Abstracts

Review of Progress in Quantitative NDE
University of Vermont
Burlington, Vermont
July 17 – 22, 2011

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

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# 2011 Review of Progress in Quantitative NDE Program Summary

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7. NDE Techniques of Civil Eng. Materials & Structures - MLB  
8. NDE for Aeronautic Weld Matlas/Welds - FLB  
9. UT Trans. (EMATs, Arrays, & Matls.) - SLVRMB | 10. NDE of Armor & Armor Systems - MLB  
15. UT Phased Arrays - SUGMB  
16. NDE for Microstructure - FLB  
B: UT Phased Arrays II - SUGMB  
24. Digital Sig. Proc. of Guided Waves - MLB  
25. X-Ray NDE - SLVRMB  
33. Composites & Resins - SUGMB  
34. Sensors (All Techniques & Sensors Material - MLB  
35. NDE for Nati. Microstructure, Properties - SLVRMB |
| 9:00 | | 2. UT Modelino - MLB  
3. EM Methods - SUGMB  
4. Imaging & Inversion Techniques - SLVRMB  
20. Probability of Detection - MLB  
21. Structural Health Monitoring - SLVRMB  
22. Signal & Image Processing - FLB | 27. Ultrasonic Wave Attenuation - MLB  
28. New Techniques & Systems - SUGMB  
29. Sensor Technologies - MLB  
30. Laser Ultrasonics - SLVRMB  
31. Benchmark Validation - SUGMB |
| 10:00 | Conferences check-in and registration  
Livak Fireplac Lounge  
2:00-6:00 pm and 7:00-9:00 pm | 11. THz Microwave NDE - JF  
12. Image Processing - MLB  
13. NDE for Materials - JF  
14. UT Nonlinear Effects & Techniques - FLB | | |
| 11:00 | Welcome Reception  
Silver Maple Ballroom  
7:00 pm | | | |
| 12:00 pm | Lunch | | | | |
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MONDAY

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Plenary Session 1
REVIEW OF PROGRESS IN QUANTITATIVE NDE
University of Vermont
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PROGRAM

Monday, July 18, 2011

PLENARY SESSION 1
A TRIBUTE TO BRUCE
L. Brasche and L. W. Schmerr, Jr., Co-Chairpersons
Silver Maple Ballroom

8:40 AM Opening Remarks
---L. Brasche, Iowa State University, Center for NDE, Ames, IA 50011

8:50 AM IPRT and Bruce
---G. A. Kraus, Iowa State University, Director, Institute for Physical Research and Technology,
2759 Gilman Hall, Ames, IA 50011-3111

9:00 AM Nonlinear Acoustics and Honeycomb Materials
---D. O. Thompson, Iowa State University, Center for NDE, Ames, IA 50011

9:20 AM Electromagnetic Transduction of Ultrasonic Waves
---F. Passarelli, Resonic NDT Systems, 4892 North Street, Camarillo, CA 93066

9:40 AM Ultrasonic Measurement Models
---T. A. Gray, Iowa State University, Center for NDE, Ames, IA 50011

10:00 AM Bruce Thompson: Adventures and Advances in Ultrasonic Backscatter
---F. J. Margetan, Iowa State University, Center for NDE, Ames, IA 50011

10:20 AM Break

10:40 AM R. B. Thompson’s Contributions to Model Assisted Probability of Detection
---W. Q. Meeker, Iowa State University, Center for NDE and Department of Statistics, Ames, IA
50011

11:00 AM Bruce Thompson – International Leader
---P. Cawley, Imperial College, 682 Mechanical Engineering, Exhibition Road, London, SW7 2AZ,
United Kingdom

11:20 AM Dr. R. Bruce Thompson and the Industry – A Model of Technology Transfer
---K. D. Smith, Pratt & Whitney, M/S 114-37, 400 Main Street, East Hartford, CT 06033

11:40 AM Closing Remarks
---J. Bernard, Iowa State University, Ames, IA 50011

12:00 PM Questions and Observations
---L. Brasche, Iowa State University, Center for NDE, Ames, IA 50011

12:20 PM Lunch

Please Note: The bolded authors throughout this program indicate the presenting author.
Nonlinear Acoustics and Honeycomb Materials
---D. O. Thompson, Iowa State University, Center for NDE, Ames, IA 50011

---The scope of research activity that Bruce Thompson embraced was very large. In this talk three different research topics in which Bruce was involved early in his career are reviewed. They include nonlinear acoustics, nondestructive measurements of adhesive bond strengths in honeycomb panels, and studies of flexural wave dispersion in honeycomb materials. In the first of these, four harmonics of a 30 Mhz finite amplitude wave were measured for both fused silica and aluminum single crystals with varying lengths and amounts of cold work using a capacity microphone with heterodyne receiver with a flat frequency response from 30 to 250 Mhz. The results for fused silica with no dislocation structure could be described by a model due to Fubini, originally developed for gases, that depends upon only the second and third order elastic constants and not the fourth and higher order constants. The same was not true for the aluminum with dislocation structures. These results raise some questions about models for harmonic generation in materials with dislocation. In the second topic, experiments were made to determine the adhesive bond strengths of honeycomb panels using the vibrational response of the panels (Chladni figures). The results showed that both the damping characteristics of panel vibrations as a whole and velocity of propagation of elastic waves that travel along the surface and sample the bondline can be correlated with destructively determined bond strengths. Finally, the phase velocity of flexural waves traveling along a 1-inch honeycomb sandwich panel was determined from 170 Hz to 50Khz, ranging from $2.2 \times 10^4$ cm/sec at the low end to $1.18 \times 10^5$ cm/sec at 40 Khz. The dispersion arises from the finite thickness of the panel and agree with the results of continuum models for the honeycomb. Above 40 Khz, this is not the case. Other contributions that Bruce made will be discussed as time permits.
Electromagnetic Transduction of Ultrasonic Waves
---Frank Passarelli, Resonic NDT Systems, 4892 North Street, Camarillo, CA 93066

---Excitation and detection of ultrasonic vibrations without physical contact has proven to be of great commercial value because they can perform nondestructive inspections of metal objects under harsh environmental conditions. First used to excite the resonant vibration of bar shaped laboratory specimens in the 1930's and then developed further by Don Thompson in the 1950's, it was Bruce Thompson's contributions that launched their practical application to a wide range of difficult NDE problems. As a fresh PhD, he recognized the importance of having a good mathematical model for the electromagnetic transduction process in order to guide the design and construction of practical transducers. His early papers presented both theoretical and experimental results that exposed the wide range of wave types that could be generated along with the environmental conditions that could be overcome. Several laboratories around the world established research programs to apply the electromagnetic transducer (EMAT) to specific NDE problems and, with Bruce's help, introduced innovations that transformed the research into practical devices and inspection techniques that are now being employed commercially throughout the world. Our paper will summarize many of these applications and show how Bruce kept making major contributions even when his primary interests were focused on the subjects of the papers to follow in this Tribute Session.
Ultrasonic Measurement Models  
---Timothy A. Gray, Iowa State University, Center for NDE, Ames, IA 50011

---The Thompson-Gray Ultrasonic Measurement Model represents the first complete, quantitative, and computationally efficient model that incorporates all the important aspects of an ultrasonic measurement, including UT probe and instrument effects, UT beam propagation in elastic media, UT transmission at curved interfaces, material property effects, and scattering from defects. Derived from Auld’s electromechanical reciprocity integral, this model relies on a few assumptions, including a paraxial approximation to beam propagation and transmission at interfaces and a quasi-planewave approximation to the fields that illuminate the defect, to yield a compact, efficient formalism for computing ultrasonic flaw signals. Uses of this model have been found in a wide range of UT measurement scenarios. Early applications used the model as a signal processing adjunct to extract the scattering amplitude from a measured waveform. Later, the advantages of using the model in a measurement simulation framework became obvious, and applications were found in specifying and optimizing UT inspection procedures, in visualizing inspection coverage, and in estimating probability of detection, or POD. The latter application has been instrumental in the concept of design for inspectability, where POD of critical flaws is a key input to the damage tolerant design process.
---Over the course of his professional career, Dr. R. Bruce Thompson published many articles on NDE, the majority dealing with topics in ultrasonics. Much of his ultrasonics work fell into two broad and somewhat overlapping categories which might be loosely termed “material characterization” and “defect detection”. The first category deals with the manner in which the internal structure of a material influences ultrasonic wave propagation and what can be learned about that structure from ultrasonic measurements. The second category includes papers dealing with the predictive infrastructure needed to simulate ultrasonic inspections, a chief aim there being to optimize inspection choices so as to more reliably detect defects. One longtime research interest of Dr. Thompson’s, with applications both to microstructure characterization and defect detection, was backscattered grain noise in metals. Over a 20 year period he led a revolving team of staff members and graduate students investigating various aspects of ultrasonic backscatter. As a member of that team, I had the privilege of working alongside Dr. Thompson for many years as different aspects of backscatter were explored. Serving as a sort of Dr. Watson to Bruce’s Sherlock Holmes, I accompanied him in these adventures in backscatter. This talk will discuss Dr. Thompson’s general approaches to modeling backscatter, the research topics he chose to explore to systematically elucidate a better understanding of the phenomena, and the many contributions to the field achieved under his leadership.
R. B. Thompson’s Contributions to Model Assisted Probability of Detection
---William Q. Meeker1, 1Center for NDE and Department of Statistics, Iowa State University, Ames, IA 50011

---Traditional empirical studies to estimate probability of detection (or POD) are expensive and time consuming. Over the past thirty years, much progress has been made in the use of physics-based models to predict POD. A deterministic model for flaw response can be combined with a probability distribution for inspection variabilities to provide a model-based POD. Actual inspections, however, involve complicated variabilities from a variety of sources and modeling all of the important ones, and especially human factors variabilities, would be difficult or impossible. Bruce Thompson’s knowledge of physics, probability, statistics and industry needs gave him the insights to pioneer and subsequently serve as the leader in the important area that is now called “Model Assisted POD” or MAPOD. The basic idea of MAPOD is to find an appropriate combination of a physics-based model, combined with limited (usually by time and cost constraints) experimental data and statistical modeling. This talk will outline Bruce Thompson’s important contributions to this area.
Bruce Thompson - International Leader
---Peter Cawley, Imperial College, 682 Mechanical Engineering, Exhibition Road, London, SW7 2AZ United Kingdom

---Bruce was not only a world leading scientist and engineer on the basis of his personal research, but he also led international efforts in QNDE. He was enormously helpful in us forming the UK Centre, RCNDE, and the World Federation of NDE Centers sprang from his vision. He travelled widely and was always interested in different national cultures and political systems. This talk will give a brief appreciation of his influence on the international stage.
Dr. R. Bruce Thompson and the Industry - A Model of Technology Transfer
---Kevin D. Smith, Pratt & Whitney, M/S 114-37, 400 Main Street, East Hartford, CT 06033

---Dr. R. Bruce Thompson has been frequently an innovator, a mentor to many of us, and always a friend. Many can and have spoken more eloquently than I as to Bruce’s scientific accomplishments. My most significant interactions with Bruce have been in finding ways to develop technical solutions and the programs necessary to solve problems for implementation in the industrial environment. Clearly he was gifted in his ability to imagine how various theories describing ultrasound could be used to solve problems, but he was also uniquely skilled at working with us in industry to solve the details needed to reach a practical solution. During his career, Bruce contributed substantially to the success of a variety of benchmark programs that influenced the direction of the industry.
Session 2
SESSION 2
UT MODELING
A. G. Every, Chairperson
Mildred Livak Ballroom

1:30 PM 3D EFIT Simulations for Investigating Lamb Wave Scattering from Flaws

1:50 PM Hybrid SAFE/FE Model for the Scattering of Guided Waves in a Stiffened Multilayered Anisotropic Plate
---L. Taupin, A. Lhémery, and V. Baronian, CEA, LIST, Gif-sur-Yvette, France; A.-S. Bonnet-BenDhia, POEMS, CNRS-ENSTA-INRIA, UMR 2706, ENSTA ParisTech, Paris, France; B. Petitjean, EADS – Innovation Works, Suresnes, France

2:10 PM Efficient Finite Element Modeling of Elastodynamic Scattering with Non-Reflecting Boundary Conditions
---A. Velichko and P. D. Wilcox, University of Bristol, Department of Mechanical Engineering, Queen’s Building, University Walk, Bristol, BS8 1TR, United Kingdom

2:30 PM The Nature of Backward Propagating Guided Waves and Their Occurrence in Supported Layers
---A. G. Every, University of the Witwatersrand, School of Physics, 1 Jan Smuts Avenue, Johannesburg, PO Wits 2050, South Africa; A. A. Maznev, Massachusetts Institute of Technology, Department of Chemistry, Cambridge, MA 02139

2:50 PM Mode Conversion of SH Guided Waves Generated by EMAT for Wall-thinning Inspection
---M. Nurmalia, N. Nakamura, H. Ogi, and M. Hirao, Osaka University, Graduate School of Engineering Science, Toyonaka, Osaka, Japan; N. Kazuyuki, Ehime University, Department of Civil and Environmental Engineering, Matsuyama, Ehime, Japan

3:10 PM Break

3:30 PM Quantized Stoneley Mode Segments in Cylindrical Three-layered Media
---H. Cui, J. Trevelyan, and S. Johnstone, Durham University, School of Engineering & Computing Sciences, South Road, DH1 3LE, Durham, United Kingdom

3:50 PM Numerical Studies of Ultrasonic Waves on the Surface of Curved Objects
---G. K. Sukumaran, P. Rajagopal, C. V. Krishnamurthy, and K. Balasubramaniam, Centre for Nondestructive Evaluation, Indian Institute of Technology - Madras, Chennai, Tamil Nadu, India

4:10 PM High-Frequency Guided Ultrasonic Waves for Hidden Defect Detection in Multi-Layer Aircraft Structures
---B. Masserey and C. Raemy, University of Applied Sciences, Department of Industrial Technologies, Fribourg, Switzerland; P. Fromme, University College London, Department of Mechanical Engineering, London, United Kingdom

4:30 PM Modal Amplitude Extraction of Guided Waves in Rails using Scanning Laser Vibrometer Measurements
---P. W. Loveday and C. S. Long, CSIR Material Science and Manufacturing, Sensor Science and Technology, Box 395, Pretoria 0001, South Africa

4:50 PM Generic Hybrid Models for Three-Dimensional Ultrasonic NDE
---W. Choi and M. J. S. Lowe, UK Research Centre in NDE, Imperial College, London SW7 2 AZ, United Kingdom; E. Skelton and R. Craster, Department of Mathematics, Imperial College, London SW7 2 AZ, United Kingdom; P. Rajagopal, Department of Mechanical Engineering, Indian Institute of Technology Madras, Chennai - 600 036, India
3D EFIT Simulations for Investigating Lamb Wave Scattering from Flaws

--- Cara A. C. Leckey, NASA Langley Research Center, Nondestructive Evaluation Sciences Branch, Hampton, VA 23681-2199; Mark K. Hinders and Corey Miller, College of William and Mary, Department of Applied Science, Williamsburg, VA 23186

--- The detection of damage in aircraft and spacecraft materials through nondestructive evaluation and structural health monitoring techniques is an important area of research at NASA. Lamb waves are ideal for the plate and pipe-like structures used in these applications, and can potentially detect some flaw types that are difficult to discover with traditional ultrasound techniques. However, the dispersive nature of Lamb waves along with complicated flaw geometries can lead to experimental signals that are difficult to interpret. High performance computing can now handle full 3-dimensional simulations of elastic wave propagation in materials. 3D simulations can be a powerful tool in understanding the complicated wave scattering involved in flaw detection. We have developed and implemented parallel 3D elastodynamic finite integration technique (3D EFIT) code to investigate Lamb wave scattering from flaws. We will present results from an example case of guided waves interacting with a rounded rectangle void-type flaw in an aluminum 2024 alloy plate. These EFIT results have been compared to experimental data and provide insight into details of the wave behavior which can aid in developing efficient experimental techniques. This talk will also discuss the extension of 3D EFIT code to simulate wave scattering from weak-bond type flaws.

Hybrid SAFE/FE Model for the Scattering of Guided Waves in a Stiffened Multilayered Anisotropic Plate

--- Laura Taupin, Alain Lhémery, and Vahan Baronian, CEA, LIST, Gif-sur-Yvette, France; Anne-Sophie Bonnet-BenDhia, POEMS, CNRS-ENSTA-INRIA, UMR 2706, ENSTA ParisTech, Paris, France; Benoît Petitjean, EADS – Innovation Works, Suresnes, France

--- Nondestructive testing of aerospace structures often requires their immobilization. Structural health monitoring (SHM) can overcome these problems. Guided elastic waves (GW) are of great interest in SHM since they propagate at long range. Structures being stiffened, optimally positioning sensors implies to determine the number of stiffeners GW can go through while remaining detectable. Here, the diffraction of GW by a stiffener bonded to a multilayered anisotropic plate is considered. Elastic and geometric invariances along stiffener axis lead to 2D computations involving the three components of particle displacement. A hybrid model is developed combining the semi-analytical finite element method for GW propagation and a finite element method (FE) for stiffener diffraction. Optimal hybridization is obtained thanks to the development of transparent boundaries of the FE domain. Such boundary conditions have been obtained for GW normally incident onto scattering features by some of us, thanks to Fraser's biorthogonality relation. Here, a numerical approach is developed to derive similar but approximate boundary conditions for the oblique incidence case for which Fraser's relation does not hold. Their use minimizes the size of the FE domain and avoids any artificial reflection. Finally, transmitted and reflected coefficients are obtained as functions of the direction of incidence.
Efficient Finite Element Modelling of Elastodynamic Scattering With Non-Reflecting Boundary Conditions
Alexander Velichko and Paul D. Wilcox, University of Bristol, Dept. of Mechanical Engineering, Bristol, United Kingdom

Mathematical modeling of the elastodynamic scattering is challenging and many practical cases can only be modeled via direct numerical approaches. Recently the current authors developed the Finite Element Local Scattering model for predicting the complete scattering behavior of an arbitrary-shaped scatterer embedded in an infinite host medium. An important feature of this procedure is that only the scatterer and its immediate vicinity is modeled. However, the FE discretization is truncated by introducing absorbing boundaries in order to absorb the scattered field and prevent it being reflected back onto the scatterer. The required thickness of absorbing region is typically of wavelength order, and therefore the absorbing region contains about 80% of all nodes in the model. This fact reduces effectiveness of the model, especially in the case of 3D wave scattering when the model size becomes very large. In the current paper, an improved FE model is presented. This model uses non-reflecting boundary conditions on the surface surrounding the scatterer which are non-local in space. The size of the model in terms of degrees of freedom is of order of magnitude less then the size of the previous model with absorbing boundaries. Example results for 2D and 3D problems are presented.

The Nature of Backward Propagating Guided Waves and Their Occurrence in Supported Layers
Arthur G. Every, University of the Witwatersrand, School of Physics, 1 Jan Smuts Avenue, Johannesburg, PO Wits 2050, South Africa; Alex A. Maznev, Massachusetts Institute of Technology, Department of Chemistry, Cambridge, MA

It is well known that the dispersion relations for guided acoustic modes in free standing plates commonly display backward propagation regions, where the group velocity $V=\frac{dw}{dk}$ is opposite in direction to the phase velocity $v=\frac{w}{k}$. At the boundaries of such regions there occur zero group velocity (ZGV), $V=0$, modes. Accurate depiction of wave packet propagation and spread in this situation requires that account be taken also of the curvature $a=\frac{d2w}{dk^2}$ of the dispersion relation. The generic types of wave packet behavior, dependent on the signs of $V$, $v$ and $a$ are illustrated in the first part of this paper. In the second part of the paper, the existence of backward propagation in supported solid layers is explored. It is shown that for a single layer on an elastic substrate, backward propagation is a rare phenomenon, because it requires that the transverse velocity of the layer be very small compared to that of the substrate. On the other hand, in certain bi-layer structures of importance in the microelectronics industry, the fundamental branch can display backward propagation. This attribute can be exploited in the metrology of these films.
Mode Conversion of SH Guided Waves Generated by EMAT for Wall-Thinning Inspection
---M. Nurmalia, Nobutomo Nakamura, Hirotugu Ogi, and Masahiko Hirao, Osaka University, Graduate School of Engineering Science, Toyonaka, Osaka, Japan; Nakahata Kazuyuki, Ehime University, Department of Civil and Environmental Engineering, Matsuyama, Ehime, Japan

---The group velocity of higher mode of shear horizontal guided wave depends on frequency and thickness, showing the dispersive characteristic. In addition, below a so-called cut-off thickness, the associated higher mode has zero group velocity and conversion to the lower mode occurs. We consider that group-velocity change originating from the mode conversion is capable of inspecting wall-thinning of plates and pipes. For understanding the mode conversion of SH guided waves, experimental work is performed to measure the experimental group-velocity and visualize the wave propagation. The elastodynamic finite-integration technique is further used for analysis. Aluminum plates with artificial thinning-region are prepared as specimens. The periodic-permanent-magnets electromagnetic acoustic transducer (PPM-EMAT) is used to generate the fundamental symmetric (SH0) and first asymmetric (SH1) modes. The pinducer capable of broad-band acoustic wave detection is used as receiver. Upon encountering a step discontinuity, both SH0 and SH1 modes showed mode conversion. Nevertheless, when the SH1 mode encounters a smooth defect, the wavenumber is modified through the tapered region of smooth defect and a total reflection occurs, not from the discontinuity but at the location of cut-off thickness in the slope. Thus, the mode conversion of SH guided waves is verified experimentally for the first time.

Quantized Stoneley Mode Segments in Cylindrical Three-layered Media
---H. Cui, J. Trevelyan, and S. Johnstone, Durham University, School of Engineering & Computing Sciences, South Road, DH1 3LE, Durham, United Kingdom

---This paper presents a theoretical analysis of the guided wave propagation along an ultrasonic transmission rod designed to transmit and receive high frequency pulses to/from liquid steel. The model of the transmission rod is a three-layered cylindrical waveguide that is composed of a steel rod, silica sheath and steel cladding. In order to reduce signal distortion caused by guided wave dispersion, guided modes with low dispersion, a propagating velocity separate from other modes, and relatively large amplitude are required. The quantized Stoneley mode segments are caused by the coupling of the infinite number of normal modes and the Stoneley wave propagating along the first cylindrical interface between the steel rod and silica sheath. Their phase velocity and group velocity dispersion relations and excitation mechanisms are studied, in order to investigate whether they satisfied the criteria. From the numerical results, we found that these segments have relatively flat group velocity and phase velocity dispersion curves in specific frequency ranges, have clearly larger group velocity (i.e. about the Stoneley velocity) than those of other modes, and also have largest amplitude along the first interface. They are promising modes for detection of inclusions in liquid steel.
Numerical Studies of Ultrasonic Waves on the Surface of Curved Objects
---Gautham K. Sukumaran, Prabhu Rajagopal, C. V. Krishnamurthy, and Krishnan Balasubramaniam, Centre for Nondestructive Evaluation, Indian Institute of Technology - Madras, Chennai, Tamil Nadu, India

---The authors are interested in the ultrasonic inspection of structures containing curved surfaces. Experimental studies in this connection led to the investigation of several interesting features of ultrasonic waves on the surface of curved objects such as cylinders and spheres. Here we present studies of ultrasonic waves on the surface of homogenous, isotropic cylindrical disks and rods, and spheres. The waves are assumed to be generated by means of a point excitation applied to the surface of the object. While some extensive analytical and experimental investigations have been performed in this area in the past, we seek to use numerical models to gain insight into the physics of the problem. We start by considering the cases of cylindrical disks and rods, which can be analyzed using two-dimensional Finite Element (FE) models. The first arriving surface wave is sought to be identified with the help of velocity calculations and displacement mode shapes plotted to a radial depth of about two wavelengths. The effect of curvature of objects on ultrasonic surface wave phenomena is then studied. Among other things, the curvature is shown to affect the dispersion and scattering of the ultrasonic surface waves. Finally, the propagation of ultrasonic waves on the surface of a spherical object is studied using a fully three-dimensional FE model. The results are discussed in light of experiments and previous studies.

