to the insulation annulus are clearly detectable. Results are presented from an investigation into the effect of bends on the propagating microwave signal conducted with the use of simulation software and an experiment involving a 6m long, 12” diameter coaxial waveguide with varying bend angles at its midpoint.
High Frequency Ultrasonic Vibration Modal Analysis Technique (UMAT) for Defect Detection
---Fei Yan and Joseph L. Rose, FBS, Inc, State College, PA 16802; Yue Liang, Cody Borigo, and Joseph L. Rose, The Pennsylvania State University, Department of Engineering Science and Mechanics, University Park, PA 16802

---Vibration modal analysis and ultrasonic guided wave tests are two commonly used defect detection techniques for Nondestructive Evaluation (NDE) and Structural Health Monitoring (SHM). Each technique has its unique technical merits and also limitations. In this paper, we discuss a new high frequency ultrasonic vibration test method that is developed to bridge the conventional low frequency vibration analysis together with ultrasonic guided wave techniques. The new ultrasonic vibration modal analysis technique (UMAT) takes advantage of the high defect detection sensitivity of ultrasonic guided waves, and at the same time, requires only a minimum number of testing points to cover a large structure, as can be achieved in low frequency vibration analysis. Time delay annular array actuators that are capable of tuning guided wave modes and frequencies are applied to introduce controlled high frequency vibrations to structures being tested. The defect detection sensitivity of the controlled vibrations depends on the sensitivity of the input guided wave modes and frequencies, which is associated with the displacement and stress wave structures of the guided waves. By looking at the vibration patterns and the resonant frequencies under guided wave mode and frequency tuning based on wave structure considerations, high defect detection sensitivity is achieved. Experimental demonstrations are carried out on both aluminum and fiber reinforced composite plate like structures.

Multi-Skip Tomographic Inversion
---Arno Volker and Joost Bloom, TNO, Stieltjesweg 1, P. O. Box 155, Delft, 2600 AD, The Netherlands

---Inspection of corrosion at pipe supports locations is difficult because of accessibility. Recently a screening technique has been developed called Multi-Skip ultrasonics. The method utilizes a pitch-catch set-up. Shear waves are transmitted that reflect multiple times in the pipe wall, from which integral wall thickness information is obtained. The method turns out to be very sensitive in detecting the presence of wall loss, but it turns out to be difficult to determine the extent of the wall loss. If the extent is not known, only a conservative estimate of depth can be derived from the Multi-Skip signals, because of the accumulative nature of the change in arrival time due to wall loss. Multi-skip tomography appears to be a promising method as an addition to Multi-Skip screening as a follow-up inspection technique. It uses full wave field inversion to determine a wall thickness profile at a particular location of the pipe on the support. As with the Multi-Skip screening method, Multi-Skip tomography is applied with the transmitter and receiver on both sides of the pipe support location and waves traveling in the axial pipe direction. The wave field inversion consists of a forward modeling step that predicts the measured wave field after which an iterative comparison process with the actually measured wave field results in an estimate of the wall thickness profile under the support.
Crack Detection Using Induction Thermography for TMF Tests
---Marc Genest, David Dudzinski, and Scott Bulmer, Institute for Aerospace Research, National Research Council Canada, Ottawa, ON, K1A 0R6 Canada

---Early fatigue crack growth behaviour is an important aspect to the total fatigue life for many engineering applications. During a thermo-mechanical fatigue (TMF) test, crack inspections are done in a disruptive manner by acetate replication method; and post-test crack evaluation is done using both optical and scanning electronic microscope methods. This paper investigates a proof-of-concept technique for induction thermography as a new in-situ, non-destructive inspection approach for use during TMF testing. The results obtained by induction thermography are compared to those obtained via traditional acetate replication method and post-test scanning electron microscope (SEM) evaluation. The induction thermography inspections were carried out at several temperatures and show that the temperature used for the TMF test does not influence the crack detection capability. It is demonstrated that induction thermography can detect cracks in the order of 500 micrometer and has potential for quantifying the crack length.

Super-Resolution Imaging with Elastic Waves
---Timothy Hutt and Francesco Simonetti, Imperial College, Mechanical Engineering, London, United Kingdom

---In conventional ultrasound imaging the accuracy in defect characterization is dictated by the diffraction limit which excludes the possibility of observing details of defects at the sub-wavelength scale. This implies that in order to enhance the resolution, a short wavelength, \( \lambda \), needs to be propagated. However, as \( \lambda \) decreases the wave experiences a higher attenuation due to absorption and scattering. Therefore, there exists a fundamental trade-off between the maximum resolution that can be achieved and the imaging depth. Super resolution imaging methods can break this limit and have been demonstrated experimentally in fluids which only support acoustic waves. However, while in acoustics all the available information is encoded in the measurements performed with longitudinal P-waves, in elastic imaging more information is available thanks to mode conversion to shear S-waves. Unfortunately, conventional arrays can only measure one component of the elastic wave field, thus affecting the possibility of separating the P and S components of the scattered field. This paper investigates the application of super resolution imaging techniques to elastic wave probing. The extent of mode conversion is studied as function of the defect size relative to \( \lambda \) and super resolution algorithms are applied to data where the separation between P and S waves is achieved by exploiting their different propagation speeds. The importance of mode conversion is further evaluated by comparing the results with an equivalent acoustic model.
Development of a Volumetric EC Solution for the Orion OME Injector
---Lloyd A. Schaefer, Aerojet, Highway 50 and Aerojet Road, Sacramento, CA 95813

---The NASA Orion program draws largely on the heritage Space Shuttle OME for its primary propulsion system. In some areas of the design however, new approaches were found necessary to meet unique performance and reliability requirements for the man-rated Orion application, which is delivered to orbit by the Ares launch system. The design IPT process responding to these performance CTQs defined a need for an inspection solution of one of the Injector's critical pressure boundary welds, which is not accessible for, and could not be validated at 90/95 by heritage UT and RT processes. We review the efforts to date to model, prototype and quantify the performance of a volumetric and surface inspection solution.
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CONFERENCE EVALUATION FORM
THIRTY-SEVENTH ANNUAL REVIEW OF PROGRESS IN QNDE
Marriott San Diego Mission Valley-San Diego, California
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