High-Frequency Guided Ultrasonic Waves for Hidden Defect Detection in Multi-Layer Aircraft Structures
---Bernard Masserey and Christian Raemy, University of Applied Sciences, Department of Industrial Technologies, Fribourg, Switzerland; Paul Fromme, University College London, Department of Mechanical Engineering, London, United Kingdom

---The use of high-frequency guided waves allows for the efficient non-destructive testing of aerospace structures. This type of structure often contains multi-layer components subjected to cyclic loading conditions, where fatigue cracks and disbonds can develop. Using commercially available ultrasonic transducers, high frequency guided waves were generated that penetrate through the complete thickness of a model structure, consisting of two adhesively bonded aluminum plates. The wave propagation along the specimen was measured using a laser interferometer. Good agreement with 2D finite element simulations was found. Two types of hidden defects were considered: localized lacks of sealant and small defects in the aluminum layer facing the sealant. The interaction of the high frequency guided waves with the hidden defects was investigated. Modal decomposition was used to determine the reflected and transmitted modes obtained from the simulations. Standard pulse-echo measurements were conducted to verify the detection sensitivity and influence of the stand-off distance predicted from the finite element simulation results. The high frequency guided waves have the potential for fatigue crack growth monitoring at critical and difficult to access fastener locations in aerospace structures from a stand-off distance.
Modal Amplitude Extraction of Guided Waves in Rails using Scanning Laser Vibrometer Measurements
---Philip W. Loveday and Craig S. Long, CSIR
Material Science and Manufacturing, Sensor Science and Technology, Box 395, Pretoria 0001, South Africa

---It is advantageous to be able to measure the amplitude of the individual modes of propagation during the development of guided wave systems for rail monitoring. This paper addresses the problem of extracting modal amplitudes from scanning laser vibrometer measurements. The wave propagation characteristics of the rail are computed, as functions of frequency, by the semi-analytical finite element method and are used to represent the frequency response at a set of measurement locations (with unknown amplitude coefficients). Experimental frequency responses are measured and the amplitude of each mode is estimated using a pseudo-inverse technique. The selection of measurement points is investigated. A set of measureable points is defined based on accessibility and scanning angles. A technique is proposed for selecting appropriate measurement points, from within this set, to yield a well-conditioned problem. It is shown that there exists a number of points, above which additional points do not add to the accuracy of the process. The method will be demonstrated on a 6 m length of rail excited by a piezoelectric transducer in the lab.

Generic Hybrid Models for Three-Dimensional Ultrasonic NDE
---Wonjae Choi and Michael J. S. Lowe, UK
Research Centre in NDE, Imperial College, London SW7 2 AZ, United Kingdom; Elizabeth Skelton and Richard Craster, Department of Mathematics, Imperial College, London SW7 2 AZ, United Kingdom; Prabhu Rajagopal, Department of Mechanical Engineering, Indian Institute of Technology Madras, Chennai - 600 036, India

---Modeling of the entire process of an ultrasonic Non-Destructive Evaluation (NDE) inspection is of increasing interest in industry, because of the cost savings compared to experimental qualifications, the possibility to investigate inspection ideas, operator training, and overall improved confidence. Analytical modeling packages, usually based on ray tracing, are good for modeling wave propagation paths through a complex component, while the Finite Element (FE) method is usually better for modeling the scattering from a complicated defect. Hybrid models to link two such heterogeneous modeling packages are attractive to enable inspection engineers to get the benefit of both of these. The authors have presented the development of the models, and showed promising validation results for two-dimensional problems during QNDE conferences in the last few years. In this paper, the hybrid model is extended to three dimensional problems. The concept of the domain-linking algorithm is presented. This links two separate modeling domains, each of which may contain a different model process. Typically one domain may be used to model the transmission and reception by the transducer, while the other models the scattering from the defect. Then validation is shown by comparing the results with those of a full three-dimensional FE model.
Session 3
SESSION 3  
**ELECTROMAGNETIC METHODS**  
K. Balasubramaniam, Chairperson  
Sugar Maple Ballroom

1:30 PM  
**Comparison of Experimental, Analytical and Numerical Results for Potential Drop Detection of Creep Damage in the Vicinity of Welds**  
---S. Prajapati and P. B. Nagy, School of Aerospace Systems, University of Cincinnati, Cincinnati, OH 45221-0070; P. Cawley, UK Research Centre in NDE, Imperial College, London SW7 2AZ, United Kingdom

1:50 PM  
**Broadband Alternating Current Potential-Drop Measurements**  
---J. Ji and J. R. Bowler, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

2:10 PM  
**Tone Burst Eddy Current Thermography for Estimation of Corrosion Defects in Aircraft Components**  
---M. Libin and K. Balasubramaniam, Centre for Nondestructive Evaluation and Department of Mechanical Engineering, Indian Institute of Technology Madras, Chennai Tamil Nadu, India; C. V. Krishnamurthy, Centre for Nondestructive Evaluation and Department of Physics, Indian Institute of Technology, Madras, Chennai Tamil Nadu, India; R. Engelbart, Boeing Research & Technology, St. Louis, MO 63166

2:30 PM  
**The Transition Matrix Method for a 2D Eddy Current Interaction Problem**  
---L. Larsson, Chalmers University of Technology, Advanced Nondestructive Testing, Göteborg, Sweden; A. Rosell, Volvo Aero Corporation, Trollhättan, Sweden

2:50 PM  
**Advances in Developing Multiscale Flaw Models for Eddy-Current NDE**  
---R. K. Murphy, H. A. Sabbagh, and E. H. Sabbagh, Victor Technologies, LLC, Bloomington, IN 47401; J. C. Aldrin, Computational Tools, Gurnee, IL; J. R. Bowler and Y. Ji, Iowa State University, Ames, IA 50011

3:10 PM  
**Break**

3:30 PM  
**Determination of the Impedance Variation of an Eddy Current Coil at the Opening of a Borehole in a Conductor**  
---H. Xie and J. R. Bowler, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

3:50 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; J. C. Aldrin, Computational Tools, Gurnee, IL 60031

4:10 PM  
**Evaluation of Eddy Current Probe Impedance Changes Due to Cracks in Boreholes**  
---H. Xie and J. R. Bowler, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

4:30 PM  
**Characterizing Randomly Anisotropic Surfaces in Eddy-Current NDE**  
---H. A. Sabbagh, R. K. Murphy, and E. H. Sabbagh, Victor Technologies, LLC, P. O. Box 7706, Bloomington, IN 47407-7706; J. C. Aldrin, Computational Tools, Gurnee, IL 60031

4:50 PM  
**An Electrical Conductivity Inspection Methodology of Polycrystalline Diamond Cutters**  
---G. Bogdanov and R. Ludwig, Worcester Polytechnic Institute, Department of Electrical and Computer Engineering, Worcester, MA 01609; J. Wiggins and K. Bertagnolli, US Synthetic, Orem, UT 84057

5:10 PM  
**Eddy Current Model-Based Technique for Tube Electromagnetic Property Measurements**  
---E. Todorov and S. Levesque, Edison Welding Institute, Engineering Services, Columbus, OH 43221-3585; K. Krzywosz, Electric Power Research Institute, NDE Technologies, Charlotte, NC 28262-7097
Comparison of Experimental, Analytical and Numerical Results for Potential Drop Detection of Creep Damage in the Vicinity of Welds
---Seeran Prajapati and Peter B. Nagy, School of Aerospace Systems, University of Cincinnati, Cincinnati, OH 45221-0070; Peter Cawley, UK Research Centre in NDE, Imperial College, London SW7 2AZ, United Kingdom

---Recent research studies indicated that directional Alternating Current Potential Drop (ACPD) measurements could be exploited for nondestructive evaluation (NDE) of creep damage. Unfortunately, creep damage is often concentrated in welded sections where the inspection is less straightforward. In this work, a directional square-electrode ACPD probe with spring-loaded contact pins was used to evaluate different levels of creep damage in the vicinity of welds. The electric transfer resistance is measured in two orthogonal directions to detect creep-induced material damage. This is particularly difficult close to weld/base-metal interfaces because the electric conductivity might change significantly from one side of the interface to the other and therefore exhibits an apparent anisotropy caused by the influence of the boundary. The feasibility of directional ACPD evaluation of creep damage in the vicinity of such transition regions was studied by experimental, analytical, and numerical means. FE simulations validated the analytical predictions and experimental observations and offer an opportunity to further investigate critical effects, such as the inclination angle of the interface relative to the surface, for the development of improved experimental techniques and data evaluation procedures.

Broadband Alternating Current Potential-Drop Measurements
---Juan Ji and John R. Bowler, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

---Alternating current potential-drop (ACPD) measurements have been carried out using four point probes together with a high performance transconductance amplifier and an accurate phase-sensitive detector. From computer captured data, electrical and magnetic properties of materials are determined with the aid of a field model of the probe current. Predictions of the observed potential drop are computed using prescribed values of the material properties and there variation with depth by using a forward model. On the other hand, by using a least squares inversion scheme, model parameters can be varied systematical until a penalty function representing the overall mismatch between predictions and measurements is minimized. In this way, estimates of the material parameters are found via model based inversion. Although designed for broadband ACPD, it can also be used at low frequencies for finding, in effect, the direct current potential drop. The system is a prototype for a smart instrument that can be used to measure alternating current potential drop on various samples. From the data, electrical and mechanical properties of the test pieces can be determined or inferred. For example the electrical conductivity profile can be obtained for samples that have undergone surface treatments that modify the near surface electrical resistivity.
Tone Burst Eddy Current Thermography for Estimation of Corrosion Defects in Aircraft Components
---M. Libin and Krishnan Balasubramaniam, Centre for Nondestructive Evaluation and Department of Mechanical Engineering, Indian Institute of Technology Madras, Chennai Tamil Nadu, India; C. V. Krishnamurthy, Centre for Nondestructive Evaluation and Department of Physics, Indian Institute of Technology Madras, Chennai Tamil Nadu, India; Roger Engelbart, Boeing Research & Technology, St. Louis, MO 63166

---Tone Burst Eddy Current Thermography (TBET) technique was used for the evaluation of corrosion type damage in Aluminum plate like structures. Both flat and curved components were considered. The effect of the parameters affecting the eddy current generation of head in the metal, including excitation frequency, electrical conductivity, standoff distances, etc were considered in optimizing the heat generation. The thermal diffusivity and thickness of the metal structure were considered while selecting the detection of the signal using a thermal sensitive IR Camera. The experiments were conducted using test samples that had simulated defects with different wall thickness losses. The experiments were supported by a multiphysics 3D Finite Element Model (FEM) using COMSOL. The results were compared with the experimental results. It was determined that this technique has some advantages for the inspection aircraft structural components compared to other modalities, particularly in curved regions.

The Transition Matrix Method for a 2D Eddy Current Interaction Problem
---Lars Larsson, Chalmers University of Technology, Advanced Nondestructive Testing, Göteborg, Sweden; Anders Rosell, Volvo Aero Corporation, Trollhättan, Sweden

---A 2D model of the eddy current interaction problem that consists of an inhomogeneity in a conductive half space is presented. The applied analytical method of solution is the transition (T) matrix method. This involves use of the free space Green’s function to generate a system of boundary integral relations. In this way, it is easy to identify the contributions to the total solution from each different scattering surface. The different parts are separated also in the computation of the impedance. This leads to low cost simulations in terms of computation time and qualify the method to be used to obtain probability of detection (POD) curves. The T matrix method is a building block method and the possibility to extend the geometry with several inhomogeneities and extra layers will be discussed. The model is compared with a finite element (FE) model and numerical examples for the case with a cylindrical inhomogeneity are given. This paper is a part of the European project, PICASSO, which addresses the possibility to enable simulated data to be used within the development of POD curves.
Advances in Developing Multiscale Flaw Models for Eddy-Current NDE
---Ronald K. Murphy, Harold A. Sabbagh, and Elias H. Sabbagh, Victor Technologies, LLC, Bloomington, IN 47401; John C. Aldrin, Computational Tools, Gurnee, IL; John R. Bowler and Yuan Ji, Iowa State University, Ames, IA 50011

---The need to accurately model multiscale phenomena is ubiquitous in eddy-current nondestructive evaluation. By means of the formulation of the forward problem in terms of volume-integral equations, we are able to develop a very simple algorithm for accurately computing the response of a very small anomaly in the presence of a much larger one. This makes the inverse problem of characterizing the small anomaly much more tractable than otherwise. We briefly describe the algorithm, and then validate it and its associated code in VIC-3D(c) through benchmark data on two test sets: (1) a notch at a bolt hole with an upper surface coil, and (2) a notch in a bolt hole with a plate surface coil.

Determination of the Impedance Variation of an Eddy Current Coil at the Opening of a Borehole in a Conductor
---Hui Xie and John R. Bowler, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

---Induction coil at the opening of a borehole has an impedance that varies with position depending on its location with respect to the edge. As a step in the process of constructing a model that predicts signals due to a crack at the edge of the hole, we have determined the impedance changes due to a crack free edge and computed the induced eddy currents adjacent to the opening. These calculations are done using the truncated region eigenfunction expansion (TREE) method in which the domain of the problem is truncated in the axial direction. This means that a solution representing the coil field at the edge of the hole can be constructed in series form. For an infinite hole, the axially truncated field can be expressed as a double Fourier series in the circumferential and axial variables, whereas the radial dependence is represented in terms of Bessel functions. In the case of a semi-infinite or finite hole, we need a triple series. This arises because the material structure is not uniform in the axial direction. Therefore one Fourier component in the axial direction representing an element of the primary coil field interacts with the edge to produce a whole spectrum of Fourier component on reflection. Knowledge of the interaction allows us to compute the coefficient in the series form and thereby predict the field and probe impedance at the opening of the hole.
Modeling Direct and Inverse Problems in Ferritic Heat-Exchanger Tubes
---Harold A. Sabbagh, Ronald K. Murphy, and Elias H. Sabbagh, Victor Technologies, LLC, Bloomington, IN 47407-7706; John C. Aldrin, Computational Tools, Gurnee, IL

---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. In this paper we develop forward and inverse models, together with laboratory data, to characterize a SEACURE tube, with and without a drilled hole and/or tube-support plate (TSP). The measured data are impedances obtained using the HP4192A impedance analyzer. We demonstrate conditions that are peculiar to ferritic tubes, and give insight into the optimum methods for characterizing the tubes and flaws within them.

Evaluation of Eddy Current Probe Impedance Changes Due to Cracks in Boreholes
---Hui Xie and John R. Bowler, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

---A theoretical model has been developed to calculate the impedance change of a coil due to cracks in a borehole. The field change from a thin planar crack is equivalent to the field generated by an electric current dipole layer oriented normal to the crack surface and volume integral equation is set up to solve the current dipole density by considering the boundary conditions at the cylindrical surface of the borehole. Numerical results show a reasonable agreement with experiment data. This model can be extended into other cylindrical geometrical shapes, such as a circularly cylindrical tube. We have developed a procedure for testing series convergence in order to control the solution accuracy. These issues are not only important for the borehole problem, but also useful for related problems in which fields are calculated for cylindrical structures.
Characterizing Randomly Anisotropic Surfaces in Eddy-Current NDE

---Harold A. Sabbagh, Ronald K. Murphy, and Elias H. Sabbagh, Victor Technologies, LLC, P. O. Box 7706, Bloomington, IN 47407-7706; John C. Aldrin, Computational Tools, Gurnee, IL, 60031

---This research is motivated by two distinct considerations: the ability to model noise in Ti-6Al-4V, and to characterize surfaces that have undergone treatment due to shot-peening, low-plasticity burnishing (LPB), etc. It turns out that a single eddy-current model for randomly anisotropic media subsumes these two problem areas. The model is numerically executed using certain novel features of the proprietary code, VIC-3D(c). Titanium and its alloys are known to be 'noisy.' They also have a hexagonal crystal structure, which, because of the random distribution and orientation of the crystallites, contributes to the material noise. We will show that with a single model we can analyze these sources of noise and develop a protocol and system requirements for detecting and inverting flaws in a random background (such as a rough surface). An important result of this study is the application of simple statistical theory toward the development of estimation-theoretic metrics.

An Electrical Conductivity Inspection Methodology of Polycrystalline Diamond Cutters

---Gene Bogdanov and Reinhold Ludwig, Worcester Polytechnic Institute, Department of Electrical and Computer Engineering, Worcester, MA 01609; Jason Wiggins and Ken Bertagnolli, US Synthetic, Orem, UT 84057

---The polycrystalline diamond cutter (PDC) is widely used in oil and gas drilling. Diamond is an ideal cutting element as it is the hardest known material. PDC manufacturing involves sintering a layer of diamond powder onto a cobalt-cemented tungsten carbide substrate. During the manufacturing process molten cobalt from the substrate infiltrates diamond powder and catalyzes sintering at roughly 6 GPa and 1500 C. Post sintering, the amount of residual metal depends on the manufacturing process parameters, and also affects the electrical conductivity of the polycrystalline diamond. Cutter performance characteristics correlate with residual metal content. Thus, electromagnetic non-destructive testing techniques can be used for monitoring performance characteristics in PDC through a relationship between metal content and electrical conductivity. In this paper, electrical conductivity imaging is applied to testing PDC. We present an instrument employing a multitude of spring-loaded probes in contact with the diamond surface of the cutter. Sequential acquisition of direct-current, four-wire resistance data is employed to reconstruct a 3D electrical conductivity distribution in the diamond layer using a least-squares algorithm. Measurements on cutter samples point to a reliable relationship between metal content and conductivity. Moreover, flaws, such as metal rich zones and cracks, can be detected.
Eddy Current Model-Based Technique for Tube Electromagnetic Property Measurements
---Evgueni Todorov and Steve Levesque, Edison Welding Institute, Engineering Services, Columbus, OH 43221-3585; Kenji Krzywosz, Electric Power Research Institute, NDE Technologies, Charlotte, NC 28262-7097

---Experience with application of remote field eddy current (RFT) techniques for inservice inspection of ferromagnetic heat exchanger tubes indicated that RFT performance needed improvement for detection and sizing of flaws in complex geometries such as tube-to-tube support plate intersections and tube sheet roll transition areas. Computer modeling was suggested for technique optimization. However, accurate electromagnetic properties needed for representative modeling are unavailable for tubes made of new ferromagnetic steel alloys. EPRI provided four heat exchanger tube specimens with outside diameter in the range from 15.8 to 25.3 mm and wall thickness in the range from 0.63 to 1.6 mm made of SAF2205, type 439 and Sea-Cure. Two encircling eddy current measurement sensors with uniform field were optimized and designed based on initial computer modeling results. A precision measurement circuit was assembled with the sensors and a lockin amplifier. Sensor computer models were updated and later validated through direct magnetic and voltage measurements. The sensor magnetic field uniformity was tested and agreed very well with model predictions. The sensor resonance frequencies were verified to ensure resonance effects would not interfere with the measurement process. The tubes electrical conductivity and initial magnetic permeability were determined through optimization process minimizing the “cost” (objective) function at three frequencies 200 Hz, 1 kHz and 2.5 kHz. The agreement between the eddy current and other conventional destructive magnetic and electrical measurements was very good where relevant comparison was possible.
Session 4
SESSION 4
IMAGING AND INVERSION TECHNIQUES
F. Simonetti, Chairperson
Silver Maple Ballroom

1:30 PM
Wideband Super-Resolution Imaging in Highly Attenuative Materials
---T. Hutt, Imperial College London, Department of Mechanical Engineering, SW7 2AZ, United Kingdom; F. Simonetti, School of Aerospace Systems, University of Cincinnati, 726 Rhodes Hall, P. O. Box 710070, Cincinnati, OH 45221

1:50 PM
Application of Time Reversal Techniques for Enhanced Focusing, Defect Detection and Imaging in Ultrasonic NDE
---H. Jeong, S. Cho, and W. Wei, Wonkwang University, Division of Mechanical and Automotive Engineering, 344-2 Sinyong-dong, Iksan, Jeonbuk 570-749, South Korea

2:10 PM
Data-Driven Imaging in Anisotropic Media
---A. Volker, Stieltjesweg, P. O. Box 155, 2600 AD Delft, The Netherlands

2:30 PM
Wavenumber Imaging for Damage Detection and Measurement in Plates
---M. D. Rogge, NASA Langley Research Center, Nondestructive Evaluation Sciences Branch, Hampton, VA 23681-2199

2:50 PM
Acceleration of the 3D Image-Based FIT With an Explicit Parallelization Approach
---K. Nakahata, Ehime University, Department of Civil and Environmental Engineering, Matsuyama, Ehime, Japan; S.-I. Ichikawa, Kyoto University, Academic Center for Computing and Media Studies, Sakyo-ku, Kyoto, Japan; T. Saitoh and S. Hirose, Tokyo Institute of Technology, Department of Mechanical and Environmental Informatics, Meguro-ku, Tokyo, Japan

3:10 PM
Break

3:30 PM
High Sensitivity Damage Detection by Sound-Speed Mapping
---P. Huthwaite, Imperial College London, Mechanical Engineering, Exhibition Road, London SW7 2AZ, United Kingdom

3:50 PM
Ultrasonic Multi-Skip Tomography for Pipe Wall Profiling

4:10 PM
Quantitative Evaluation for Nano and/or Micro Scaled Thin Film System with SAM
---B. R. Tittmann, The Pennsylvania State University, Department of Engineering Science and Mechanics, University Park, PA 16802; A. K. Kalkan, Department of Mechanical and Aerospace Engineering, Stillwater, OK 74078; I. K. Park, Seoul National University of Science and Technology, Department of Mechanical Engineering, Seoul 139-743, Korea

4:30 PM
Eddy Current Nondestructive Problem Inversion When Planar Constant Field Probes are Used
---A. L. Ribeiro and H. G. Ramos, Instituto de Telecomunicacoes, Instituto Superior Tecnico, Lisboa, Portugal
Wideband Super-resolution Imaging in Highly Attenuative Materials
---Tim Hutt, Imperial College London, Department of Mechanical Engineering, SW7 2AZ United Kingdom; Francesco Simonetti, School of Aerospace Systems, University of Cincinnati, 726 Rhodes Hall, P. O. Box 710070, Cincinnati, OH 45221

---Continuous progress in ultrasonic array technology is driving the development of more advanced image formation methods for more sensitive and selective damage detection. Scattering of ultrasonic signals from a defect can be seen as a process of information encoding and transmission from the damaged area to the imaging system. The encoding is governed by the physical mechanisms describing the wave-damage interaction while the transmission is mediated by wave propagation in the parent material. The quality of the image is determined by the amount of information that the imaging system can retrieve from the incoming wavefield and depends on the encoding mechanism and the efficiency of energy transfer through space. At a single frequency, multiple scattering effects ensure that theoretically unlimited resolution information is encoded in the wavefield leaving the defect; however, limited radiation efficiency causes part of this information to be lost in the presence of noise. In particular, for a given noise level, wavelength, and defect size the number of measurements that yield non-redundant information is finite. Super-resolution imaging methods attempt to maximize the amount of information that can be extracted from these measurements and as a result, they are more sensitive to noise than other techniques such as beamforming. This paper explores the possibility of improving the stability of super-resolution techniques using wideband image formation, which increases the amount of available independent measurements by exploiting the information content of neighboring frequencies. We demonstrate the validity of this approach with a set of experiments performed in glycerol - a highly attenuative liquid - where stable super-resolved images beyond the Rayleigh limit were obtained.

Application of Time Reversal Techniques for Enhanced Focusing, Defect Detection and Imaging in Ultrasonic NDE
---Hyunjo Jeong, Sungjong Cho, and Wei Wei, Wonkwang University, Division of Mechanical and Automotive Engineering, 344-2 Sinyong-dong, Iksan, Jonbuk 570-749, South Korea

---In this work, we report some results on the application of time reversal (TR) techniques for enhanced focusing, defect detection and imaging in ultrasonic NDE. Compared to the conventional phased array technique for beam focusing, the TR method does not require a prior knowledge about the properties and structures of the media and the transducer. Therefore, it provides more accurate focusing in generally anisotropic and inhomogeneous media. The TR concept can also be applied for beam focusing on defects in components with nonplanar surface geometry. Another application of TR concept is the baseline-free damage detection and localization through the Lamb wave time reversal approach. Combination of nonlinear elastic wave spectroscopy and time reversal is another important technique for detecting nonlinear defects such as cracks, delaminations or disbands. We present these results obtained through simulations and experiments.
Data-Driven Imaging in Anisotropic Media
---Arno Volker, Stieltjesweg, 1, P.O. Box 155, 2600 AD Delft, The Netherlands

---Anisotropic materials are being used increasingly in high performance industrial applications, particularly in the aeronautical and nuclear industries. Some important examples of these materials are composites, single-crystal and heavy-grained metals. Ultrasonic array imaging in these materials requires exact knowledge of the anisotropic material properties. Without this information, the images can be adversely affected, causing a reduction in defect detection and characterization performance. The imaging operation can be formulated in two consecutive and reciprocal focusing steps, i.e., focusing the sources and then focusing the receivers. Applying just one of these focusing steps yields an interesting intermediate domain. The resulting common focus point gather (CFP-gather) can be interpreted to determine the propagation operator. After focusing the sources, the observed travel-time in the CFP-gather describes the propagation from the focus point to the receivers. If the correct propagation operator is used, the measured travel-times should be the same as the time-reversed focusing operator due to reciprocity. This makes it possible to iteratively update the focusing operator using the data only and allows the material to be imaged without explicit knowledge of the anisotropic material parameters. Furthermore, the determined propagation operator can also be used to invert for the anisotropic medium parameters. This paper details the proposed technique and demonstrates its use on simulated array data from a specimen of Inconel single-crystal alloy commonly used in the aeronautical and nuclear industries.

Wavenumber Imaging for Damage Detection and Measurement in Plates
---Matthew D. Rogge, NASA Langley Research Center, Nondestructive Evaluation Sciences Branch, Hampton, VA 23681-2199

---This paper presents a method for analyzing ultrasonic wavefield data using the Short-Time Fourier Transform (STFT) applied in the spatial domain. Unlike data obtained by sparse arrays of transducers, full wavefield data contains information local to the structure and can be used to obtain more detailed measurements of damage type, location, size, etc. By calculating the STFT of the wavefield in the spatial domain, the wavenumber spectrum is determined for the inspected locations. Because wavenumber is affected by local geometry and material properties of the structure through which Lamb waves propagate, the wavenumber spectrum can be analyzed to assess the location, severity, and size of damage. The technique is first applied to data obtained from two- and three-dimensional finite element simulations of corroded aluminum, diffusion bonded aluminum, and composite plates with delamination. Next, the technique is applied to experimental wavefield data obtained using a Laser Doppler Vibrometer and automated positioning stage to measure the out of plane velocity on a Cartesian grid on the surface of aluminum samples with simulated corrosion. Both the numerical and experimental results show the usefulness of the technique for vehicle structure inspection applications.
Acceleration of the 3D Image-Based FIT With an Explicit Parallelization Approach

---Kazuyuki Nakahata, Ehime University, Department of Civil and Environmental Engineering, Matsuyama, Ehime, Japan; Shin-ichi Ichikawa, Kyoto University, Academic Center for Computing and Media Studies, Sakyo-ku, Kyoto, Japan; Takahiro Saitoh and Sohichi Hirose, Tokyo Institute of Technology, Department of Mechanical and Environmental Informatics, Meguro-ku, Tokyo, Japan

---Time domain simulation tools for ultrasonic and electromagnetic waves in materials with a complex outer surface or various inclusions have been developed by combining the finite integration technique (FIT) 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 made from CAD data as well as actual object images such as captured three dimensional (3D) curve data, X-ray pictures, etc. After image processing, the voxel data are directly fed into the wave simulation by the FIT. In this study, the 3D image-based FIT is refined for a high-speed calculation using an explicit parallelization approach. The target model is divided to 3D computational blocks, and then each block is calculated and communicated with the flat MPI. The MPI scalability of a large memory problem is dramatically improved and calculation speed becomes more than two times faster than our previous code. Here some applications for the ultrasonic- and electromagnetic-wave testing are demonstrated.

High Sensitivity Damage Detection by Sound-Speed Mapping

---Peter Huthwaite, Imperial College London, Mechanical Engineering, Exhibition Road, London SW7 2AZ, United Kingdom

---Current ultrasonic imaging methods in NDE are restricted to detecting material features that cause sudden impedance discontinuities, such as the case of a crack. However, some forms of damage, e.g. radiation damage or early stage creep, cause localized but not discontinuous impedance changes. Although limited backscattering is associated with these defects, the phase and amplitude of ultrasonic waves passing through encode valuable information about its mechanical properties, e.g. ultrasonic velocity, which can allow defect detection and characterization. We investigate the possibility of obtaining quantitative images of ultrasonic velocity across the material. We propose a robust and flexible method that combines the strengths of Travel Time Tomography — a low resolution imaging method used in geophysics — and diffraction tomography that has higher resolution but is limited to a narrow range of defect sizes. We study different array configurations depending on the accessibility of the inspection area. Accurate mapping of corrosion depth in a plate is demonstrated for Guided Wave Tomography (GWT) with the ideal full view configuration. When the component is accessible from one side only, we show that reflection from the opposite side can be used to reconstruct the velocity field. The analysis uses numerical simulations and preliminary experimental results.
Ultrasonic Multi-Skip Tomography for Pipe Wall Profiling
---Arno Volker, Alan Hunter, and Rik Vos, TNO (Netherlands Organisation for Applied Scientific Research), Delft, The Netherlands; Maarten Lorenz, Shell Global Solutions International B.V., Amsterdam, The Netherlands

---The inspection of wall loss corrosion is difficult at pipe supports due to the limited accessibility. However, the recently developed ultrasonic multi-skip screening technique is suitable for this problem. The method employs ultrasonic transducers in a pitch-catch geometry positioned on opposite sides of the pipe support. Shear waves are transmitted in the axial direction within the pipe wall, reflecting multiple times between the inner and outer surfaces before reaching the receivers. Along this path, the signals accumulate information on the integral wall thickness (e.g., via variations in travel time). The method is very sensitive in detecting the presence of wall loss, but it is difficult to quantify both the extent and depth of the loss. If the extent is unknown, then only a conservative estimate of the depth can be made due to the cumulative nature of the travel time variations. Multi-skip tomography is an extension of multi-skip screening and has shown promise as a complimentary follow-up inspection technique. In recent work, we have developed the technique and demonstrated its use for reconstructing high-resolution estimates of pipe wall thickness profiles. The method operates via a model-based full wavefield inversion; this consists of a forward model for predicting the measured wavefield and an iterative process that compares the predicted and measured wavefields and minimizes the differences with respect to the model parameters (i.e., the wall thickness profile). This paper presents our recent developments in multi-skip tomographic inversion, focusing on the initial localization of corrosion regions for efficient parameterization of the surface profile model and utilization of the signal phase information for improving resolution.

Quantitative Evaluation for Nano and/or Micro Scaled Thin Film System with SAM
---Bernhard R. Tittmann, The Pennsylvania State University, Department of Engineering Science and Mechanics, University Park, PA 16802; A. K. Kalkan, Department of Mechanical and Aerospace Engineering, Stillwater, OK, 74078; I. K. Park, Seoul National University of Science and Technology, Department of Mechanical Engineering, Seoul 139-743, Korea

---A mechanical scanning acoustic reflection microscope (hereinafter called simply “SAM”) operating with a tone-burst wave having a center frequency ranging from 200MHz to 2GHz is a useful tool for nondestructively visualizing a defect (e.g., delamination, inclusion, micro-crack and the like) located at an interface between an opaque nano and/or microscaled thin film and an isotropic/anisotropic substrate. The interior image obtained by the SAM clarifies the cause of deterioration of adhesive strength at an interface of a thin film system. Further, a technique with the SAM for analyzing a velocity of a surface acoustic wave (hereinafter called simply “SAW”) obtained by monitoring a change of a transducer output (i.e., V(z) curve technique) may quantitatively determine whether specimens are having poor adhesive strength at the interface between the film and the substrate. The technique can be applied to evaluate a thin film system having no defect but having poor adhesion. This article presents the experimental and theoretical results obtained by the SAM for nondestructively evaluating the interface of the thin film system, such as metal thin films (Cu, Cr, Ni )for detection of defects, such as delaminations and nanoscale cracks and polymer films (polystyrene) with poor adhesion but no singular defects.
Eddy Current Non-Destructive Problem Inversion when Planar Constant Field Probes are Used

---A. Lopes Ribeiro and H. Geirinhas Ramos, Instituto de Telecomunicações, Instituto Superior Técnico, 1049-001 Lisboa, Portugal

---In a constant field probe the excitation field on a given material point is invariant under a limited translation of the probe, and the eddy currents are uniform when the material is free of defects. When superficial defects are present the eddy currents are perturbed. If the probe is provided with a high sensitivity magnetic field sensor with the measurement direction orthogonal to the excitation field, the sensor signal output is correlated to the current perturbation, and indirectly to the defect geometry. The current perturbation may be considered as a collection of current eddies. Thus, the sensor output may be considered as the convolution between the field of a single eddy and the function describing the eddies distribution on the material surface. In this paper we present a method of inversion based on a kernel method with Tikhonov regularization. The kernel is precisely the field of a single eddy as detected by the magnetic sensor. Using this method it is possible to infer about the surface current density distribution starting from the magnetic sensor signal over a scanned area.
Session 5
1:30 PM  Study of the Incident Angle of the Ultrasonic Probe Waves in Optimizing the Application of Non-Linear Acoustic Time Shift and Non-Linear coda Wave Interferometry Techniques on Concrete Structures  
---D. Bui, S. A. Kodjo, and P. Rivard, Groupe de Recherche sur l’Auscultation et l’Instrumentation des Infrastructures en Beton, Departement de Genie Civil, Universite de Sherbrooke, Sherbrooke, Canada; B. Fournier, Departement de Geologie et Genie Geologique, Universite Laval, Quebec, Canada

1:50 PM  Implementation of Efficient Trajectories for an Ultrasonic Scanner Using Chaotic Maps  
---A. Baltazar, A. Almeda, and C. Treesatayapun, CINVESTAV Unidad Saltillo, Robotics and Advanced Manufacturing Program, Carr, Saltillo-Monterrey km 13.5, Ramos Arizpe, Coahuilla, 25900, Mexico

2:10 PM  Accelerating Calculation for NDE Simulator of FEM by Using Multi-GPGPUs and its Procedures for Evaluation  
---Y. Hirose, M. Nagano, Y. Sakai, Y. Iriya, and Y. Ikegami, ITOCHU Techno-Solutions Co., Tokyo, Japan

2:30 PM  Ultrasonic Guided Wave Vibration Formulation  
---C. Borigo, Y. Liang, and J. L. Rose, Pennsylvania State University, Engineering Science and Mechanics Department, 212 Earth Engineering Science Building, University Park, PA 16802; F. Yan and J. L. Rose, FBS Inc., State College, PA 16802

2:50 PM  Fuel Tube Spacer-Pad Spot-Weld Quality Estimation Using Guided Ultrasonic Waves  
---Suresh P and K. Balasubramaniam, Indian Institute of Technology Madras, Centre for Nondestructive Evaluation and Department of Mechanical Engineering, Chennai, Tamil Nadu, India

3:10 PM  Break

3:30 PM  Experimental Assessment of the Performance of Guided Wave Travel Time Tomography  
---A. Volker and R. Vos, TNO, P. O. Box 155, 2600 AD Delft, The Netherlands

3:50 PM  An Automatic Fastener-Linked-Defect Inspection Method in NDT  
---J. X. Qiao and M. Armbruster, GE Inspection Technologies, 50 Industrial Park Road, Lewistown, PA 17044-9312

4:10 PM  Universal Ultrasonic Goniometer for Rayleigh- and Surface Skimming Longitudinal Wave Dispersion Measurements  
---M. Barth, M. Kuettner, and B. Koehler, Fraunhofer IZFP-D, Department Micro and Nano Evaluation, Dresden, Germany; J. Bamberg and H.-U. Baron, MTU Aero Engines GmbH, Munich, Germany

4:30 PM  Graphics Processing Unit (GPU) Based Computation for NDE Applications  
---Nahas CA, P. Rajagopal, and K. Balasubramaniam, Centre for Nondestructive Evaluation, Indian Institute of Technology – Madras, Chennai, Tamil Nadu, India

4:50 PM  Visualization of Phased-Array Sound Fields and Flaw Interaction Using the Photo-Elastic Effect  
---T. Schmitte and T. Orth, Salzgitter Mannesmann Forschung GmbH, Systemtechnik – Zerstorungsfreie Prufung, 47259, Duisburg, Germany; T. Kersting, Europipe GmbH – Werk Mulheim, 45473 Mulheim an der Ruhr, Germany
Study of the Incident Angle of the Ultrasonic Probe Waves in Optimizing the Application of Non-Linear Acoustic Time Shift and Non-Linear Coda Wave Interferometry Techniques on Concrete Structures

---Diem Bui, Serge A. Kodjo, and Patrice Rivard, Groupe de Recherche sur l’auscultation et l’Instrumentation des infrastructures en béton, Département de génie civil, Université de Sherbrooke, Sherbrooke, Canada; Benoît Fournier, Département de géologie et génie géologique, Université Laval, Québec, Canada

---Techniques based on non-linear acoustics have been proven sensitive to micro-defects in heterogeneous materials, hence, suited for evaluation of concrete structures. But these techniques are still lab-constrained for their implementation on-site is very restrictive. The time shift method - where an ultrasonic wave probes the medium while a low frequency elastic wave disturbs it - and the coda wave interferometry are of the few techniques applicable on-site. Because of the dimensions and the geometry of structures in service, their implementation demands the probe transducers to be set on the same side of the structures. This project aims to study two types of configurations for transducers: the indirect transmission where transducers are at a 90° angle with the surface of the structure and the semi-direct transmission at a 45° angle. Tests performed on sound and damaged concrete have shown that the indirect configuration produces interference between the direct and the backscattered waves reducing the probe signal's frequency but does not affect the sensitivity of the configuration. However, the semi-direct configuration, in addition to coda wave, permits the distinction of other types of waves in the signal. This allows the use of each wave individually in the application of the time shift technique.

Implementation of Efficient Trajectories for an Ultrasonic Scanner Using Chaotic Maps

---Arturo Baltazar, Alejandro Almeda, and Chidentree Treesatayapun, CINVESTAV Unidad Saltillo, Robotics and Advanced Manufacturing Program, Carr. Saltillo-Monterrey km 13.5, Ramos Arizpe, Coahuila, 25900, Mexico

---Typical ultrasonic methodology for nondestructive scanning evaluation uses systematic scanning paths. In many cases, this approach is time inefficient and also energy and computational power consuming. Here, a methodology for the scanning of defects using an ultrasonic echo-pulse scanning technique combined with chaotic trajectory generation and probability theory is proposed. This is implemented in a Cartesian coordinate robotic system developed in our lab. To cover the entire search area, a chaotic function and a proposed mirror mapping were incorporated. To improve detection probability, our proposed scanning methodology is complemented with a probabilistic approach of discontinuity detection. The developed methodology was found to be more efficient than traditional ones used to localize and characterize hidden flaws.
Accelerating Calculation for NDE Simulator of FEM by Using Multi-GPGPUs and its Procedures for Evaluation
---Yoshiyasu Hirose, Miki Nagano, Yukihiro Sakai, Yoshikazu Iriya, and Yasushi Ikegami, ITOCHU Techno-Solutions Co, Tokyo, Japan

---We improve our original FEM code "ComWAVE" for analyzing NDE problems so that it can be available on multi-GPGPUs system and we realize remarkably faster calculation using the system compared with CPU as in the past. In the case of 3D ultrasonic propagating model which has about 57 million elements and includes anisotropic materials, it takes 1,247 seconds to run 1900 steps (corresponds to 10us) by two GPGPUs. This is about 40 times faster than 12.6 hours, which is the result by CPU for the same model. This improvement makes it possible to shorten a calculation time greatly, especially for the large-scale problems, e.g., evaluation of echoes from complex shapes of crack such as SCC or the problems which need iterative calculations, e.g., searching for the optimal condition for NDT. We show the effectiveness of the improved code through concrete examples. Moreover, we mention to the analyzing procedure for keeping a good accuracy using the simulator. Especially, when we use the new restart function which can move the computation area according to wave propagation, it enables us to improve dramatically in numerical accuracy.

Ultrasonic Guided Wave Vibration Formulation
---Cody Borigo, Yue Liang, and Joseph L. Rose, Pennsylvania State University, Engineering Science and Mechanics Dept., 212 Earth-Engineering Science Building, University Park, PA 16802; Fei Yan and Joseph L. Rose, FBS Inc., State College, PA

---A novel transient-guided-wave-based approach to predicting natural vibration frequencies and mode shapes of a plate has been developed. This theory uses the orthogonal propagating and evanescent guided wave modes to fully satisfy the elasticity structural vibration boundary value problem for a semi-infinite plate. This technique is able to accurately calculate natural resonant frequencies and full three-dimensional displacement fields in such a plate without making any classical plate theory assumptions, which neglect the crucially important through-thickness displacement field. Since this calculation makes no such assumptions, all compressional, flexural, and shear plate vibration modes are identified. In addition to solving the three-dimensional elasticity structural vibration problem and developing the through-thickness displacement field, further insight is obtained by relating transient guided wave propagation and steady-state vibration, as well as revealing the relative amplitude and phase of propagating guided wave modes associated with any particular plate vibration mode. Efforts are underway to expand this technique to plates finite in all dimensions. This information is being used to develop an ultrasonic vibration structural health monitoring technique. The premise of this technique is to achieve full structural guided wave saturation by driving a structure to steady-state vibration induced by a continuous guided wave excitation. The sensitivity of the induced vibration state to particular defects is directly dependent on the guided wave loading function applied to the structure. This loading function, achieved by phased annular array transducers, is specifically chosen to excite particular guided wave modes in the structure.
Fuel Tube Spacer-Pad Spot-Weld Quality Estimation Using Guided Ultrasonic Waves
---Suresh P and Krishnan Balasubramaniam, Indian Institute of Technology Madras, Centre for Nondestructive Evaluation and Department of Mechanical Engineering, Chennai, Tamil Nadu, India

---A guided wave technique for quality analysis of the spot weld spacer pad on the PHWR fuel tubes using the strength of signal energy that is reflected from the welds is discussed here. Currently, several groups are working to develop real-time ultrasonic system for spot weld quality monitoring on the fuel tube, because potentially it allows one to eliminate expensive destructive tests, reduce the amount of off-line ultrasonic inspections and ensure the inspection quality. However, due to the rather small spot size of these welds (less than 1 mm in diameter), the current methods were found to be difficult to implement. Hence, a guided wave method was explored. A fixture was developed in order to generate L(0,1) and F(1,1) modes in the wall of the tube and traveling along the length of the tube. Couplant was not used and instead uniform pressure was applied to ensure the coupling of the wave into the tube. The results were verified using a finite element model using ABAQUS. The experimentally obtained guided wave reflected signals were correlated destructive assays. The main goal of such testing systems is to reduce operational time and provide reliable means of quality inspection. The basic aim this work will be to extend this method to an online method for monitoring the reflected ultrasonic guided wave energy signal and thereby providing a in-process control of the spot welding.

Experimental Assessment of the Performance of Guided Wave Travel Time Tomography
---Arno Volker and Rik Vos, TNO, P. O. Box 155, 2600 AD Delft, 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 it provides a wall thickness map in between two sensor rings. The wall thickness map provides quantitative information about the remaining wall thickness, location and extent of the corrosion. The performance of guided wave tomography has been evaluated experimentally assessing the sizing accuracy and the smallest corrosion spots that can be detected with this technology. The results show accurate sizing, with a sizing accuracy better than 10% of the nominal wall thickness. Additionally, the maximum distance between the transmitter and receiver rings and the presence of different coatings have been evaluated. The results demonstrate the robustness of the technology under a range of practical conditions.
An Automatic Fastener-Linked-Defect Inspection Method in NDT
---Joanna X. Qiao and Michael Armbruster, GE Inspection Technologies, 50 Industrial Park Rd, Lewistown, PA 17044-9312

---The inspection and detection of the Fastener linked cracks or corrosion is one of the challenging tasks of aircraft maintenance. As known, the aircraft skin is composed of a multi-layer structure held together by fasteners or rivets. Due to the applied stress, the cracks or corrosion are most often occurring around the fastener holes and buried under the surface. These small cracks, located in a lower layer, close to the fastener make the detection very difficult. However, undetected, they may ultimately lead to mechanical failure later in service with significant consequences. The goal of the proposed method is to tackle this challenging detection problem; provide a novel approach with enhanced capability of automatic fastener inspection with improved defect detection. There are no pre-knowledge requirements related to the fastener’s location, their distribution, nor the need to be centered on the fastener. Based on the reference knowledge of the known defect free fastener sub-image, the method is capable of automatically tracing the fastener’s random positions on the blind 2D inspection image, and assessing individual fastener linked quality.

Universal Ultrasonic Goniometer for Rayleigh- and Surface Skimming Longitudinal Wave Dispersion Measurements
---Martin Barth, Martin Kuettner, and Bernd Koehler, Fraunhofer IZFP-D, Dep. Micro and Nano Evaluation, Dresden, Germany; Joachim Bamberg and Hans-Uwe Baron, MTU Aero Engines GmbH, Munich, Germany

---There are several approaches for determination of the Rayleigh wave dispersion of surface treated materials. Most of them are based either on ultrasonic probes in contact technique or on laser excitation or detection of ultrasound. Disadvantages of these methods for in-service use are coupling problems (contact methods) and very high device costs (laser based methods). The paper presents an immersion technique trying to avoid the disadvantages of the previous approaches for practical use. The High resolution Ultrasonic GOniometer (HUGO) allows to vary both: the sound beam angles and the distance between the excitation and detection sound beams. Thus, the Rayleigh wave velocity and its dispersion can be determined by two independent methods: by the drop in the reflexion coefficient at the Rayleigh angle and by change in travel time for a given change in travel distance. The dispersion can also be determined for surface skimming longitudinal waves. The application for stress determination in surface treated aero-engine materials is discussed.
Graphics Processing Unit (GPU) Based Computation for NDE Applications
---Nahas CA, Prabhu Rajagopal, and Krishnan Balasubramaniam, Centre for Nondestructive Evaluation, Indian Institute of Technology - Madras, Chennai, Tamil Nadu, India

---Advances in parallel processing in recent years are helping to improve the cost of numerical simulation. Breakthroughs in Graphical Processing Unit (GPU) based computation now offer the prospect of further drastic improvements. GPUs were originally invented in order to offload work from Central Processing Units (CPUs) while running computationally intense graphic applications such as video games. However, developments such as NVIDIA compute unified device architecture (CUDA) have simplified GPU programming dramatically. Thus computationally intense non-graphical programs such as numerical simulation can also now be solved through GPU based processing that favors parallel computation by design. Here we consider the Finite Difference (FD) method in the time domain for solving the problems of heat diffusion and acoustic wave propagation. All calculations are performed on a normal PC, with the GPU provided by NVIDIA GeForce 9800 GT graphics card containing 112 CUDA cores. An implementation of the time domain FD algorithm for the heat equation and the scalar wave equation suited to parallel computation using this GPU architecture is presented. The challenges in parallelizing the solution of the equations for GPU based computation are highlighted, including the problem of minimizing GPU-CPU data transfer for achieving optimal performance. The performance of the GPU-implementation of the FD algorithm so developed is then compared with that offered by standard CPU-implementations in normal C code and MATLAB. We show that over CPU based computation with simple or no parallelization, the GPU-based FD algorithm speeded up the solution by factor of ten with C and a factor of hundred with MATLAB. Finally we discuss factors that can help improve the efficiency of GPU-based computation.

Visualization of Phased-Array Sound Fields and Flaw Interaction Using the Photo-Elastic Effect
---Till Schmitte and Thomas Orth, Salzgitter Mannesmann Forschung GmbH, Systemtechnik – Zerstorungsfreie Prufung, 47259 Duisburg, Germany; Thomas Kersting, Europipe GmbH – Werk Mulheim, 45473 Mulheim an der Ruhr, Germany

---The use of phased array transducers in ultrasonic testing opens a new range of applications and significantly increases testing speed in common setups. It is possible to influence easily the beam direction and shape and thereby introduce imaging techniques into the “UT world”. However, the simple understanding of UT “beams” and a ballistic approach of flaw interaction can be misleading. Therefore, simulation techniques are used to engineer the UT beam angle and shape in order to result in optimal testing results. An alternative solution to this problem is using a photo-elastic imager, as has been shown by Ginzel et. al. Using this technique a glass model of the specimen to be investigated is produced and a polarized light beam is transmitted through the insonified area. Making use of stress induced birefringence a contrast proportional to the UT amplitude can be produced and it is possible to evaluate the evolution of the UT pulse in time. Using image processing the sound field can be derived. As the speed of sound in glass and steel are quite comparable these results can be viewed as being representative for the testing situation in steel. It is important to note that this technique images the situation using a real UT PA electronics (we use MicroPulse 5, from PeakNDT Ltd., UK) and a real UT probe, which is an advantage over simulation programs as the influence of non-ideal probes or electronics is included in the analysis. In this contribution we will show measurements and quantitative evaluations from 1d and 2d phased array probes and will demonstrate the influence of e.g. missing elements of the probe on the sound field. In addition, we can compare the photo-elastic visualization to simulation results. The influence of convex and concave surface reflection as can be found in inspection of pipes on the sound field is studied. Another interesting aspect is the interaction of UT waves with test flaws like notches or drill-holes.
TUESDAY

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**Session 10 – POSTERS – 1:30 – 3:10 PM – Mount Mansfield Room**

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LUNCH
Session 6
Tuesday, July 19, 2011

SESSION 6
THERMOGRAPHY AND THERMOSONICS I
X. Han, Chairperson
Sugar Maple Ballroom

8:30 AM  Quantitative Thermal Tomography Imaging of Complex Material Structures
---J. G. Sun, Argonne National Laboratory, 9700 South Cass Avenue, Argonne, IL 60439

8:50 AM  Application of “Difference Thermography” to Damage Characterization in Ceramic Composites

9:10 AM  An Analytic Study of the Pulsed Thermography Defect Detection Limit – The Defect Aspect Ratio Greater Than Two Rule-of-Thumb
---D. P. Almond and S. G. Pickering, University of Bath, Department of Mechanical Engineering, Claverton Down, Bath BA2 7AY, United Kingdom

---K. Eisler, M. Goldammer, M. Rothenfusser, and C. Homma, Siemens AG, GTF Nondestructive Evaluation, Munich, Bavaria, Germany; W. Arnold, University Goettingen, 1. Physikalisches Institut, Goettingen, Lower Saxony, Germany and Saarland University, Department of Materials Science and Technology, Saarbruecken, Saarland, Germany

9:50 AM  Composite Delamination Depth Profiling in Sonic-IR Imaging
---S. X. Zhao and G. M. Newaz, Wayne State University, Department of Mechanics, Detroit, MI 48202; X. Han, Wayne State University, Department of Electrical and Computer Engineering, Detroit, MI 48202; L. D. Favro and R. L. Thomas, Wayne State University, Department of Physics, Detroit, MI 48202

10:10 AM  Break

10:30 AM  Transducer Degradation and Excitation Repeatability of High Power Broadband Piezoelectric Stack Actuators for Vibrothermography
---J. Vaddi, S. D. Holland, and R. S. Reusser, Iowa State University, Center for NDE, Aerospace Engineering, Ames, IA 50011

10:50 AM  The Influence of Fatigue Parameters on Vibrothermographic Crack Heating Phase 1: Repeatability
---R. S. Reusser, S. D. Holland, and J. Vaddi, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

11:10 AM  Modeling Turbine Blade Crack Detection in Sonic IR Imaging With a Method of Creating Flat Crack Surface in FEA
---D. Zhang and X. Han, Department of Electrical and Computer Engineering, Wayne State University, Detroit, MI 48202; G. Newaz, Department of Mechanical Engineering, Wayne State University, Detroit, MI 48202; L. Favro and R. Thomas, Department of Physics and Astronomy, Wayne State University, Detroit, MI 48202

11:30 AM  Defect Characterization by Inductive Heated Thermography
---M. Noethen and N. Meyendorf, Fraunhofer Institute for Non-Destructive Testing, Dresden Branch (IZFP-D), Maria-Reiche-Strasse 2, 01109, Dresden, Germany; Y. Jia, Univ. of Puerto Rico

11:50 AM  Artificial Disbonds for Calibration of Transient Thermography Inspection of Thermal Barrier Coating System
---G. Ptaszek, P. Cawley, D. Almond, and S. Pickering, Research Centre for NDE (RCNDE); A. Power, Imperial College, London, SW7 2AZ, United Kingdom

12:10 PM  Lunch
Quantitative Thermal Tomography Imaging of Complex Material Structures  
---J. G. Sun, Argonne National Laboratory, 9700 South Cass Avenue, Argonne, IL 60439

---Pulsed thermal imaging has been widely used for nondestructive evaluation of engineering materials such as composites and coatings. Current methods may measure the gross thermal property or detect flaws within the material. They however are not suited for quantitative determination of the property and flaw distributions within complex material systems. Recently a thermal tomography method was developed that can resolve the volumetric distribution of material’s thermal effusivity within the entire material volume. In this paper we will present typical experimental results and demonstrate the capability of quantitative data analysis for complex material structures. The performance and limitation of this method in terms of detection sensitivity and spatial resolution will also be discussed.

Application of “Difference Thermography” to Damage Characterization in Ceramic Composites  

---Significant variations in the local thermal properties of ceramic composites limit the capabilities of thermographic detection of damage. By application of “difference thermography” to ceramic composites undergoing aging, it is shown it is possible to improve the characterization of the aging process. Prior to the aging process, a baseline thermal response of the ceramic composite is measured. Following the aging process, the thermal response is measured. The aged and baseline responses are registered to each other, then a point-by-point difference calculated to produce a “difference thermography” signal. Physics based models are used to reduce the “difference thermography” signal to an improved characterization of the damage. The results of the analysis are compared to x-ray tomography data acquired on the same set of specimens.
An Analytic Study of the Pulsed Thermography Defect Detection Limit – The Defect Aspect Ratio Greater Than Two Rule-of-Thumb

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

---Remarkably, there has been no analytic consideration of the origin of the widely accepted limitation on pulsed thermography defect detection performance that defect aspect ratio (diameter/depth) must exceed two. A simple modification of the one-dimensional expression for the contrast of a layer has been developed that provides an accurate prediction of peak contrast and contrast peak time for defects of all aspect ratios. The modification is based on the assumption that defect image contrast is limited by the diffusion of trapped heat from above the defect to the defect edge. The analytic model results have been shown to agree with numerical modelling for a range of materials, including composites which have anisotropic thermal conductivity. Both peak defect image contrast and occurrence time are found to be systematic functions of defect aspect ratio but, in addition, contrast falls with defect depth. The rule-of-thumb is only true for a limited range of defect depths and it depends critically on absorbed excitation/flash energy. The analytic impulse excitation model can be developed for other forms of excitation (long pulse or periodic) or used to model time derivative processing of thermography data. The possibility of developing a thermographic NDE expert system will be discussed.


---Konstantin Eissler, Matthias Goldammer, Max Rothenfusser, and Christian Homma, Siemens AG, GTF Nondestructive Evaluation, Munich, Bavaria, Germany; Walter Arnold, University Goettingen, 1. Physikalisches Institut, Goettingen, Lower Saxony, Germany and Saarland University, Department of Materials Science and Technology, Saarbruecken, Saarland, Germany

---The spectral selective thermography with infrared (IR) filters can be used to determine or distinguish materials such as contaminations on a metal substrate. With additional visual information the IR signal can furthermore be selectively accentuated or suppressed for easier evaluation of passive and active thermography measurements. For flash thermography the detected IR signal between 1.5 and 5.1 µm is analyzed with regard to the spectral material information. Up to now, by using IR filters, the remaining signal is often too weak for a reliable interpretation of the data. We propose using fitting algorithms to distinguish specifically emitting materials from "IR gray" materials with constant emissivity like a gray body. For better interpretation of IR measurements especially for objects of complex geometry or of small dimensions, a color picture of the specimen with no parallax to the IR image is essential. We present a hybrid camera setup using a beam splitter which is transparent in the infrared and reflecting in the visual spectrum that provides combined hybrid images of both the infrared and the visual range. Possible applications range from localization of defects, identification of false indications to area monitoring with image segmentation.
Composite Delamination Depth Profiling in Sonic-IR Imaging
---Selina X. Zhao and G. M. Newaz, Wayne State University, Department of Mechanics, Detroit, MI 48202; Xiaoyan Han, Wayne State University, Department of Electrical and Computer Engineering, Detroit, MI 48202; L. D. Favro and R. L. Thomas, Wayne State University, Department of Physics, Detroit, MI 48202

---Impact damage remains a major issue for aerospace composite structures. Considerable internal damage can occur in laminated composites from external impact loads in service with only minimal visual detectability from the surface of the structure. Damage can occur at any ply depth without visual indications on the front surface. Accurate depth measurements can aid repair assessments. This method is focused on investigating depth profiling of composite delaminations by using Sonic-IR, which is a nondestructive evaluation method (NDE) technique that makes images of defects using an infrared camera with an ultrasonic transducer as a stimulation source. The depth profiling relies on the time delays of the temperature increases at the surface from the different defect depths. To process the time vs. temperature data captured from the camera, polynomial curve fitting was used. A mathematical model has been built to calculate time vs. second derivative of temperature curves for depth measurements. The samples used to calibrate the mathematical model data are carbon fiber composite panels with ply thickness variance and inserts with known depths.

Transducer Degradation and Excitation Repeatability of High Power Broadband Piezoelectric Stack Actuators for Vibrothermography
---Jyani Vaddi, Stephen D. Holland, and Ricky Reusser, Iowa State University, Center for NDE, Aerospace Engineering, 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. Vibration is usually generated by an ultrasonic welder or a broadband piezoelectric stack actuator which transduces electrical energy into mechanical vibrations. Defect detection in vibrothermography depends on specimen vibration, which in turn is proportional to velocity spectrum (Voc) of the transducer (with sufficient coupling). A long standing problem has been generation of repeatable specimen vibrations. The broadband piezoelectric stack actuators give much better trigger-to-trigger repeatability than the welder system. Even with the broadband piezostack, at sufficiently high excitation voltages, the transducer behavior becomes nonlinear and less repeatable. Also, as the transducer degrades over time, its Voc changes significantly. We investigate the reasons for this nonlinear behavior and present experimental results on the effects of excitation voltage and transducer degradation on Voc. Using these results, we suggest how to improve the repeatability of vibration generation and to enhance the longevity of the transducer.
The Influence of Fatigue Parameters on Vibrothermographic Crack Heating Phase 1: Repeatability
---Ricky S. Reusser, Stephen D. Holland, and Jyani Vaddi, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---Vibrothermography finds cracks through heat generation from frictional rubbing of crack face asperities. The amount of heat generated is determined by the frictional characteristics of the crack faces that were created during the fatigue crack growth process. According to fracture mechanics the fundamental parameters of crack growth are load ratio, R, and stress intensity factor, $\Delta K$. The goal of this work is to evaluate how the parameters of crack growth influence vibrothermographic detectability. The first step is to quantify the amount of variability in heat generation under constant or slowly varying parameters. By opening and closing the crack in a fixture, we can probe different portions of the crack independently. By exciting resonant modes, we quantitatively relate heating to applied vibrational engineering stress and evaluate the inherent variability of the cracks themselves. We show how much variation in heating is observed across nominally identical specimens and across different portions of the crack.

Modeling Turbine Blade Crack Detection in Sonic IR Imaging with a Method of Creating Flat Crack Surface in FEA
---Ding Zhang and Xiaoyan Han, Department of Electrical and Computer Engineering, Wayne State University, Detroit, MI 48202; Golam Newaz, Department of Mechanical Engineering, Wayne State University, Detroit, MI 48202; Lawrence Favro and Robert Thomas, Department of Physics and Astronomy, Wayne State University, Detroit, MI 48202

---Sonic Infrared (IR) Imaging Nondestructive Evaluation (NDE) technology has shown inherent advantages for defect detection in aircraft structures. It can image a wide area within a second or two for metal material targets. Due to the high stress of aircraft engine turbine blades they bear during their operation, fatigue cracks can form after a number of hours of service. Sonic IR imaging shows its great potential on this application. However, interaction of the sonic excitation and subsequent crack heating requires fundamental understanding of physical and thermal processes in complex geometries such as turbine blades. Simulation modeling can provide results to better understand contributions of some parameters where experimental arrangements are hard to produce. Because of the irregular shapes of turbine blades, their Finite Element Analysis (FEA) models are always dominated by tetra elements. The problem is that the usual procedure of using tetra elements is very hard to create flat crack surface in such complex shapes. A new method to create flat crack surface is designed for an actual blade. In this paper, we will present data of modeling turbine blade crack detection with external ultrasound excitation as the results of applying this new method, guided by our experimental Sonic IR imaging study on the blade.---This work is sponsored partly by the Air Force (supervised by current Program Manager Siamaack Mazdiyasni, originally by Craig Neslen, at WPAFB ) through Prime Contract #FA8650-10-D-5210, Task Order 0001 to UTC, Subcontract #10-S7101-01-C1, and partly by Wayne State University.
Defect Characterization by Inductive Heated Thermography
---M. Noethen and N. Meyendorf, Fraunhofer Institute for Non-Destructive Testing, Dresden Branch (IZFP-D), Maria-Reiche-Strasse 2, 01109, Dresden, Germany; Y. Jia, University of Puerto Rico

---During inductive-thermographic inspection, an eddy current of high intensity is induced into the inspected material and the thermal response is detected by an infrared camera. Anomalies in the surface temperature during and after inductive heating correspond to inhomogeneities in the material. A finite element simulation of the surface crack detection process using active thermography with inductive heating has been developed. The simulation model is based on the finite element software ANSYS. The simulation tool was tested and used for investigations on steel components with different longitudinal orientated cracks, varying in shape, width and height. This paper focuses on surface connected longitudinal orientated cracks in different materials. The results show that depending on the excitation frequency the temperature distribution of the material under test are different and a possible way to measure the depth of the crack will be discussed.

Artificial Disbonds for Calibration of Transient Thermography Inspection of Thermal Barrier Coating Systems
---G. Ptaszek, P. Cawley, D. Almond, and S. Pickering, Research Centre for NDE (RCNDE), Alstom Power, Imperial College, London, SW7 2AZ United Kingdom

---Transient thermography is commonly used for the detection of disbonds in thermal barrier coatings (TBC). As for other NDT techniques, reference test specimens are required for calibration, but unfortunately, real disbonds are very difficult to use because it is difficult to control their size, and larger ones tend to spall. Flat bottomed holes are commonly used, but these overestimate the thermal contrast obtained for a defect of a given diameter. This paper quantifies the differences in thermal response using finite element analysis validated by experiments, and proposes a form of artificial disbond that gives a better representation of the thermal responses seen with real defects. Real disbonds tend to have a non-uniform gap between the disbonded surfaces across the defect, and the effect of this on the thermal response is evaluated using finite element simulations. It is shown that the effect can be compensated for by adjusting the diameter of the calibration defect compared to the real defect.
Session 7
SESSION 7
NDE TECHNIQUES OF CIVIL ENGINEERING MATERIALS AND STRUCTURES
L. Jacobs, Chairperson
Mildred Livak Ballroom

8:30 AM  A Nonlinear Wave Mixing Method for Detecting Alkali-Silica Reactivity of Aggregates
---M. Liu and J. Qu, Department of Civil and Environmental Engineering, Northwestern University, Evanston, IL 60208; G. Tang and J. Qu, Department of Mechanical Engineering, Northwestern University, Evanston, IL 60208; L. J. Jacobs, School of Civil and Environmental Engineering, Georgia Institute of Technology, Atlanta, GA 30332-0360

8:50 AM Application of the Mechanical Perturbation Produced by Traffic as a New Approach of Nonlinear Acoustic Technique for Detecting Microcracks in the Concrete: A Laboratory Simulation
---F. Moradi-Marani, S. A. Kodjo, P. Rivard, and C. P. Lamarche, Universite de Sherbrooke, Civil Engineering Department, 2500 Boulevard l’Universite, Sherbrooke, Quebec, J1K 2R1, Canada

9:10 AM Detection of ASR Gel in Cement-Based Materials Using Microwave Nondestructive Testing
---K. M. Donnell and R. Zoughi, Missouri University of Science and Technology, Applied Microwave Nondestructive Testing Laboratory (amntl), Department of Electrical and Computer Engineering, Rolla, MO 65409-6524; K. E. Kurtis, School and Civil and Environmental Engineering, Georgia Institute of Technology, Atlanta, GA 30332

9:30 AM Microstructure-Property Relationships and the NDE of Civil Engineering Materials
---E. N. Landis, University of Maine, 5711 Boardman Hall, Orono, ME 04469

9:50 AM A Study on Issues Relating to Testing of Soils and Pavements by Surface Wave Methods
---L. Shibin and J. C. Ashlock, Iowa State University, Department of Civil, Construction, and Environmental Engineering, 405 Town Engineering Building, Ames, IA 50011

10:10 AM Break

10:30 AM Application of Microwave 3-D Imaging Techniques for Detection and Evaluation of Corrosion of Steel Rebars in Cement-Based Structures
---S. Kharkovsky, J. T. Case, and R. Zoughi, Missouri University of Science and Technology (S&T), Department of Electrical and Computer Engineering, Rolla, MO 65409-0040; S.-W. Bae, Texas Tech University, Department of Civil and Environmental Engineering, Lubbock, TX; D. J. Belarbi, University of Houston, Department of Civil and Environ. Engineering, Houston, TX 77004

10:50 AM Use of Microwaves for the Detection of Corrosion Under Insulation: The Effect of Bends
---R. E. Jones and M. J. S. Lowe, Imperial College, Mechanical Engineering, London, SW7 2AZ, United Kingdom; F. Simonetti, University of Cincinnati, School of Aerospace Systems, Cincinnati, OH 45221; I. P. Bradley, BP, Sunbury on Thames, TW16 7LN, United Kingdom

11:10 AM Measurement of Longitudinal Thermal Stresses in Continuously Welded Rail Through Diffuse Ultrasonic Backscatter
---C. M. Kube and J. A. Turner, University of Nebraska-Lincoln, Department of Engineering Mechanics, W317.4 Nebraska Hall, Lincoln, NE 68588; M. Fateh, Federal Railroad Administration, Office of Research and Development, 1120 Vermont Avenue, N.W., Washington, DC 20590

11:30 AM Effective Visualization of Impact-Echo Data for Bridge Deck NDE
---J. S. Popovics, T. Oh, and S. Ham, University of Illinois, Department of Civil and Environmental Engineering, 205 N. Mathews Avenue, Urbana, IL 61801

11:50 AM Air-Coupled Impact-Echo Test Using a Parabolic Microphone
---J. Zhu, The University of Texas at Austin, Department of Civil, Architectural and Environmental Engineering, Austin, TX 78712-0273

12:10 PM Lunch
A Nonlinear Wave Mixing Method for Detecting Alkali-Silica Reactivity of Aggregates

---Minghe Liu and Jianmin Qu, Department of Civil and Environmental Engineering, Northwestern University, Evanston, IL 60208; Guangxin Tang and Jianmin Qu, Department of Mechanical Engineering, Northwestern University, Evanston, IL 60208; Laurence J. Jacobs, School of Civil and Environmental Engineering, Georgia Institute of Technology, Atlanta, GA

---Alkali-silica reaction (ASR) is a deleterious reaction in concrete. Significant ASR damage could undermine the durability of concrete structures and may result in reduced service life. Several nondestructive techniques based on acoustics have been used to assess ASR damage. It has been shown that nonlinear acoustics is more sensitive to internal stresses as well as to micro-cracks induced by ASR damage. In this investigation, we developed a co-linear wave mixing method for assessing ASR damage in concrete. By mixing two longitudinal waves, a new longitudinal wave with a lower frequency is generated. The amplitude of this new wave is proportional to the acoustic nonlinear parameter $\beta$ which can then be obtained from the frequency spectrum of the newly generated longitudinal wave. Our experimental results show that (i) the acoustic nonlinearity parameter is closely correlated to ASR damage in concrete, (ii) the nonlinear wave mixing technique developed here is capable of measuring the changes in the acoustic nonlinearity parameter caused by ASR damage, even in its early stages, and (iii) the nonlinear wave mixing method has the potential to identify the different stages of ASR damage and to track the intrinsic characteristics of the ASR damage.

Application of the Mechanical Perturbation Produced by Traffic as a New Approach of Nonlinear Acoustic Technique for Detecting Microcracks in the Concrete: A Laboratory Simulation

---F. Moradi-Marani, S. A. Kodjo, P. Rivard, and C. P. Lamarche, Université de Sherbrooke, Civil Engineering Department, 2500, Boul.'lUniversité, Sherbrooke, Québec J1K 2R1, Canada

---Experiences have showed that only a few of nonlinear acoustics techniques are currently applied on field structures, because their large-scale implementation causes various problems. Recently, a new method based on nonlinear acoustics has been proposed at the Université de Sherbrooke for the characterization of the damage associated with Alkali-Silica Reaction. This method consists in quantifying the influence of an external mechanical disturbance on the propagation of a continual ultrasonic wave that probe the material. In this method, the mechanical perturbation produced by an impact causes sudden opening of microcracks and, consequently, the velocity of the probe ultrasonic wave is suddenly reduced. Then it slowly and gradually returns to its initial value while the microcracks are closing. The goal of this study is to create the opening/closing of micro-cracks from waves generated by traffic instead of using an impact. This paper presents a laboratory set-up made of three large concrete slabs used to study the nonlinear behavior of concrete using the disturbance caused by traffic. The traffic is simulated with a controlled high-accuracy jack to produce a wave similar to that produced by traffic. Results obtained from this study will be used in the future to design an in-situ protocol for assessing ASR-affected bridge.
Detection of ASR Gel in Cement-Based Materials Using Microwave Nondestructive Testing
---Kristen M. Donnell and Reza Zoughi, Missouri University of Science and Technology, Applied Microwave Nondestructive Testing Laboratory (amntl), Department of Electrical and Computer Engineering, Rolla, MO 65409-6524; Kimberly E. Kurtis, School of Civil and Environmental Engineering, Georgia Institute of Technology, Atlanta, GA

---At microwave frequencies, the electrical behavior of dielectric materials is described by the dielectric constant. One may measure the complex (magnitude and phase) reflection and transmission coefficients of a microwave signal interacting with a dielectric material, from which the dielectric constant (and changes in material characteristics) may be extracted. Recently, microwave methods have been used to evaluate a number of important material properties associated with cement-based materials (curing where free water becomes bound, filling of pores with free salt over time and its gradient of penetration, etc). Consequently, production of alkali-silica reaction (ASR) gel and its tendency to attract free water from the environment are issues that may be investigated using microwave techniques. This paper presents an initial investigation regarding the feasibility of microwave nondestructive testing to detect/evaluate the production of ASR gel in cement-based materials. To this end, samples were formed using reactive and non-reactive crushed aggregate. These samples were stored in a humid environment (to accelerate the production of ASR gel), and their microwave transmission properties measured over time. The results show that the transmission properties of the non-reactive sample differ from those of the reactive sample, indicating that detection/evaluation of ASR is feasible using microwave techniques.

---The key to successful NDE of complex heterogeneous materials is to focus not only on the interrogation technique, but how the measurement is related to the desired performance property. In this work, the focus is on key microstructural features that can be directly measured, and how we can use those measurements to predict performance of heterogeneous civil engineering materials. Not surprisingly, the key to focus on microstructure, and appropriately matching the interrogation techniques with the models that can predict strength, toughness, durability, and other properties of interest. We find that numerical models developed to directly mimic micromechanical phenomena offer great promise for making a robust nondestructive measurement-performance link. As examples, particle-based and lattice-based models allow incorporation of measurable microstructural features such as porosity and pore size distribution, phase distribution, as well as other spatially varying properties such as moisture. Examples are presented where x-ray tomography is used to produce 3D images of concrete microstructure, and how that information is can be incorporated into spatially matched numerical models to predict performance. The argument is made that physically based models for micromechanical phenomena represent the next step towards a viable NDE system for complex civil engineering materials.

---Eric N. Landis, University of Maine, 5711 Boardman Hall, Orono, ME 04469
A Study on Issues Relating to Testing of Soils and Pavements by Surface Wave Methods

---Lin Shibin and Jeramy C. Ashlock, Iowa State University, Department of Civil, Construction, and Environmental Engineering, 405 Town Engineering Building, Ames, IA 50011

---A study on the differences between testing soils and pavements using surface wave methods is presented. Both applications are based on the geometric dispersion of surface waves in layered media. The stiffness of soil typically increases with depth while that of pavement decreases with depth, and the resulting wave propagation phenomena in the two material types thus gives rise to significant differences between their dispersion curves, as can be observed from experimental and theoretical dispersion results. The differences in theoretical dispersion curves are illustrated using the transfer matrix method and the stiffness matrix method for soils and pavements, respectively. The Levenberg-Marquardt method and the simulated annealing method are applied for inversion and their relative merits and differences are discussed. The relevant frequency ranges of dispersion curves are studied with consideration to attenuation of waves with depth and resolution as a function of wavelength and layer thickness. The goal of this study is to offer insight into the selection of appropriate surface wave methods for soils and pavements, and to improve the accuracy and uniqueness of testing results.

Application of Microwave 3-D Imaging Techniques for Detection and Evaluation of Corrosion of Steel Rebars in Cement-Based Structures

---Sergey Kharkovsky, Joseph T. Case, and Reza Zoughi, Missouri University of Science and Technology, Department of Electrical and Computer Engineering, Rolla, MO 65409-0040; Sang-Wook Bae, Texas Tech University, Department of Civil and Environmental Engineering, Lubbock, TX; Abdeldjelil (DJ) Belarbi, University of Houston, Department of Civil and Environmental Engineering, Houston, TX 77004

---Microwave nondestructive testing and imaging techniques have the potential to detect and evaluate the corrosion of reinforcing steel bars. For this purpose relatively high-resolution imaging and high penetration depth are required. To satisfy these conflicting requirements, signal processing techniques such as microwave three-dimensional (3-D) imaging techniques are used. Since these techniques involve a swept-frequency approach, they allow for signal averaging which improves the signal-to-noise ratio (S/N) associated with an image. Thus, one may increase the operating frequency and take advantage of this S/N improvement and overcome the problem of signal attenuation while producing reasonably high-resolution images. This paper presents and discusses the attributes and results of using continuous-wave microwave 3-D imaging for evaluation of reinforced cement mortar structures. These techniques were used to detect corrosion and thinning of reinforcing steel bars and were demonstrated through methodically planned experiments which investigated the following parameters: (1) different reinforcing bar sizes, (2) whether or not the reinforcing bar is corroded, (3) different depth of the reinforcing bar locations, and (4) distance and spacing between reinforcing bars. A comparison between these results and the results obtained by other methods is discussed. Future work related to the evaluation of reinforced concrete members is also discussed.
Use of Microwaves for the Detection of Corrosion Under Insulation: The Effect of Bends
---Robin E. Jones and M. J. S. Lowe, Imperial College, Mechanical Engineering, London SW7 2AZ, United Kingdom; Francesco Simonetti, University of Cincinnati, School of Aerospace Systems, Cincinnati, OH 45221; Ian P. Bradley, BP, Sunbury on Thames, TW16 7LN, United Kingdom

---Corrosion Under Insulation (CUI) is a significant cause of pipeline failure in the oil and gas industry. Recently, the use of guided microwaves propagating inside the insulation annulus and travelling along the pipeline length, has been proposed to detect regions of wet insulation in a similar fashion to long-range ultrasonic guided wave inspection. In a straight pipeline, laboratory experiments have shown that the transverse electromagnetic (TEM) mode can be excited with a SNR approaching 40dB leading to very high sensitivity; water volumes presenting a cross-sectional extent of only 5% of the insulation annulus prove to be readily detectable. In this paper, we further investigate the potential of this approach by studying the SNR of the TEM mode propagating across pipe bends typical of those encountered in refineries. We present the results of a numerical analysis where the transmission of TEM is studied for different bend radii and angles. We show that due to mode conversion, the transmission coefficient is an oscillating function of the bend angle with the first minimum occurring at about 45° and the maxima at 0 and 90°. For the typical industrial bend radii, which are in the range of three to five times the pipe diameter, the oscillatory behavior is less pronounced and the transmission coefficient is above 90% for most angles, thus indicating that inspection beyond a bend will not pose a problem. These simulated results are validated by comparison with experimental results on a 12" diameter waveguide and are found to be in excellent agreement.

Measurement of Longitudinal Thermal Stresses in Continuously Welded Rail through Diffuse Ultrasonic Backscatter
---Christopher M. Kube and Joseph A. Turner, University of Nebraska-Lincoln, Department of Engineering Mechanics, W317.4 Nebraska Hall, Lincoln, NE 68588; Mahmood Fateh, Federal Railroad Administration, 300 Ala Moana Boulevard, Room 3202, Honolulu, HI 96850-0001

---The nondestructive measurement of stresses in materials has been an established goal within NDE for decades. Recently, a method of measuring stresses in polycrystalline metals through the analysis of ultrasonic scattering has been developed. The scattering results through reflections from grain boundaries and discontinuities of the microstructure. The acoustoelastic response of individual grains due to temperature and stress gradients has a direct influence on the strength of the scattering. A specific instance of application is found within the railroad industry for the measurement of thermally induced longitudinal stress in continuously welded rail. In this case, the grains deform due to the coupled influence of both temperature and stress. First, signal processing methods for decoupling these two components to produce a stress measurement are shown. Then, the decoupled measurements of stress and temperature for stainless steel and steel rail sections will be presented. It was found that this scattering technique has produced measurement resolutions on the order of $10^{-4}$ per MPa stress change. This work has resulted in the production of a single point measurement device. Finally, future applications and possible utilizations of this technique are given.
Effective Visualization of Impact-Echo Data for Bridge Deck NDE
---John S. Popovics, Taekeun Oh, and Suyun Ham, University of Illinois, Department of Civil and Environmental Engineering, 205 N. Mathews Avenue, Urbana, IL 61801

---The work reported here represents a portion of a larger effort to develop a rapid and accurate nondestructive evaluation (NDE) approach to inspect large areas of concrete bridge deck structures. Contactless (acoustic) impact-echo scan data are employed so that a large amount of data can be readily collected. These data must be manipulated and presented such that infrastructure engineers can effectively visualize the condition of the structure. To address this problem, we present the data in the form of “4-dimensional” images, which indicate the location of delamination defects within concrete bridge decks. The basis of the 4-D plot is introduced, and the effects of image parameter variation, such as frequency range and transparency index, are studied. Then 4-D images from simulated and actual impact-echo data are presented; data from dynamic finite element simulations and experiments from actual deck samples are used. The effectiveness of 4-D images in defining the location, size and severity of deck delamination are discussed. The results demonstrate that the proposed visualization approach is effective.

Air-Coupled Impact-Echo Test Using a Parabolic Microphone
---Jinying Zhu, The University of Texas at Austin, Department of Civil, Architectural and Environmental Engineering, Austin, TX 78712-0273

---Impact-echo (IE) test is a commonly used NDT method to determine slab thickness or locate defects in concrete structures. Like many stress wave based NDT methods, the IE test is limited by the test speed due to the contact requirement between the sensor and concrete surface. The air-coupled sensor has been proposed as a solution. One objective of this paper is to investigate wave propagation in air-solid system when an impact force is applied on the solid plate surface. Numerical simulation shows that the impact-echo mode vibration in the solid plate radiates energy into air, which has the same IE frequency and propagates in a direction almost normal to the plate. Another objective of this study is to use a parabolic reflector to improve the signal-to-noise ratio. Experimental studies indicate that the impact-echo signal amplitude can be improved by 20dB by using a 15 cm diameter parabolic reflector.
Session 8
SESSION 8

NDE FOR AUSTENITIC WELD MATERIALS AND WELDS

T. Capobianco, Chairperson
Frank Livak Ballroom

8:30 AM Effects of Microstructure and Texture on Ultrasonic Inspection of Austenitic Weld Metals
---G. A. Young, Jr., T. E. Capobianco, J. Pyle, and F. Khan, Knolls Atomic Power Laboratory, Bechtel Marine Propulsion Corporation, Schenectady, NY 12301-1072

9:10 AM In-Process Laser-Ultrasonic Testing for Inspection of Thick Weld Structures
---S. Yamamoto, T. Hoshi, and M. Ochiai, Toshiba Corporation, Power and Industrial Systems Research and Development Center, Yokohama, Kanagawa, Japan; T. Ogawa, Y. Fujita, and S. Asai, Toshiba Corporation, Keihin Product Operations, Yokohama, Kanagawa, 236-8523, Japan

9:30 AM Thermographic Testing of Spot Welds

9:50 AM Ultrasonic Imaging for Early Detection of Type-IV Cracking in Creep Tested Modified 9Cr-1Mo Ferritic Steel Weld Joints
---G. S. Kumar, Safety Research Institute, Atomic Energy Regulatory Board, Kalpakkam, Tamil Nadu, India; K. S. Chandravati, G. K. Sharma, A. Kumar, K. Laha, T. Jayakumar, and B. Raj, Gandhi Centre for Atomic Research, Metallurgy and Materials Group, Kalpakkam, Tamil Nadu, 603102, India

10:10 AM Break

10:30 AM Autofocus Imaging: Experimental Results in an Anisotropic Austenitic Weld
---J. Zhang, B. W. Drinkwater, and P. D. Wilcox, Department of Mechanical Engineering, University Walk, University of Bristol, Bristol, BS8 1TR, United Kingdom

---J. Moysan, G. Corneloup, C. Gueudre, and M.-A. Ploix, Laboratoire de Characterisation Non Destructive, Universite de la Mediterranee, Av. G. Berger, 13625 Aix en Provence, France; B. Chassignole, EDF R&D, site des Renardieres, 77250, Moret sur Loing, France

11:10 AM Quantitative Evaluation of Ultrasonic Sound Fields in Anisotropic Austenitic Welds Using A 2-D Ray Tracing Method
---S. R. Kolkoori, M.-U. Rahaman, J. Prager, M. Kreutzbruck, Federal Institute for Materials Research and Testing (BAM), Department of Acoustical and Electromagnetic Methods, Berlin, Germany

11:30 AM Automated Flaw Detection Scheme for Cast Austenitic Stainless Steel Weld Specimens Using Hilbert Huang Transform of Ultrasonic Phased Array Data
---T. Khan, S. Majumdar, and L. Udpa, Michigan State University, Department of Electrical and Computer Engineering, East Lansing, MI 48824; P. Ramuhalli, S. Crawford, A. Diaz, and M. T. Anderson, Pacific Northwest National Laboratory, Richland, WA

11:50 AM Finite Element Simulation of Array Beam Focusing on Defects in Austenitic Welds Based on the Time Reversal Ultrasomics
---H. Jeong, S. Cho, and W. Wei, Wonkwang University, Division of Mechanical and Automotive Engineering, Iksan, Jeonbuk, 570-749, South Korea

12:10 PM Lunch
Effects of Microstructure and Texture on Ultrasonic Inspection of Austenitic Weld Metals
---George A. Young Jr., Thomas E. Capobianco, Joseph Pyle, and Fateh Khan, Knolls Atomic Power Laboratory, Bechtel Marine Propulsion Corporation, Schenectady, NY, 12301-1072

---Ultrasonic inspection of austenitic weld metals is notoriously difficult due to the interaction of the sound beam with a complex weld microstructure. This paper reviews the origins of dendritic weld microstructure as related to alloy content and welding parameters, and examines the propagation of ultrasound as a function of orientation through that microstructure. An effort is made to characterize common interfaces in welds that can confound ultrasonic inspection results. Examples are illustrated for several austenitic weld metals used in commercial nuclear power generation. Results are reported of immersion ultrasonic scans of all-weld-metal test blocks with side drilled holes. The welds are characterized via state-of-the-art electron backscatter diffraction, which provides important quantitative information on the grain size, shape, crystallographic texture (e.g., preferred vs. random orientation), and degree of plastic strain in the weld of interest. Results show that, in general, welds with coarse columnar grain structures and strong crystallographic texture are among the most difficult to ultrasonically inspect. However, variations in welding parameters and alloy content have a noticeable effect on the ability to inspect heavy section welds.

In-Process Laser-Ultrasonic Testing for Inspection of Thick Weld Structures
---Setsu Yamamoto, Takeshi Hoshi, and Makoto Ochiai, Toshiba Corporation, Power and Industrial Systems Research and Development Center, Yokohama, Kanagawa, Japan; Tsuyoshi Ogawa, Yoshihiro Fujita, and Satoru Asai, Toshiba Corporation, Keihin Product Operations, Yokohama, Kanagawa, 235-8523, Japan

---The thick welded part was conventionally inspected by the ultrasonic testing (UT) after welding. If the UT could be performed during welding, it should drastically save time and cost of manufacturing. Therefore, we have developed in-process Laser-Ultrasonic Testing (LUT) technique during welding at elevated temperature. LUT is applicable to structures with high temperature because of its non-contacting feature. In addition, to apply the in-process LUT to thick welding parts having a thickness of more than 100mm we have developed the synthesis aperture focus technique (SAFT) to improve sensitivity of LUT. By using the developed method, signal to noise ratio (S/N) of echo from a side drilled hole (SDH) 1mm in diameter in 150mm thickness specimen was improved from 3 to 7. Moreover we show the in-process testing result with actual 150mm thickness pipe with high temperature more than 200 degrees C.
Thermographic Testing of Spot Welds

---Spot welding is one of the key technologies for joining of sheet metal components in automobile manufacture. The main factor controlling the spot weld quality and the mechanical properties, respectively, is the nugget diameter. However, due to the rough conditions in the production process the required nugget diameter cannot always be achieved. A lot of NDE-approaches to determine and control the nugget diameter have been described in literature, such as in-situ and ex-situ ultrasound applications or magnetic techniques. However, in most cases state of the art is still destructive testing. We present a thermographic technique, which is based on the qualitative determination of the spot weld’s thermal resistance. The feasibility is shown on the basis of a series measurement on sample welds joining 1 mm thick zinc coated TRIP steel. The evaluation and interpretation of the measuring data is optimized by using variance analysis. This leads to a statistical criterion which allows us to distinguish well-done welds from the typical error classes, namely stick welds and welds at the splash limit.

Ultrasonic Imaging for Early Detection of Type-IV Cracking in Creep Tested Modified 9cr-1mo Ferritic Steel Weld Joints
---Gnanamuthu Suresh Kumar, Safety Research Institute, Atomic Energy Regulatory Board, Kalpakkam, Tamil Nadu, India, Kovi Seetharam Chandravati,Govind Kumar Sharma, Anish Kumar, Kinkar Laha, Tammana Jayakumar, and Baldev Raj, Indira Gandhi Centre for Atomic Research, Metallurgy and Materials Group, Kalpakkam, Tamil Nadu, 603102 India

---Modified 9Cr-1Mo ferritic-martensitic steel (grade 91) is widely used as a structural material for heat exchangers and steam generators in power industries due to its high temperature creep strength, good thermal conductivity, low thermal expansion coefficient and good resistance to oxidation and stress corrosion cracking. The performance of the weld joint is a life limiting factor for a component operating at high temperature. Operational experience obtained from the usage of the weld joint at high temperature shows that failures are due to type IV cracking in heat affected zone (HAZ) near the base metal in intercritical/ fine grained HAZ. As the type IV damage initiates internally, its initiation cannot be detected using surface techniques such as in-situ metallography. Hence, ultrasonic imaging has been used for early detection of Type-IV cracking. In order to simulate type IV damage, steel weld joints were subjected to creep tests at 923 K and 50 MPa for different time durations from 527 h to 2820 h (sample ruptured). Ultrasonic C-scan imaging using a 25 MHz immersion focused transducer has been carried out. Ultrasonic velocity was found to be the minimum in the weld region and increased in the HAZs to reach a maximum in the parent metal. Hence, the HAZs could be differentiated from the weld and parent metals based on the velocity or in-turn the time of arrival of the backwall echo. In the samples creep tested for durations up to 1011 h (~16 % failure strain), no localized damage could be detected. However, in the samples creep tested for more than 1992 h (~50 % failure strain), high attenuation was observed in the HAZs, on one or both sides of the weld joints. The location of high attenuation was identified to be typical of the type IV cracking region. The study clearly demonstrated that ultrasonic measurements can be used for detection of the initiation of the type IV damage, when the damage is still confined internally.
Autofocus Imaging: Experimental Results in an Anisotropic Austenitic Weld
---Jie Zhang, Bruce W. Drinkwater, and Paul D. Wilcox, Department of Mechanical Engineering, University Walk, University of Bristol, Bristol BS8 1TR, United Kingdom

---The quality of an ultrasonic array image, especially for isotropic material, highly depends on accurate information about medium properties. Inaccuracy of medium properties can cause image degradation, e.g., blurring, mislocating of reflectors, and introduction of artifacts. In this paper, for a specific anisotropic austenitic steel weld, an autofocus imaging technique is presented. The array data from a beacon system was captured firstly, and then used to statistically extract isotropic weld properties by using the Monte-Carlo inversion approach. This beacon system consists of two separated arrays, in which one array is used to capture transmitted signals from elements in the other array and image them. The Monte-Carlo inversion approach is comprised of a generalized weld model and an efficient ray-tracing model by using Dijkstra’s algorithm. Ultrasonic images for the beacons and defects were finally generated by using the Total Focusing Method (TMF). Focused images, generated by using the extracted experimental weld map, and unfocused images, generated by using a constant wave speed, were compared and analyzed. It is shown that the location errors greater than 6mm are reduced to 2mm by using the autofocus imaging approach.

Modelling Welded Material for Ultrasonic Testing Using MINA: Theory and Applications
---Joseph Moysan, Gilles Corneloup, Cécile Gueudré, and Marie-Aude Ploix, Laboratoire de Caractérisation Non Destructive, Université de la Méditerranée, Av. G. Berger, 13625 Aix en Provence, France; Bertrand Chassignole, EDF R&D, site des Renardières, 77250, Moret sur Loing, France

---Austenitic steel multi-pass welds exhibit a heterogeneous and anisotropic structure that causes difficulties in the ultrasonic testing. Increasing the material knowledge is a long term research field for LCND laboratory and EDF Les Renardières in France. A specific model has been developed: the MINA model (Modelling anisotropy from Notebook of Arc welding). Welded material is described in 2D for flat position arc welding with shielded electrode at a functional scale for UT modeling. The grain growth is the result of three physical phenomena: epitaxial growth, influence of temperature gradient, and competition between the grains. The model uses phenomenological rules to combine these three phenomena. A limited number of parameters is used to make the modelling possible from the information written down in a notebook of arc welding. We present all these principles with 10 years’ hindsight. To illustrate the model’s use, we present results for a K-shape weld and make comparison with the corresponding macrograph. In conclusion we give also insights on other research topics around this model: inverse problem using a F.E.M. code simulating the ultrasonic propagation, attenuation, in position welding, 3D prospects.
Quantitative Evaluation of Ultrasonic Sound fields in Anisotropic Austenitic Welds Using A 2-D Ray Tracing Method
---S. R. Kolkoori, M.-U. Rahaman, J. Prager, M. Kreutzbruck, Federal Institute for Materials Research and Testing (BAM), Department of Acoustical and Electromagnetic Methods, Berlin, Germany

Ultrasonic investigation of inhomogeneous anisotropic materials such as austenitic welds is complicated because its columnar grained structure yields curved energy ray paths, beam splitting and asymmetrical beam profiles. A ray tracing method has potential advantage in analyzing the sound propagation and therewith optimizing the ultrasonic inspection parameters. The paper presents a 2-D ray tracing approach to calculate energy ray paths, ray amplitudes and travel time for the three wave modes quasi longitudinal, quasi shear vertical and shear horizontal waves in austenitic weld materials. The inhomogeneity in the austenitic weld material is represented by discretizing the inhomogeneous region into several homogeneous layers. At each interface between the layers the reflection and refraction problem is computed and yields energy direction, amplitude and energy coefficients. The ray amplitudes are computed by taking into account directivity, phase and divergence factor. The presented method includes reflections at the stress free boundary as well as mode conversions at the interfaces. Using the ray tracing method, the effect of material inhomogeneity on sound propagation, amplitudes and travel times from point sources as well as finite dimension transducers are studied in the context of quantitative ultrasonic nondestructive evaluation of austenitic weld materials. Experiments are performed on austenitic weld samples using longitudinal beam transducers as a transmitting probe and amplitudes at the back surface are scanned by means of an electrodynamical probe. The ultrasonic sound fields in austenitic welds obtained from the 2-D ray tracing method are compared with the experimental results and reasons for the discrepancies are discussed.

Automated Flaw Detection Scheme for Cast Austenitic Stainless Steel Weld Specimens Using Hilbert Huang Transform of Ultrasonic Phased Array Data
---Tariq Khan, Shantanu Majumdar, and Lalita Udpa, Michigan State University, Department of Electrical and Computer Engineering, East Lansing, MI 48824; Pradeep Ramuhalli, Susan Crawford, Aaron Diaz, and Michael T. Anderson, Pacific Northwest National Laboratory, Richland, WA

The objective of this work is to develop processing algorithms to detect and localize the flaws using NDE ultrasonic data. Data was collected using cast austenitic stainless steel (CASS) weld specimens on-loan from the U.S. nuclear power industry’s Pressurized Water Reactor Owners Group (PWROG) specimen set. Each specimen consists of a centrifugally cast stainless steel (CCSS) pipe section welded to a statically cast (SCSS) or wrought (WRSS) section. The paper presents a novel automated flaw detection and localization scheme using low frequency ultrasonic phased array inspection signals in the weld and heat affected zone of the base materials. The major steps of the overall scheme are preprocessing and region of interest (ROI) detection followed by the Hilbert Huang transform (HHT) of A-scans in the detected ROIs. HHT offers time-frequency-energy distribution for each ROI. The accumulation of energy in a particular frequency band is used as a classification feature for the particular ROI.
Finite Element Simulation of Array Beam Focusing on Defects in Austenitic Welds Based on the Time Reversal Ultrasonics

---Hyunjo Jeong, Sungjong Cho, and Wei Wei, Wonkwang University, Division of Mechanical and Automotive Engineering, Iksan, Jonbuk 570-749, South Korea

---Phased array transducers are being widely used for ultrasonic inspection of defects in austenitic welds. Some of the attractive features of phased arrays include electronic focusing and steering capabilities. However, these features cannot be accurately obtained because of generally unknown inhomogeneous and anisotropic nature of weld metal. Nonplanar surface geometries of butt welds can cause additional difficulty in conventional phased array focusing. The time reversal focusing technique provides an alternative method since this does not require a prior knowledge about the properties and structures of the media and the transducer. In this work, we employ the time reversal technique for array beam focusing on a defect(s) in a typical austenitic weld structure. Using the finite element simulation results, we demonstrate these concepts and show that time reversal focusing provides a better focusing behavior.
Session 9
8:30 AM  Assessment of the Performance of Different EMAT Configurations for Shear Horizontal and Torsional Waves  
---R. Ribichini, F. Cegla, and P. Cawley, Imperial College London, Mechanical Engineering, Exhibition Road, London SW7 2AZ, United Kingdom; P. B. Nagy, University of Cincinnati, Aerospace Engineering & Engineering Mechanics, Cincinnati, OH 45221-5038

8:50 AM  FE Modeling of Ultrasonic NDT of EMAT Phenomena to Detect Cracks in Ferromagnetic Materials  
---N. N. Kishore and H. Sahu, Indian Institute of Technology, Kanpur 20816, India; T. H. Aditya, General Electric Co., Bangaluru, India

---D. Premel, C. Reboud, S. Chatillon, and S. Mahaut, CEA, LIST, F-91191, Gif-sur-Yvette, France

9:30 AM  Boundary Element Approach for Simulation of Electromagnetic Acoustic Transducer  
---S. Hirose and T. Saitoh, Tokyo Institute of Technology, Department of Mechanical and Environmental Informatics, Meguro-ku, Tokyo, Japan

---Y. Qin, D. Xiang, Y. Yang, and F. Li, Intelligent Automation Inc., 15400 Calhoun Drive, Suite 400, Rockville, MD 20855

10:10 AM  Lunch

10:30 AM  Guided Wave Mode Control With Annular Array Transducers  

10:50 AM  Pulsed Arrays: A New Method of Flaw Detection by Generating a Frequency Dependent Angle of Propagation  
---S. J. Hill and S. M. Dixon, University of Warwick, Department of Physics, Coventry, CV4 7AL, United Kingdom

11:10 AM  Larger Amplitude Ultrasonic Measurement System Using Laminated Transducer and Multi-Channel Pulsar  
---T. Mihara, Graduate School of Engineering, University of Toyama, Toyama, Japan; Y. Kamiyama, Graduate School of Engineering, University of Toyama, Toyama, Japan; Y. Udagawa, ISL Co. Ltd.

11:30 AM  Size Effects of PZT Elements on Ultrasonic Testing  
---Z. Li, K. Gong, and Y. Liu, Peking University, Department of Mechanics & Engineering Science, 5 Yiheyuan Road, Haidian District, Beijing, 100871 China

11:50 AM  High Temperature Thickness Measurements Using a Bismuth Titanate Piezoelectric Transducers  
---S. E. Burrows, K. L. McAughey, R. S. Edwards, and S. M. Dixon, University of Warwick, Department of Physics, Coventry, United Kingdom

12:10 PM  Lunch
Assessment of the Performance of Different EMAT Configurations for Shear Horizontal and Torsional Waves
---Remo Ribichini, Frederic Cegla, and Peter Cawley, Imperial College London, Mechanical Engineering, Exhibition Road, London SW7 2AZ, United Kingdom; Peter B. Nagy, University of Cincinnati, Aerospace Engineering & Engineering Mechanics, Cincinnati, OH 45221-5038

---Guided wave inspection is an established technique for the rapid screening of large structures. The fundamental shear horizontal (SH0) wave-mode in plates and the torsional mode T(0,1) in pipe-like structures are especially useful due to their non-dispersive character. Electromagnetic Acoustic Transducers (EMATs) based on either the Lorentz force or magnetostriction can be used to generate guided waves. Different EMAT configurations can be employed, the most common being Lorentz force Periodic Permanent Magnet (PPM) and magnetostrictive EMATs, directly applied on the sample or with a bonded strip of highly magnetostrictive material on the structure. This work compares the performance of these solutions on steel plates. A Finite Element model has been used to assess the performance of the different configurations and the predictions have been validated with experimental tests. The analysis shows that magnetostrictive EMATs directly applied on steel plates have comparatively poor performance, dependent on the precise magneto-mechanical properties of the testpiece. Large signal amplitudes can be achieved when a layer of highly magnetostrictive material is attached on the structure, but this compromises the non-contact nature of the transducer. PPM EMATs generate intermediate wave amplitudes while being non-contact and insensitive to the variations in properties seen across typical steels.

FE Modeling of Ultrasonic NDT of EMAT Phenomena to Detect Cracks in Ferromagnetic Materials
---N. N. Kishore and Hemant Sahu, Indian Institute of Technology, Kanpur 20816, India; T. H. Aditya, General Electric Co., Banguluru, India

---Electromagnetic Acoustic Transduction (EMAT) is a versatile technique which can generate elastic stress pulses inside a pre-magnetized metallic specimen, in the presence of a dynamic magnetic field. This facilitates the generation of ultrasonic waves, for the purpose of Non Destructive Testing. The non-contact nature of EMAT technique makes it capable of high speed inspection and high temperature operation. The versatility of the technique is due to its capability of producing waves with any polarization direction, viz., P-, SV or SH-modes. The objective of this work is to present a complete EMAT model right from wave generation in the specimen to the voltage response of a waveform reflected from a possible defect (crack), so that the model can be used in non-destructive testing. In the present work, Finite element algorithms have been developed to solve 2D model of both ideal (conductors with zero area of cross-section) and practical (conductors with finite area of cross-section) EMAT. In the first stage, FE form of the governing equations is solved to find the magnetic vector potential (MVP) and later, simulation of the ultrasonic SH wave generation through the corresponding FE model is taken up. This is followed by modeling of the receiving mechanism, which is capable of including the effects of the current densities (viz Lorentz, Magnetization and Magnetostriction), through which voltage response is obtained. And finally this model is applied to a variety of defective specimens for the purpose of finding position, orientations and size of different kinds of defects.
Simulation of the Inspection of Planar Non-Magnetic Materials With Electro-Magnetic Acoustic Transducers
---Denis Prémel, C. Reboud, S. Chatillon, and S. Mahaut, CEA, LIST, F-91191, Gif-sur-Yvette, France

---EMATs (ElectroMagnetic Acoustic Transducers) constitute an alternative to standard piezoelectric probes, for generating and receiving ultrasonic waves. Such probes use the combination of a static magnetic field and induced electrical currents due to permanent magnets and winding coils, respectively. For non-magnetic materials, the main source of elastic waves is the Lorentz force, generated close to the component surface. Major advantages of EMATs are the absence of coupling medium and the possibility to generate surface or bulk waves with arbitrary polarity and orientation, by changing the orientation of the magnets and the coils. However, these probes show a poor sensitivity as receivers. In order to optimize the design of EMATs, CEA-LIST has developed simulation tools, based on semi-analytical models dedicated to eddy current and ultrasonic testing, in order to predict signals obtained when inspecting a planar non-magnetic piece. First, induced currents due to the coils are computed in time domain and a recently developed module calculates the static magnetic field due to the magnets. Then, the Lorentz force distribution is used as an input for the simulation of ultrasonic bulk waves and flaw interaction in the piece. This communication presents different applications and experimental validations for bulk waves inside conductive materials.

Boundary Element Approach for Simulation of Electromagnetic Acoustic Transducer
---Sohichi Hirose and Takahiro Saitoh, Tokyo Institute of Technology, Department of Mechanical and Environmental Informatics, Meguro-ku, Tokyo, Japan

---EMAT (Electromagnetic Acoustic Transducer) is a nondestructive testing technology, in which ultrasonic waves are transmitted and received in a non-contact manner for electrically conductive or magnetic materials. To improve the performance of EMATs, modeling and analysis of electromagnetic and elastodynamic fields are necessary. In this paper, a time-domain BEM analysis is developed for electromagnetic acoustic waves generated by the Lorentz type EMAT. Time convolution integrals in the BEM are evaluated by the convolution quadrature method, which makes numerical solutions stable. Some numerical examples for 2D and 3D problems are presented to show the efficiency of the proposed method.
A Miniaturized Electromagnetic Acoustic Transducer for Impact Acoustic Wave Detection
---Yexian Qin, Dan Xiang, Yubing Yang, and Fang Li, Intelligent Automation Inc., 15400 Calhoun Dr. Suite 400, Rockville, MD 20855

---A miniaturized electromagnetic acoustic transducer (EMAT) is developed for impact acoustic wave detection. In this new sensor design, two Neodymium Iron Boron (NdFeB) permanent magnets are used to provide high magnetic field and make the EMAT to be compact in size (13×5×5 mm3). The effect of a sensor’s geometry on its frequency response was numerically analyzed for determining the size of EMAT during the sensor design. Miniaturized EMAT sensors were constructed and tested for detection of impact acoustic waves in aluminum plates of different thicknesses. To validate the experimental results of the EMAT sensor, impact acoustic waves generated by a small dropping ball have been analytically calculated. The experimental results show good agreement with the analytical ones. An application of this EMAT sensor for kissing bond inspection is presented.

Guided Wave Mode Control With Annular Array Transducers
---Jaya Koduru and Joseph Rose, Pennsylvania State University, Department of Engineering Science and Mechanics, State College, PA; Jaya Koduru, Mistras Group Inc, Princeton Junction, NJ 08536

---Ultrasonic guided waves are fast emerging as a reliable tool for continuous structural health monitoring (SHM). Their multi-modal nature along with their long range propagation characteristics offer several possibilities for interrogating structures. However, the presence of several modes in a structure at any frequency complicates the analysis and is often desired to have a single guided wave mode in the structure. Earlier attempts at guided wave mode control involved developing linear and annular array comb/IDT transducers. However, these transducers are limited to a particular wavelength and a change in wavelength necessitates a change in the transducer. In this paper we propose the development of an actuator which can generate omni-directional guided waves with mode control. A simplified actuator model to approximate the transducer behavior is studied using a constant pressure loading assumption of the array elements. Using optimization techniques the amplitude and time delays needed to maximize a desired mode while suppressing the others is computed. Theoretical computations are experimentally validated on an aluminum structure with a four element annular array transducer.
**Pulsed Arrays: A New Method of Flaw Detection by Generating a Frequency Dependent Angle of Propagation**
---S. J. Hill and S. M. Dixon, University of Warwick, Department of Physics, Coventry, CV4 7AL United Kingdom

---A new method of using an array of generation sources, pulsed simultaneously to generate a wavefront with a frequency dependent angle of propagation has been developed. If a pulsed array is used to generate a wave with a frequency dependent angle of propagation, the angle at which the wave was launched can be identified by measuring the frequency of the detected wave. In an isotropic material this means that it is possible use a second transducer to locate the position of the scatterer, whereas with a conventional single element generator method, it can only be located onto an ellipse. In addition to an increased scan speed, the resolution of detection should also be improved. A theoretical framework is put forward to explain how the wavefront is created from the superposition of the waves from the individual elements, and how the frequency varies along the wavefront. Finite element models and experimental measurements were also carried out, and both agree with the analytic model. This method will have applications within NDE, but also possibly for sonar and radar techniques.

**Larger Amplitude Ultrasonic Measurement System Using Laminated Transducer and Multi-Channel Pulsar**
---Tsuyoshi Mihara, Graduate School of Engineering, University of Toyama, Toyama, Japan; Yoshinori Kamiyama, Graduate School of Engineering, University of Toyama, Toyama, Japan; Yoshio Udagawa, ISL Co. Ltd.

---High efficient acoustic transducer has been required for several industrial fields because a signal to noise ratio and the applicable limitation can be also improved. Especially in the detection of crack tip and accurate sizing of crack in highly scattered materials, in the nonlinear ultrasonic measurement for industrial crack structures and in the measurement of high attenuated composite structures, higher S/N ratio have been always required. In this study, we focused on the laminated piezoelectric element as the ultrasonic transducer which has been used as an acoustic actuator. However, the laminated transducer has a severe limitation to improve the acoustic efficiency because the increase of the number of laminate element causes the decrease of the electric impedance. To improve this problem, we combined the laminated PZT elements transducer to the multiple ultrasonic palsar. Thus, we developed the new ultrasonic measurement system consists of a laminated PZT elements transducer and a new eight-channel pulsar. Some demonstrations about the availability of the developed transducer and a measurement system were investigated.
Size Effects of PZT Elements on Ultrasonic Testing
---Zheng Li, Kezhuang Gong, and Yu Liu, Peking University, Department of Mechanics & Engineering Science, 5 Yiheyuan Rd., Haidian District, Beijing, 100871 China (PRC)

---PZT (Lead Zirconate Titanate) elements are widely used as an actuator or a sensor of ultrasonic waves in ultrasonic testing. The effects of a PZT sensor’s length and an actuator’s driving frequency on the ultrasonic testing are investigated in terms of the wave velocity measurement of Al coupons in this paper. Both experiments and numerical simulation are conducted and theoretical analysis is also performed to reveal the mechanism of the length effect. Two sets of PZT sensors with different lengths are considered and the half-cycle sinusoidal tone bursts with different driving frequencies are used to drive the PZT actuator. Three signal processing techniques including a direct time-domain method, the Morlet wavelet transform and the cross-correlation analysis (CCA) are introduced to calculate the wave velocity and their effectiveness is also discussed. Results show that as the length of the PZT sensor increases, the wave velocity decreases and its error becomes larger. Also, the wave velocity becomes smaller with the increasing driving frequency of the actuator.

High Temperature Thickness Measurements Using A Bismuth Titanate Piezoelectric Transducer
---Susan E. Burrows, Kevin L. McAughey, Rachel S. Edwards, and Steve M. Dixon, University of Warwick, Department of Physics, Coventry, United Kingdom

---Bismuth titanate Bi4Ti3O12 was prepared through a sol-gel process, characterized and built as a high temperature ultrasound transducer. Platinum electrodes and wires were used throughout for high temperature stability and Pyrogel 100 used as couplant. The piezoelectric coefficient was found to be stable up to 550ºC. Repeatable thickness measurements were made up to 250ºC on aluminium test samples using a pulse-echo technique, and the efficiency of the transducer studied under thermal cycling.
NOTE: Student posters are to be displayed in the Mt. Mansfield Room Monday, July 18th, from 3:00 to 6:00 p.m. for evening judging ONLY—not for public display. For Monday’s judging, no identification (author names, institutional names, etc.) should be shown on the posters in order to preserve anonymity during the closed judging period. The posters will be open for public viewing with author and institutional titles during the regular Poster Session 10 on Tuesday, July 19th, from 1:30-3:10 p.m. For more details on the student poster competition, please see the “Conference Guide” document (page 14) on the QNDE web site at: http://www.qndeprograms.org.

- Quantification of Precipitates and Their Effects on the Response of Nickel-Base Superalloy to Shot Peening
- Model Assisted Development of a Laminography Inspection System
- Reconstruction of Internal Velocity Distributions for Defect Characterization at High Temperature
- Improving the Reliability of Automated Nondestructive Inspection
- Analysis of Rayleigh Wave Interactions for Surface Crack Characterization
- Non-Destructive Evaluation of Highway Structures in Service Affected by Alkali-Silica Reaction
- Application of Mellin Transform Features for Robust Ultrasonic Guided Wave Structural Health Monitoring
- Experimental Characterization of Creep Damage Using the Nonlinearity Ultrasonic Technique
- Finite Element Simulation of Crack Depth Measurement Using Diffuse Ultrasound in Concrete
- Characterization of Fatigue Damage in A36 Steel Specimens Using Nonlinear Rayleigh Surface Waves
- Crack Depth Measurement in Concrete Using Diffuse Ultrasound
- Quantification of Surface Wetting in Plate-Like Structures Via Guided Waves
- Implementation of 2D Computational Models for NDE on GPU
- A Multiple Angle Material Parameter Extraction Method for Stacked Layers of Dielectrics Using THz Time Domain Spectroscopy
- Modal Preference of Cumulative Second Harmonic Generation in Lamb Waves
- Air-Coupled Impact-Echo Test Using a Parabolic Reflector with the Microphone
- Simulation of Air-Coupled Zero-Group Velocity Lamb Modes
- A Study on Issues Relating to Testing of Soils and pavements by Surface Wave Methods
- An Ultrasonic Guided Wave Method to Estimate Applied Biaxial Loads
- Load-Differential Features for Automated Detection of Fatigue Cracks Using Guided Waves
- Further Study of Coupling Materials in Sonic Infrared Imaging NDE on Aluminum Samples

3:10 PM Break
Tuesday, July 19, 2011

SESSION 10 – POSTERS

UT MODELING AND APPLICATIONS, MATERIALS AND STRUCTURES,
AND ADHESIVE BONDS

Mount Mansfield Room

1:30 PM

UT Modeling and Applications

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

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

The Effect of Crack Morphology on Ultrasonic Response
---R. A. Roberts, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

Acoustic Field Computation of Ultrasonic Phased Array Based on Space Impulse Response
---L. Wang, C. Xu, D. Xiao, and S. Li, Beijing Institute of Technology, School of Mechanical Engineering, Beijing, P. R. China

A General Kirchhoff Approximation for Echo Simulation in Ultrasonic NDT
---V. Dorval, S. Chatillon, M. Darmon, and S. Mahaut, CEA, LIST, F-91191, Gif-sur-Yvette, France

Materials and Structures

Characterization of Microcracking in Concrete Using Diffuse Ultrasound
---P. Shokouhi and E. Niederleithinger, BAM Federal Institute for Material Research and Testing, Unter den Eichen 87, Berlin, Germany (Please note: this poster will be presented by J. Prager.)

Detecting Vertical Cracks in Concrete Pavement by Means of Surface Waves
---G. Saghaee, M. Karray, and P. Rivard, Universite de Sherbrooke, Department of Civil Engineering, 2500 Boulevard Universite, Sherbrooke, Quebec, J1K 2R1, Canada

Delamination Boundary Identification Using Impact Echo Multisensor Data Fusion for Concrete Structures
---Y. Zhang and X. Wei, Georgia Institute of Technology, School of Electrical and Computer Engineering, Atlanta, GA 30332; X. Dai and J. Zhu, University of Texas at Austin, Department of Civil, Architectural and Environmental Engineering, Austin, TX; F. A. Fetra and N. Gucunski, Rutgers University, Department of Civil and Environmental Engineering, Piscataway, NJ 08901
Using NDT Response of Multichannel Analysis of Surface Wave (MASW) to Characterize Near Surface Damage in Concrete Structures
---V. Shahsavari, G. Ballivy, J. Rhazi, K. Saleh, and B. Piwakowski, Department of Civil Engineering, University of Sherbrooke, Canada

Impedance Measurement of the Carbon Steel Corrosion Materials Using Pulsed Eddy Current (PEC)

Nonlinear Elastic Behavior of Sub-Critically Damaged Body Armor Panels
---J. Fisher and D. E. Chimenti, Iowa State University, Center for NDE, Ames, IA 50011

Components of Variation in NDE of Riveted Aluminum Aerostructures – A 30 Year Retrospective
---L. Schaefer, 925 W. Baseline Road, Suite 105-F8, Tempe, AZ 85283

Limitations of Symmetry in FE Modeling: A Comparison of FEM and Air-Coupled Resonance Imaging
---R. A. Livings and V. Dayal, Iowa State University, Department of Aerospace Engineering, Ames, IA 50011; D. J. Barnard and D. K. Hsu, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

Adhesive Bonds

Proof Testing of Adhesive Bonding of Composites by Laser Shockwave
---M. Perton, A. Blouin, and J.-P. Monchalin, National Research Council Canada, Industrial Materials Institute, Boucherville, Quebec, Canada; J. Barroeta, Robles Carleton University, Ottawa, Ontario, Canada; J. M. Sands, Army Research Laboratory, Composite and Hybrid Materials Branch, Weapons and Materials Division, Aberdeen, MD; R. Cole and A. Johnston, National Research Council Canada, Institute for Aerospace Research, Ottawa, Ontario, Canada

Evaluation of Adhesive Properties on Nano-Scaled Thin Film by Ultrasonic-AFM
---T. S. Park, D. R. Kwak, I. K. Park, C. Miyasaka, and T. S. Park, Seoul National University of Science and Technology, Department of Mechanical Engineering, 172 Gongreung 2-dong, Nowon-gu, Seoul, 139-743, Korea

Characterization of an Epoxy Bonded Aluminium Alloy Sample Applying Dynamic Acousto-Elastic Testing
---C. Larocca, J. Moysan, and C. Payan, Laboratoire de Caracterisation Nondestructive, Universite de la Mediterranee, Aix en Provence, France

3:10 PM Break
Quantification of Precipitates and their Effects on the Response of Nickel-Base Superalloy to Shot Peening

---This paper reports on a microstructural study of a nickel-base superalloy, Inconel 718, with a focus on quantifying precipitate density and their effects on conductivity variations. The study is motivated by eddy current (EC) characterization of residual stresses, where observed EC signals are attempted to correlate with stress profiles on shot peened superalloy surfaces. It has been observed that the correlation is less universal than anticipated, and in fact strongly influenced by the material hardness, or the aging conditions. For example, the soft sample surface exhibits significantly stronger EC signals than the fully hardened sample when both are shot peened at the same Almen intensity. Thus, the objective of the present study is to examine this complex material response against aging and shot peening treatments at the microstructure scale, by the use of techniques such as Transmission Electron Microscopy (TEM) and Scanning Electron Microscopy (SEM). We will describe preparations of a series of Inconel 718 samples aged and shot peened at various conditions, and present microstructural data obtained from SEM and TEM images, such as depth dependences of precipitate densities, correlated with bulk properties such as the hardness and conductivity.---This material is based upon work supported in part by the Air Force Research Laboratory under contract # FA8650-04-C-5228 at Iowa State University Center for NDE.

Model Assisted Development of a Laminography Inspection System

---Traditional computed tomography (CT) is an efficient method of determining the internal structure of an object through non-destructive means; however, inspection of certain objects, such as those with planar geometries or with limited access, requires an alternate approach. An alternative is laminography and has been the focus of a number of researchers in the past decade for both medical and industrial inspections. Many research efforts rely on geometrically-simple analytical models, such as the Shepp-Logan phantom, for the development of their algorithms. Recent work at the Center for Non-Destructive Evaluation makes extensive use of a forward model, XRSIM, to study artifacts arising from the reconstruction method, the effects of complex geometries and known issues such as high density features on the laminography reconstruction process. The use of a model provides full knowledge of all aspects of the geometry and provides a means to quantitatively evaluate the impact of methods designed to reduce artifacts generated by the reconstruction methods or that are result of the part geometry. We will present comparisons to experimental data and to traditional CT reconstruction algorithms illustrating the use of forward simulations to quantitatively assess reconstruction algorithm development and artifact reduction.
Reconstruction of Internal Velocity Distributions for Defect Characterization at High Temperature

---Exposure to hydrogen in high temperature environments can cause damage accumulation in structural steels, particularly in the chemical and petrochemical industries. The interaction mechanisms are complex and varied; however, a common type of damage is hydrogen attack which occurs in carbon and low alloy steels at high temperature and pressure. It manifests itself by the appearance of small methane voids in the steel which cause a slight reduction in ultrasonic velocity. A potential method to monitor the degradation would therefore be to measure this change in ultrasonic velocity. This paper aims to demonstrate the feasibility of this by means of monitoring very small ultrasonic velocity changes in the underlying material. The spatial velocity changes are introduced by local heating of the material. An array of ultrasonic waveguides capable of withstanding temperatures in excess of 600°C was used to acquire the signals, and a two dimensional Algebraic Reconstruction Technique (ART) based on the time of flight of each backwall reflection was then used to reconstruct a velocity map within the heated (damaged) material. The results from the reconstruction of the temperature distribution within the test specimen give an indication of the inspection sensitivity that could be expected from such a method.

Improving the Reliability of Automated Non-Destructive Inspection

---In industrial NDE it is increasingly common for data acquisition to be automated, driving a recent multiple increase in the availability of data. The collected data need to be analyzed and currently this is largely done manually by a skilled operator - a rather painstaking task given that much of data contains no indications. There is therefore scope for the inspection reliability to be improved while reducing the time taken for the data analysis through partial automation. This optimizes the use of the operator’s time by using all the available experimental data, in conjunction with an understanding of the physics of the inspection, to prioritize regions of interest. The project output is a software system general enough to fit a wide array of NDE applications. Nonetheless, the work so far has focused on two specific examples of automatic NDE: the ultrasonic inspection of power station rotor bores and the ultrasonic immersion inspection of aerospace titanium turbine discs. The research incorporates elements of image-processing, machine vision, optimization, information theory, as well as of course the theory of ultrasonic NDE. The poster presented outlines the work completed to date in the development of the software, along with some results from testing.
**Analysis of Rayleigh Wave Interactions for Surface Crack Characterization**

---We present a non-contact ultrasonic technique for more fully characterizing surface cracks in metals, through combining measurements of the Rayleigh wave velocity in the in-plane and out-of-plane directions using electromagnetic acoustic transducers (EMATs). Through understanding the interaction of the Rayleigh wave with a surface-breaking defect, one can measure both the vertical depth and the inclination of the defect to the surface. The ability to determine these crack characteristics is very beneficial in NDT measurements, giving the ability to more fully assess the type of a crack and its severity when compared to previous work, which considered only defects inclined normal to the surface. At close proximity to a crack, the Rayleigh wave signal is enhanced significantly due to the interference of incident Rayleigh wave with reflected and mode-converted waves from the crack. This enhancement was previously reported to be larger in the in-plane than the out-of-plane motion for cracks inclined normal to the surface. In view of full characterization of surface cracks, we extend this study to inclined cracks of various depths, using EMATs to generate and detect ultrasonic signals. The detection EMATs have been optimized to be sensitive to primarily either in-plane or out-of-plane velocity, and are kept at fixed separation and scanned along the sample. Time-domain signals are put through a number of analysis techniques to see the effects of the interaction of Rayleigh wave and defect and to understand the enhancement behavior for each component. The wave behavior is also modeled using commercial finite element method software. The viability of these measurements for full characterization of surface cracks will be discussed.

**Non-Destructive Evaluation of Highway Structures in Service Affected by Alkali-Silica Reaction**

---Alkali-silica reaction (ASR) is a widespread problem affecting concrete structures all over the world. Although we now know the mechanism of the reaction and mitigation procedures, little is known regarding how far advanced the problem is on existing structures or if it is even affected. Thus, it is important to be able to diagnose the problem, evaluate the extent of damages and to monitor changes to evaluate mitigation interventions without affecting structural integrity. Many non-destructive techniques exist but they haven’t been proven efficient for on-site investigation. The Auscultation and Instrumentation Research Group (GRAI) from Université de Sherbrooke has been testing a few of them on structures in service to determine the efficiency, the accuracy and the optimal parameters for their use on-site. The results should be analyzed and gathered in a methodological guide to be part of an inspection protocol for structures affected by ASR.
Application of Mellin Transform Features for Robust Ultrasonic Guided Wave Structural Health Monitoring

---In the design of structural health monitoring systems, the use of guided wave ultrasonic techniques has become popular due to their capability for detecting damage over long distances. However, guided wave-based systems are sensitive to environmental and operational conditions. This leads to false-positive results for most conventional detection methods. In this paper, we investigate the capabilities of the Mellin transform (MT) for detecting damage under variable environmental conditions. The MT is chosen due to its unique relationships with scaling operations and wave velocity. In an experiment, we measured guided waves between two permanently attached piezoelectric transducers across a steel pipe under continuously varying pressure. To simulate damage, we placed a mass scatterer on the pipe. From the measurements, we extracted MT related features and used machine learning algorithms to classify when the mass was on the pipe. Our results demonstrate the MT features to detect, on average, the mass with a 91.7% accuracy while similar Fourier transform features detect it with only a 68.9% accuracy. We also discuss how the MT achieves robustness against variations in wave velocity and how this relates to the effects of many environmental conditions, such as pressurization.

Experimental Characterization of Creep Damage Using the Nonlinearity Ultrasonic Technique

---Previous research has shown that the acoustic nonlinearity parameter beta is a reliable, ultrasonically measurable parameter to track and quantify the state of damage in different metallic materials. One way to measure beta is to employ one-dimensional longitudinal waves in the through-transmission mode. While this technique has demonstrated its feasibility for accurately measuring the acoustic nonlinearity, it is also very sensitive to unwanted nonlinearities introduced by other extraneous sources. This research develops an experimental procedure to measure the absolute acoustic nonlinearity parameter and applies the technique to quantify creep damage in specimens. Measurement results show a clear correlation between the level of creep damage and the acoustic nonlinearity.
Finite Element Simulation of Crack Depth Measurement Using Diffuse Ultrasound in Concrete

---This research simulates the measurement of the depth of surface breaking cracks in a concrete slab using diffuse ultrasound. The major objectives of the numerical simulations are to find optimal parameters in the experimental setup including source-receiver distance and operating frequency and to investigate the effects of irregular crack shapes and the presence of rebars under the crack tip. A two dimensional finite element model for a crack with varying depth in a concrete slab is developed using a commercial finite element code (ANSYS). The diffuse material properties of the concrete are obtained from experiments on uncracked concrete slabs. The model is validated by comparing numerical diffuse energy evolution curves with those from experiments. Possible errors in the measured crack depth due to non-perpendicular, partially closed cracks and rebars that can act as additional scatterers, are analyzed from the numerical simulations.

Characterization of Fatigue Damage in A36 Steel Specimens Using Nonlinear Rayleigh Surface Waves

---This research characterizes damage in A36 steel (a typical material for steel bridges) specimens caused by low cycle fatigue using nonlinear Rayleigh surface waves. Fatigue damage produces the increased acoustic nonlinearity that leads to the generation of measurable higher harmonics in the initially monochromatic Rayleigh wave signals. Four specimens are used for the low cycle fatigue tests in the tension-tension mode with a constant stress amplitude. The fatigue tests are interrupted at different numbers of cycles for the nonlinear ultrasonic measurements. Tone burst Rayleigh wave signals are generated and detected using a pair of wedge transducers. The amplitudes of the first and second order harmonics are measured at varying propagation distances to obtain the nonlinearity parameter for a given damage state. The experimental results show a large increase of acoustic nonlinearity in early stage of fatigue life. This acoustic nonlinearity is also measured for samples undergoing quasi static tensile tests, where different amounts of quasi static axial loads are applied to a specimen. The results from the fatigue tests and quasi static tensile tests are compared. These results demonstrate the initial feasibility to use the present technique for quantitative inspection of steel bridge components.
Crack Depth Measurement in Concrete Using Diffuse Ultrasound

---Surface breaking cracks can significantly reduce the load bearing capability of a concrete structure. The first step to evaluate serviceability of an in-field concrete structure is to have accurate information on existing crack damage. It is thus of paramount importance to be able to accurately determine the depth of cracks in these concrete structures. This research employs a non-traditional, diffusive ultrasonic technique to measure the depth of surface cracks in concrete. Ultrasonic measurements on a 10x13x24 inch concrete block containing an artificial crack with varying depth from 1 to 4 inches are conducted. Contact transducers with one transmitting and the other receiving the ultrasonic signals, are mounted on the concrete surface on opposite sides of the crack. A tone burst signal in frequency range from 400 to 500 kHz is generated. In this frequency regime, wavelengths are sufficiently short (comparable with aggregate size) so that a diffuse ultrasonic signal is detected. The arrival of the diffuse ultrasonic energy at the receiver is delayed by the existence of the crack. Diffusivity decreases as the crack depth increases at all frequencies of interest. This lag-time and the diffusivity are measured and a finite element model is used to solve the inverse problem to determine crack depth from these measured diffuse ultrasonic parameters. Results show that maximum errors in this laboratory setup are less than 10%.

Quantification of Surface Wetting in Plate-like Structures via Guided Waves

---Ultrasonic guided waves provide a convenient and reliable method for inspection of large structural areas using a sparse array of surface-mounted transducers. However, structural health monitoring (SHM) with guided waves can be problematic because variable operational conditions can significantly affect the measured ultrasonic signals. Although homogeneous temperature variations have been well-researched and successful compensation algorithms developed, few studies have considered variable surface wetting. This paper reports results from an experimental investigation of the effects of surface wetting on guided wave signals recorded from a spatially distributed array affixed to a stiffened aluminum plate. Droplets of water are applied to the plate in a random and increasing manner until more than ten percent of the plate is wet, and the percent surface area covered at each increment of wetting is independently measured via digital photographs of the plate surface. Ultrasonic guided wave signals resulting from a broadband chirp excitation are recorded from all transducer pairs in between increments of wetting. Frequency-dependent features are calculated from these signals to investigate which combinations of features and transducer pairs are most effective at quantifying the degree of surface wetting. This study is a first step in the process of assessing and compensating for the effects of surface wetting on the performance of a guided wave SHM system.
Implementation of 2D Computational Models for NDE on GPU

---Computational models are very valuable in Non-Destructive Evaluation to solve the forward problem, which in turn enable optimization of sensor/system design and operation. Finite element (FE) models have proved to provide accurate prediction of sensor measurements for variety of defect mechanisms. The FE modeling method has some special properties in that the derived stiffness matrix is sparse, has low storage requirement and well suited for iterative solvers. However, the computational time to solve such systems can still be prohibitive. In recent years there has been increased interest in Graphics Processing Unit (GPU) hardware since they have introduced IEEE floating point compliance and the number of operations per second is faster than that of many multi-core systems. This paper presents an attempt to implement a simulation model for electromagnetic NDE on a GPU. A sample electromagnetic NDE problem is examined and the solution is computed on both CPU and GPU. Different solution methods (biCG and CG ), matrix storage formats and matrix-vector computational strategies will be investigated. Analysis of the storage requirements for the matrix on the GPU is tabulated and a full-timing breakdown of the process will be presented and discussed.

A Multiple Angle Material Parameter Extraction Method for Stacked Layers of Dielectrics Using THz Time Domain Spectroscopy

---Characterization of stacked dielectric layers has been one of the challenging problems in nondestructive evaluation (NDE). Solution techniques to this problem will be beneficial in characterizing complex composite structures. Immediate application areas include pharmaceutical drugs, bio-imaging, structural health monitoring of civil structures and electronic packages. The Terahertz (THz) spectral range (0.3-10THz) is one of the least explored regions of the electromagnetic spectrum. In NDE, THz has many advantages. Its small wavelengths as compared to microwave NDE imaging techniques result in the ability to detect finer defects. Many materials have rich spectral content in this spectral region which lends to identifying materials with high specificity. THz radiation is non-ionizing and is thus safer to use in medical applications as opposed to X-ray imaging. Implementation of THz in the characterization of multi-stacked layers will be of significant importance. This paper proposes a method that utilizes different incidence angle transmission measurements through multi-stacked dielectrics in order to characterize the dielectric properties of each of the layers. The number of measurements is dependent on the number of dielectrics in a stack. Both theoretical models and experimental results will be presented. Key factors that will be investigated include number of stacked layers, thicknesses of individual layers, different dielectric materials, and incident angles.
Modal Preference of Cumulative Second Harmonic Generation in Lamb Waves

---While the simultaneous phase and group velocity matching has been established as the necessary condition for the cumulative second harmonic generation in Lamb waves, there have been disagreements in different theoretical and experimental results, particularly on the symmetry of the second harmonic waves. Previous theoretical results show that only symmetric second harmonic modes can be cumulative; an experiment reports a cumulative propagation of an anti-symmetric second harmonic mode. This research experimentally investigates the symmetry properties of the second harmonic Lamb wave mode. Two Lamb mode pairs (a1-a2, a2-a4) and one symmetric mode pair (s1-s2) at the longitudinal velocity are evaluated under the same condition (material and experimental setup). Tone burst signals from a high power gated amplifier are fed to a wedge transducer to generate a specific Lamb wave mode in aluminum plates. Detected signals are then processed using the continuous wavelet transform (CWT) to extract the amplitude of the second harmonic mode. Results show that all considered modes grow with the propagation distance but their accumulation rates (apparent nonlinear parameters) differ by orders of magnitude.

Air-Coupled Impact-Echo Test Using a Parabolic Reflector with the Microphone

---The Impact-echo testing is a common nondestructive evaluation technique for concrete plate structures in civil engineering. The recent development of the air-coupled Impact-Echo (ACIE) method introduces the possibility for rapidly scanning large areas and increases the practicality of in-situ measurements. However, sensors used in the ACIE tests are susceptible to ambient noise and direct acoustic waves, which complicates in-situ ACIE measurements. This research focuses on the results of ACIE measurements taken using a parabolic reflector together with the standard measurement microphones to increase the signal to noise ratio for ACIE measurements. The effects of sensor location with respect to impact location are discussed.
Simulation of Air-Coupled Zero-Group Velocity Lamb Modes

---The impact-echo test is a commonly used nondestructive test (NDT) method in civil engineering to determine thickness and locate defects in concrete structures. The key of this method is the measurement of the zero-group-velocity (ZGV) S1 Lamb mode. The measured frequency of this mode is then correlated to the plate thickness. This symmetric Lamb mode with a group velocity of zero traps energy in a local area of the plate, and radiates acoustic waves in air. The radiated acoustic waves have the same frequency as in the solid plate, and propagate in the direction almost normal to the plate surface, which can be measured by an air-coupled sensor. Therefore, in this study, air-coupled sensing is proposed to detect the ZGV S1 mode, as a solution to rapid NDT scanning of large concrete structures. This study employs finite element analysis to investigate the wave field in the air caused by an impact point force on a solid plate. The simulation results successfully capture the behavior of the air-concrete slab system and visualize the pressure field in air. This study validates the feasibility of using of the air-coupled sensing technology to perform the impact-echo method.

A Study on Issues Relating to Testing of Soils and Pavements by Surface Wave Methods

---A study on the differences between testing soils and pavements using surface wave methods is presented. Both applications are based on the geometric dispersion of surface waves in layered media. The stiffness of soil typically increases with depth while that of pavement decreases with depth, and the resulting wave propagation phenomena in the two material types thus gives rise to significant differences between their dispersion curves, as can be observed from experimental and theoretical dispersion results. The differences in theoretical dispersion curves are illustrated using the transfer matrix method and the stiffness matrix method for soils and pavements, respectively. The Levenberg-Marquardt method and the simulated annealing method are applied for inversion and their relative merits and differences are discussed. The relevant frequency ranges of dispersion curves are studied with consideration to attenuation of waves with depth and resolution as a function of wavelength and layer thickness. The goal of this study is to offer insight into the selection of appropriate surface wave methods for soils and pavements, and to improve the accuracy and uniqueness of testing results.
An Ultrasonic Guided Wave Method to Estimate Applied Biaxial Loads

---Guided wave propagation in a homogeneous plate is known to be sensitive to both temperature changes and applied stress variations. Previous work regarding homogeneous biaxial stresses has focused on the forward problem, showing that dispersion of Lamb waves depends upon both the direction of propagation and the stress tensor. Here we consider the inverse problem of recovering loading information from measured changes in phase velocity at multiple propagation directions using a single mode at a specific frequency. These changes depend upon both the magnitude and orientation of the principle stresses. Although there is no closed form solution, prior numerical results indicate that phase velocity changes exhibit a sinusoidal angular dependence. Here it is shown that all coefficients can be estimated from a single uniaxial loading experiment. The general inverse problem for homogeneous biaxial stresses can thus be solved by fitting an appropriate sinusoid to the phase velocity versus angle data and relating the coefficients to the unknown stress components. The phase velocity data are obtained from time shifts of direct arrivals between elements of a sparse array of guided wave sensors whose direct paths of propagation are oriented at different angles. This method is applied to experimental data recorded during a fatigue test, and the additional complication of the resulting fatigue cracks interfering with some of the direct arrivals is addressed via an outlier analysis. Results from multiple experiments show that applied stresses can be successfully recovered from the measured changes in guided wave signals.

Load-Differential Features for Automated Detection of Fatigue Cracks using Guided Waves

---Guided wave structural health monitoring (SHM) is being used to assess the integrity of platelike structures for aerospace, civil and mechanical applications. Prior research has investigated how guided wave propagation is affected by applied loads, which induce anisotropic changes in both dimensions and phase velocity. In addition, it is well-known that applied tensile loads open fatigue cracks and thus enhance their detectability using ultrasonic methods. Here we introduce a class of load-differential methods in which signals recorded from different loads at the same damage state are compared without using previously obtained damage-free data. Changes in both transducer pair-wise signals and delay-and-sum images are considered as a function of differential loads. Load-differential features are extracted from these signals and images that capture the effects of loading as fatigue cracks are opened. Damage detection thresholds are adaptively set based upon the load-differential behavior of the various features, which enables implementation of an automated fatigue crack detection process. The efficacy of the proposed approach is examined using data from fatigue tests performed on aluminum plate specimens that are instrumented with a sparse array of surface-mounted ultrasonic guided wave transducers.
Further Study of Coupling Materials in Sonic Infrared Imaging NDE on Aluminum Samples

---Sonic Infrared (IR) Imaging has been proving as a very promising NDE technology even though it has not been around for very long. This technology uses acoustic/ultrasound excitation externally and infrared imaging to identify defects in materials. Coupling materials are typically employed between the sound transducer and a target. It has been talked by this research group that this coupling have shown importance in SonicIR. We have learned that coupling materials affect the vibration and heating in cracks. Systematic study has been done quantitatively by the authors over some selected coupling materials through experimental study on aluminum samples. We will present our results in this presentation.
UT Modeling and Applications

Plate Wave Transmission/Reflection at Arbitrarily Shaped Obstructions
---R. A. Roberts, Iowa State University, Center for NDE, Applied Sciences Complex II, 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 problem is posed as multiple semi-infinite plates attached together by a joining body of arbitrary shape. A boundary integral formulation of the scattering problem is applied to the joining body, over which a traction free boundary condition is specified on surfaces not attached to the adjoining plates. Over the surfaces to which the plates are attached, tractions and displacements are related through impedance relations computed for the adjoining plates. Application of established numerical integral equation methods leads to a determination of motions on the plate edges, from which transmission and reflection coefficients are obtained using the far-field form of the corresponding infinite plate Green function. The canonical calculation considers plane wave incidence at arbitrary angle of incidence. Responses for other incident field geometries (e.g. point source) are obtained through a Fourier integral in spatial frequency. Results will be presented showing the transmission and reflection characteristics of various geometric features of interest.

Resonant Guided Wave Scattering at an Anisotropic Layer Delamination
---R. A. Roberts, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames IA 50011

---This paper reports on a study of guided wave scattering at 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. Computational results reveal a substantial drop in transmission (with a corresponding increase in reflection) of the lowest order guided mode at frequencies corresponding to resonant motions of the delaminated section. In addition to detecting the delamination, this observation raises the possibility of gauging its size by noting the frequency at which the resonance occurs.
UT Modeling and Applications

The Effect of Crack Morphology on Ultrasonic Response
---R. A. Roberts, Iowa State University, Center for NDE, Ames IA 50011

---Work is reported on a numerical study of the effect of crack face roughness on ultrasonic response. The mean and variance of pulse-echo scattering amplitudes are compiled by examining scattering from ensembles of cracks displaying random surface profiles, where roughness is parameterized by peak-to-valley height and correlation length. A goal of the work is to establish limits of validity of approximate scattering theories (e.g. Kirchhoff) when applied to cracks displaying a complicated morphology. To this end, work compares exact and approximate computational solutions to the integral equation scattering formulation for the two-dimensional scattering problem, thereby enabling comparison at large crack dimensions (~6 wavelengths in length), at which a corresponding three dimensional study would be computationally prohibitive. Results display the dependence of response amplitude mean and variance on crack length, response bandwidth, angle of incidence, wave mode type, roughness height, and roughness correlation length.---This work was performed at the Center for NDE at Iowa State University with funding from the Air Force Research Laboratory through S&K Technologies, Inc., on delivery order number 5007-IOWA-001 of the prime contract F09650-00-D-0018.

UT Modeling and Applications

Acoustic Field Computation of Ultrasonic Phased Array Based on Space Impulse Response
---Lijiu Wang, Chenguang Xu, Dingguo Xiao, and Shuang Li, Beijing Institute of Technology, School of Mechanical Engineering, Beijing, P.R. China

---The Spatial Impulse Response theoretical expressions of transmitting aperture for simple element was studied and transmitting acoustic field of that was calculated by using space impulse response method. According to Huygens' theory, non-focusing and focusing transmitting acoustic field were calculated and phased focusing theory was validated. The results show that the function of single channel and multi-channels transmission can be achieved with the method and the distributed condition of transmitting acoustic field can be attained accurately. It provides a theoretical reference for analyzing the characteristic of phased array transducer.
UT Modeling and Applications

A General Kirchhoff Approximation for Echo Simulation in Ultrasonic NDT
---Vincent Dorval, Sylvain Chatillon, Michel Darmon, and Steve Mahaut, CEA, LIST, F-91191, Gif-sur-Yvette, France

---The CIVA simulation platform, developed at CEA-LIST, includes a module dedicated to the computation of defect responses in ultrasonic nondestructive testing. The Kirchhoff approximation is often used for the modeling of such echoes. It consists in separating the flaw surface into an illuminated face and a shaded face. Then the field on the illuminated face is obtained by locally approximating the surface by an infinite plane and applying geometrical acoustics. The field on the shaded face is assumed to be zero. A model based on this approximation is used in CIVA to compute crack and backwall echoes. In its current version, it is limited to free surfaces and requires an isotropization when dealing with anisotropic materials. A new model using a more general formalism has been developed. It is based on reciprocity principles and is valid for any host and flaw materials (liquid, isotropic, and anisotropic solid). Experimental validations confirm that this new model can be used for a wider range of applications than the previous one.

UT Modeling and Applications

High Temperature Ultrasonic EMAT Measurements
---Susan E. Burrows, University of Warwick, Department of Physics, Gibbet Hill Road, Coventry, CV4 7AL, United Kingdom

---High temperature ultrasonic measurement techniques for defect detection and monitoring of plant and components are presented. A watercooled electromagnetic acoustic transducer (EMAT) is used in conjunction with a NdYAG laser to make thickness measurements, the laser generating ultrasound and the EMAT acting as detector. Thickness measurements in mild steel are also performed using a pulsed electromagnet EMAT. This is capable of operating at 300C for long term usage or 600C for short periods.
**UT Modeling and Applications**

**Measurement of Elastic Moduli of a Thin Metallic Foil with EMAT Generated Lamb Waves**
---Dong Jin Lee, Bongyoung Ahn, and Seung Hyun Cho, Korea Research Institute of Standards and Science, Center for Safety Measurement, Daejeon, Korea; Dong Jin Lee and Younho Cho, Pusan National University, School of Mechanical Engineering, 30, Jangjeon, Geumjeong, Busan 609-735, Korea; Gang Won Jang, Sejong University, Faculty of Mechanical and Aerospace Engineering, 98, Gunja-dong, Gwangjin-Gu, Seoul, 143-747, Korea

---Guided wave can be applied to measure some mechanical properties of a structure since its dispersion characteristics depend on the geometry and material properties. Several studies have been reported on the elastic moduli measurement of a thin plate with Lamb waves. In this work, EMAT generated Lamb waves are considered to measure the elastic moduli of a thin metallic foil. This method presents a convenient and practical alternative since the EMAT enables the noncontact and non-couplant transduction of Lamb waves. A testing apparatus using an embedded magnet and precisely positioned patterned coils was setup to lessen the systematic uncertainties. Then, the Young's modulus and shear modulus were calculated by the sensitivity based optimization algorithm from the measured group velocities.

**Materials and Structures**

**Characterization of Microcracking in Concrete using Diffuse Ultrasound**
---Parisa Shokouhi and Ernst Niederleithinger, BAM Federal Institute for Material Research and Testing, Unter den Eichen 87, Berlin, Germany (Please note this poster will be presented by J. Prager.)

---Diffuse ultrasonic measurements are used to quantify and characterize stress-induced volumetric microcracking in concrete specimens. The test specimens were subjected to stepwise uniaxial compression. At each step, the loading was held constant and a series of ultrasonic measurements parallel and perpendicular to the loading were obtained. Unusually long signals were recorded, so that the diffuse ultrasonic regime could be studied. Diffuse or incoherent ultrasound consists of ultrasonic energy beyond the coherent field. In the diffuse regime, the measured ultrasonic response is a superposition of reflections from scatters within concrete. Therefore, the diffusion of ultrasound in concrete is greatly affected by concrete microstructure including microcracks. The parameters governing the diffusion of ultrasound in concrete (i.e., diffusivity, dissipation and transport mean free path) at each loading step were calculated and the evolution of these parameters with the increasing load was investigated. Using Coda Wave Interferometry (CWI), the corresponding changes in the velocity of diffuse ultrasonic waves were also monitored. The changes in the diffusion parameters and the velocities were used to assert the state of microcracking at various load levels.
Detecting Vertical Cracks in Concrete Pavement by Means of Surface Waves
---Gholamreza Saghaee, Mourad Karray, and Patrice Rivard, Université de Sherbrooke, Department of Civil Engineering, 2500 boul. Université, Sherbrooke, Québec J1K 2R1, Canada

---Cracks are one of the most common problems in the concrete elements from both a structural and material points of view. These cracks may be related to various damaging processes such as structural loads, chemical and physical phenomena. Having access to only one surface of concrete element (such as pavement) reduces the efficiency of conventional ultrasonic pulse velocity (UPV) tests. Some surface wave methods have been developed but they require the use of a series of sensors, which makes the technique quite time-consuming. In this article, detection of cracks in the concrete slabs by means of surface waves was investigated in order to find the new possibilities in crack detection procedure with a limited number of sensors. Numerical and experimental study was performed on concrete slab. 2D numerical modeling was done by means of finite difference code; FLAC. In the experimental part, a concrete slab containing artificial cracks was tested. The test configuration included accelerometers, amplifiers, computer and data acquisition software. The data obtained from the numerical simulation and laboratory tests were analyzed by means of MATLAB. The results showed that using the power spectra and average power energy of the signals is a suitable method to detect cracks location in concrete even in cases where the cracks are not open-surface.

Delamination Boundary Identification Using Impact Echo Multisensor Data Fusion for Concrete Structures
---Ying Zhang and Xiangmin Wei, Georgia Institute of Technology, School of Electrical and Computer Engineering, Atlanta, GA 30332; Xiaowei Dai and Jinying Zhu, University of Texas at Austin, Department of Civil, Architectural and Environmental Engineering, Austin, TX; Farhad A. Fetrat and Nenad Gucunski, Rutgers University, Department of Civil and Environmental Engineering, Piscataway, NJ 08901

---Impact echo has been widely used as a nondestructive evaluation method for concrete delamination detection. Impact echo is a point-wise detection method. The frequency spectrum of measured surface motion at a testing point, which results from a short-duration mechanical impact nearby, provides the depth of reflector beneath the testing point. However, in actual measurements, the surface motion of a testing point above sound concrete also includes responses of internal delamination if it is close to the defect region. That makes it a challenge to accurately determine delamination boundaries. In this paper, a multi-sensor data fusion approach is proposed to locate delamination boundaries using impact echo. Numerical simulation of a concrete slab with an artificial delamination is conducted to derive the fusion rules. The spatial distribution of surface motion resulting from mechanical impacts applied at different locations is analyzed. The variations of relative amplitudes of reflected P-wave from the delamination and the concrete slab bottom with source and receiver locations show some interesting patterns that can be used to accurately locate delamination boundaries and depth. A multi-sensor data fusion process is developed based on these observations. The data fusion process is further verified using experimental data.
Using NDT Response of Multichannel Analysis of Surface Wave (MASW) to Characterize Near Surface Damage in Concrete Structures
---Vahid Shahsavari, Gérard Ballivy, Jamal Rhazi, Kaveh Saleh, and Bogdan Piwakowski, University of Sherbrooke 2500, Department of Civil Engineering, de l’Université, Sherbrooke (Québec), Canada J1K 2R1

---Nowadays, many environmental and climatic factors such as weathering actions, temperature variation, chemical attacks, abrasion and other degradation processes can cause near surface damage (0.1 m to 0.5 m) to most concrete structures exposed to severe environmental conditions. As such, the spread of such damage and, subsequently, the loss of mechanical properties of materials are very progressive in long term. The main purpose of MASW (Multichannel Analysis of Surface Waves) method is to characterize near surface damage in concrete structures as a nondestructive testing procedure, to estimate the thickness of layers and determine shear-wave velocity profiles Vs needed for evaluating the properties of subsurface rigidity. The originality of this research is the application of MASW for the evaluation of near surface damage in concrete structures. Indeed, major applications of this method are concerning geotechnical applications. Experiments has been conducted on three large volume of concrete slabs (3 m, 3.50 m and 0.80 m) with different typical simulated near surface pathologies in order to test the accuracy of MASW method. The results demonstrate that the proposed MASW method is a high potential non-destructive evaluation method which can be easily used to detect and localize near surface damage in concrete structures.

Impedance Measurement of the Carbon Steel Corrosion Materials Using Pulsed Eddy Current (PEC)
---Dong-Man Suh*, Kunjang College, Dept. of NDT, Gunsan, Conbuk, Korea; Kwan-Seob Jang and Hong-Geun Lee, Sae-an Corp., Seoul, Korea; *Raynar Co., Ltd. Daejon, Korea

---Although the conventional eddy current testing is a powerful method to detect flaws of tube in online processing. But it is difficult to measure the deep depth differences of the testing materials, because eddy current density has changed its magnitude with distance from the surface. The pulsed eddy current system is enveloped to control a depth difference and submitted the multi-pointing method to select criteria which could be obtained depth differences by the period of resistivity on the pulsed eddy current transient signals. In this paper, we used the pulsed eddy current technique to improve the capability of depth difference measurement and studied multi-pointing method to evaluate the thickness with variation of resistivity. The present paper relates to a defect impedance measurement using a pulsed eddy current (PEC). The PEC signals were stored with a program for time-sharing and displaying the PEC signal on a graph, which processes a resultant value to be displayed. A display unit connected to the measurement unit, that displays the resultant value being output from the measurement unit, and an input unit connected to the measurement unit, that sets a phase (a value selected from an arbitrary location by time-sharing the measured PEC signal), frequency (a frequency value of the input PEC signal) and gain (a time axis range of the reflected PEC signal) of the PEC signal irradiated to the object. So, in this study, we have investigated performance of pulsed eddy current testing method by measuring impedance variation of fabricate of specimens. From the investigation results, pulsed eddy current test can be one of corrosion detect for inspection of corrosion by impedance plane. Thus, we apply pulsed eddy current testing method inspecting the corrosion under insulation. And then the investigation results obtained from mock-up specimens by one inch thickness with 10% resolution.
Materials and Structures

**Nonlinear Elastic Behavior of Sub-Critically Damaged Body Armor Panels**
---Jason Fisher and D. E. Chimenti, Iowa State University, Center for NDE, Ames, IA 50011

---A simple go/no-go test for body armor panels using pressure-sensitive, dye-indicator (PSD) film has been shown to be statistically effective in revealing subcritical damage to the armor. Previous measurements have shown that static indicator levels are accurately reproduced in dynamic loading events. Further impact tests on armor worn by a human resuscitation dummy using instrumented masses with an attached accelerometer and embedded force transducer have been performed and analyzed. New impact tests have shown a reliable correlation between PSD film indication (as digitized images) and impact force for a wide range of impactor energies and masses. Numerical evaluation of digital PSD images is presented and correlated with impact parameters. Relationships between impactor mass and energy, and corresponding measured force are shown. We will also report on comparisons between ballistic testing performed on panels damaged under various impact conditions and tests performed on undamaged panels.---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.

Materials and Structures

**Components of Variation in NDE of Riveted Aluminum Aerostructures - A 30 Year Retrospective**
---Lloyd Schaefer, 925 W. Baseline Road, Suite 105-F8, Tempe, AZ 85283

---In-service health monitoring of riveted Aluminum Fuselage & Wing structures has been a vital component of continued air-worthiness validation for both civilian and military aircraft around the world. The characteristics & variation of acute and chronic modes of degradation, as well as the NDE sensing strategies applied to detect them, are complex and have undergone considerable development over the past 3 decades. Often times, as we have seen in recent early failures beyond visual damage tolerance assumptions, we are challenged to understand, in a modular way, the reliability of applied NDE. This paper conducts a literature review of the technologies, modeling, and reliability assessments deployed for the inspection of riveted Aluminum aircraft structure. From this review we will attempt to understand how well this segment of NDT is working, and what trends are occurring.
Materials and Structures

Limitations of Symmetry in FE Modeling: A Comparison of FEM and Air-Coupled Resonance Imaging
---Richard A. Livings and Vinay Dayal, Iowa State University, Department of Aerospace Engineering, Ames, IA 50011, Dan J. Barnard and Dave K. Hsu, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---It has long been an accepted practice to use symmetry in Finite Element Modeling. Whenever modeling a large structure, we turn to symmetry in order to significantly reduce the model size and computation time. But is symmetry always the solution to long computation times, and is it always accurate? This study is aimed at modeling a whole ceramic tile and several possible symmetric models under several different loading cases and comparing them to each other and Air-Coupled Ultrasonic scans to determine if the Finite Element Models can accurately predict the vibrational resonance patterns. The reason for the accuracy or inaccuracy will also be examined. The understanding of the limitations of using symmetry to model large structures will be very useful in all future modeling.

Adhesive Bonds

Proof Testing of Adhesive Bonding of Composites by Laser Shockwave
---Mathieu Perton, Alain Blouin, and Jean-Pierre Monchalin, National Research Council Canada, Industrial Materials Institute, Boucherville, Quebec, Canada; Julieta Barroeta, Robles Carleton University, Ottawa, Ontario, Canada; James M. Sands, Army Research Laboratory, Composite and Hybrid Materials Branch, Weapons and Materials Division, Aberdeen, MD; Rick Cole and Andrew Johnston, National Research Council Canada, Institute for Aerospace Research, Ottawa, Ontario, Canada

---Adhesive bonding, particularly of composite laminates, presents many practical advantages when compared to other joining methods but its use is limited, particularly in aircraft structures, since there is presently no nondestructive inspection technique to ensure the quality of the bond. We are developing a technique based on the generation of high amplitude compression ultrasonic waves by a powerful laser under water confinement. These waves are converted into tensile waves by reflection from the assembly back surface. The resulting tensile forces can be made strong enough to cause a delamination inside the laminate or a disbond. Bond strength can be evaluated by increasing the laser pulse energy until disbond. A good bond is unaffected by a certain level of stress whereas a weaker one is damaged. The method can be made to be completely noninvasive throughout the whole composite assembly. The sample back surface velocity is measured by an optical interferometer and used to estimate stress history inside the sample. The depth and size of disbonds are revealed after testing by laser-ultrasonics. Experimental results confirmed by numerical simulations show that the proposed method is able to differentiate weak bonds from strong bonds and to quantitatively evaluate bond strength.
Evaluation of Adhesive Properties on Nano-Scaled thin film by Ultrasonic-AFM
---Tae Sung Park, Dong Ryul Kwak, Ik Keun Park, Chiaki Miyasaka, and Tae Sung Park, Seoul National University of Science and Technology, Department of Mechanical Engineering, 172 Gongreung 2-dong, Nowon-gu, Seoul, 139-743 Korea

---In recent years, as nano scale structured thin film technology has emerged in various fields such as the materials, biomedical and the quantitative nondestructive adhesion evaluation of thin film has become an important issue in terms of the longevity and durability. In this study, Adhesive properties on nano-scaled thin film was evaluated by ultrasonic AFM. We are fabricated the nano-scaled thin film with different adhesive condition as process control. The contact resonance frequency variation is measured by UAFM. And we visualize the amplitude and phase images for adhesive condition. We can confirm that the contact resonance frequency is decreased as increasing the adhesion strength. Consequently, the contact resonance frequency, amplitude and phase images could be useful to evaluate the adhesive condition and visualize the nano scaled flaws in nano structured thin film system.

Characterization of an Epoxy Bonded Aluminium Alloy Sample Applying Dynamic Acousto-Elastic Testing
---Christine Larocca, Joseph Moysan, and Cédric Payan, Laboratoire de Caractérisation Non Destructive, Université de la Méditerranée, Aix en Provence, France

---This paper is aimed at studying the potentialities to discern a change in the nonlinear signature of an aluminium/epoxy interface, then to examining if that could be associated with a particular behavior type (adhesive/cohesive). We have developed a specific experimental approach to assess the nonlinearity of the interface using an aluminium patch bonded on a beam. A high frequency ultrasonic pulse is superimposed to a low frequency vibration. The change in the HF pulse reflexion coefficient is evaluated as a function of the LF vibration amplitude, and then one can extract the nonlinear behavior of the bonded joint. The results are interpreted as regards with micrographics of the epoxy joint after having the patch removed.
Session 11
Tuesday, July 19, 2011

SESSION 11
TERAHERTZ AND MICROWAVE NDE
H. Ringermacher, Chairperson
Jost Foundation Room

3:30 PM  Spectral and Spatial Nondestructive Examination of Dielectric Materials with THz – Time Domain Spectroscopy
---J. Beckmann, D. Fratzscher, L. S. von Chrzanowski, and U. Ewert, Federal Institute of Materials Research and Testing, Division 8.3 Radiological Methods, Berlin, Germany

3:50 PM  Terahertz Sizing of Discontinuity
---C.-P. T. Chiou, D. K. Hsu, and D. J. Barnard, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

4:10 PM  Terahertz Computed Tomography of NASA Thermal Protection System Materials
---D. J. Roth¹, S. Reyes-Rodriguez², D. A. Zimdars³, R. W. Rauser⁴, and W. W. Ussery⁵, ¹NASA Glenn Research Center, Cleveland, OH 44135; ²Michigan State University, East Lansing, MI 48824; ³Picometrix, LLC, 2925 Boardwalk Drive, Ann Arbor, MI 48104; ⁴University of Toledo, Toledo, OH 43606-3390; ⁵Lockheed Martin Space Systems Company, Denver, CO 80201

4:30 PM  On Resolution Design Constraints in Synthetic or Real Aperture Microwave Imaging
---J. T. Case, M. T. Ghasr, 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

4:50 PM  Simultaneous Evaluation of Multiple Key Material Properties of Complex Stratified Structures with Large Spatial Extent
---M. Fallahpour, H. Kajbaf, M. T. Ghasr, and R. Zoughi, Missouri University of Science and Technology (S&T), Electrical and Computer Engineering Department, Applied Microwave Nondestructive Testing Laboratory (amntl), Rolla, MO 65409

5:10 PM  Quantitative Material Characterization Using Near-Field Microwave Measurements and SAR Processing
---M. T. Ghasr, J. T. Case, and R. Zoughi, Missouri University of Science and Technology, (S&T), Electrical and Computer Engineering Department, Applied Microwave Nondestructive Testing Laboratory (amntl), 140 Emerson Electric Co. Hall, 301 W. 16th Street, Rolla, MO 65409
Spectral and Spatial Nondestructive Examination of Dielectric Materials with THz - Time Domain Spectroscopy
---Joerg Beckmann, Daniel Fratzscher, Lars S. von Chrzanowski, and Uwe Ewert, Federal Institute of Materials Research and Testing, Division 8.3 Radiological Methods, Berlin, Germany
---Time domain spectroscopy can measure time of flight (ToF) as well as the shape of an electromagnetic pulse. THz based methods were developed for characterization of bottles filled with unknown liquids in the German project “Handheld”. The THz pulse reflection was used for instance for the measurement of the concentration of ethanol in water. The reliability of the method was evaluated by a probability of detection (POD) trial. The POD study was performed with the T-ray 2000 system operating with a pulse range of 0.5 to 2 THz for different dielectric container materials. ToF measurements of THz pulses were also performed for nondestructive test of non-metallic objects with different inherent structures of imperfections. The ToF of the reflected pulses were recorded during the object scan, stored on the computer and visualized as a two dimensional B-scan image. Each test sample shows a characteristic B scan image due to existing differences of location, shape and sizes of imperfections inside the object. The images were improved by a synthetic aperture refocusing technique (SAFT) and converted to tomograms for visualization of the different shape and sizes of discontinuities of the selected objects.

Terahertz Sizing of Discontinuity
---Chien-Ping T. Chiou, David K. Hsu, and Dan J. Barnard, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011
---In recent year, terahertz radiation (a.k.a. T-ray) has emerged as a powerful NDE technique. As seen in many T-ray C-scan images, a low-intensity “ring” outline, resulted from signal phase cancellation, appears around the boundary of discontinuity. The presence of such ring outline provides a unique “finger print” for T-ray in detecting discontinuity such as delamination. In this work, several inversion schemes were studied for further determining the thickness of discontinuity by taking advantage of the “ring” feature. The feasibility of these schemes was validated experimentally with a special “hidden delamination” embedded in fiber-glass composites, in which a smaller saw cut (delamination) was shadowed by a larger one above. T-ray has also shown great potential in assessing the conditions of thin coating like paints. We discuss extension of the inversion schemes and other considerations for this application.
Terahertz Computed Tomography of NASA Thermal Protection System Materials
---D. J. Roth1, S. Reyes-Rodriguez2, D. A. Zimdars3, R.W. Rauser4, and W. W. Ussery5,
1NASA Glenn Research Center, Cleveland, OH 44135; 2Michigan State University, East Lansing, MI 48824; 3Picometrix, LLC, 2925 Boardwalk Dr., Ann Arbor, MI 48104; 4University of Toledo, Toledo, OH 43606-3390; 5Lockheed Martin Space Systems Company, Denver, CO 80201

---A terahertz axial computed tomography system has been developed that uses time domain measurements in order to form cross-sectional image slices and three dimensional volume renderings of terahertz-transparent materials. The system can inspect samples as large as 0.0283 m³ (1 ft³) with no safety concerns as for x-ray computed tomography. In this study, the system is evaluated for its ability to detect and characterize flat bottom holes, drilled holes, and embedded voids in foam materials utilized as thermal protection on the external fuel tanks for the Space Shuttle. X-ray micro-computed tomography was also performed on the samples to compare against the terahertz computed tomography results and better define embedded voids. Limits of detectability based on depth and size for the samples used in this study are loosely defined. Image sharpness and morphology characterization ability for terahertz computed tomography are qualitatively described.

On Resolution Design Constraints in Synthetic or Real Aperture Microwave Imaging
---Joseph T. Case, M. Tayeb Ghasr, 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

---Microwave nondestructive evaluation (NDE) techniques combined with synthetic aperture radar (SAR) have already been shown to be useful and robust when performing wide band imaging of samples and materials including: spray-on-foam-insulation (SOFI) on the fuselage of the space shuttle, rebar in concrete, the detection of contraband for airport security, and more. To optimize such a system to perform the previously mentioned tasks, the designer must pick the optimal sampling step size to measure the field reflected from the specimen under test. The sampling step size applies to real or synthetic apertures. In the literature, the optimal sampling step size has been repeatedly reported as equal to the resolution. The resolution is dependent upon distance between the target and the aperture, aperture dimensions, and antenna beamwidth. However, sampling at the resolution has been previously shown to obtain only a wider resolution than desired. A simple derivation of the optimal sampling step size to obtain a desired resolution will be presented. Design curves including distance of the target to the aperture, aperture dimensions, and antenna beamwidth are also presented that quantify image quality for sampled data according to the metrics of root mean squared (RMS) error and percent resolution widening for a given sampling step size.
Simultaneous Evaluation of Multiple Key Material Properties of Complex Stratified Structures with Large Spatial Extent
---Mojtaba Fallahpour, Hamed Kajbaf, Mohammad Tayeb Ghasr, and Reza Zoughi, Missouri University of Science and Technology (S&T), Electrical and Computer Engineering Department, Applied Microwave Nondestructive Testing Laboratory (amntl), Rolla, MO 65409

---Measured complex reflection coefficient of a spatially extended stratified composite structure, using an open-ended waveguide, can be effectively used to extract key material and geometrical characteristics of a given layer. This is accomplished using a combination of an electromagnetic model and corresponding measurement data. Previously, it was shown that one parameter can be extracted if all others are known. However, practically is desirable to extract as many pieces of information as possible. To this end the model must be “inverted”. However, there is no closed form solution for the inverse problem. Consequently, we introduce two methods, namely; genetic algorithm (GA), and neural networks (NN) to simultaneously extract several pieces of information about the structure. The former approach uses an optimizer, which defines key unknowns and uses an analytical approach to estimate reflection coefficients, and a cost-function that must be minimized. The latter approach employs the forward model to train NN. The trained NN is then capable of estimating the unknown parameters over the frequency band. This paper presents these approaches along with several experimental results. Information such as thickness and dielectric properties of a layer in a stratified structure is shown to be extracted concurrently.

Quantitative Material Characterization Using Near-Field Microwave Measurements and SAR Processing
---Mohammad T. Ghasr, Joseph T. Case, and Reza Zoughi, Missouri University of Science and Technology, Electrical and Computer Engineering Department, Applied Microwave Nondestructive Testing Laboratory, 140 Emerson Electric Co. Hall, 301 W. 16th Street, Rolla, MO 65409

---Microwave near-field nondestructive evaluation (NDE) techniques when coupled with complete forward electromagnetic models provide effective tools for quantitative material characterization. Promising results have been achieved for characterizing multilayered dielectric media similar to those found in composite structures such as aircraft radomes. However, in all of these cases the modeling is based on the material having an infinitely-extended spatial extent parallel to the aperture of the antenna. However, for many practical applications this may not be the case, resulting in evaluation inaccuracies. This paper presents a method in which a 3-D synthetic aperture radar (SAR) algorithm and its inverse is utilized to extract complex reflection coefficient information from the sample while masking unwanted edge effects caused by the finite spatial extent of the sample. The extracted reflection coefficient will be similar to that of an infinitely-extended sample due to the inherent properties of the SAR algorithm. This extracted reflection coefficient may then be directly used with a previously-developed electromagnetic model to estimate material properties. The efficacy of this method will be verified using numerical simulation as well as experimental verification of the results using several samples.
Tuesday, July 19, 2011

SESSION 12
PROCESS CONTROL NDE
L. Brasche, Chairperson
Mildred Livak Ballroom

3:30 PM  New Concepts for Process Monitoring of Critical Aero Engine Component Manufacture
---D. Veselovac, Chair of Manufacturing Technology, WZL – Laboratory for Machine Tools and Production Engineering, RWTH Aachen – Aachen University of Technology, Department of Monitoring and EDM/ECM, Aachen, Germany

4:10 PM  Automatic Tracking of the Weld Line in Radiographic Images
---R. Sikora and P. Baniukiewicz, West Pomeranian University of Technology, Faculty of Electrical Engineering, Sikorskiego 37, 70313 Szczecin, Poland

4:30 PM  In-Die Ultrasonic and Off-Line Air-Coupled Monitoring and Characterization Techniques for Drug Tablets
---J. D. Stephens, B. R. Kowalczyk, and C. Cetinkaya, Clarkson University, Department of Mechanical and Aeronautical Engineering, Potsdam, NY 13699; B. C. Hancock and G. Kaul, Pfizer Inc., MS 8156-006, Eastern Point Road, Groton, CT 06340; I. Akseli, Boehringer Ingelheim, GmbH, 900 Ridgebury Road, Ridgefield, CT 06877-1058

4:50 PM  Ultrasonic Measurements of Polyimide Materials During Heating
---R. T. Ko², C. W. Lee², T. Storage¹, and M. Y. Chen¹, ¹Air Force Research Laboratory, Wright-Patterson Air Force Base, OH 45433; ²University of Dayton Research Institute, 300 College Park, Dayton, OH 45469
New Concepts for Process Monitoring of Critical Aero Engine Component Manufacture

---Drazen Veselovac, Chair of Manufacturing Technology, WZL - Laboratory for Machine Tools and Production Engineering, RWTH Aachen - Aachen University of Technology, Department of Monitoring and EDM/ECM, Aachen, Germany

Manufacturing of critical rotating aero engine components is becoming more and more a sensitive sequence within the production of compressor and turbine parts of aero engines. Due to high temperature resistive alloys, such as new powder metallurgical nickel alloys, manufacturing process are getting critical even if they are designed to work on a very robust level. Anomalies like excessive thermal and mechanical load in the subsurface layers of the machined surfaces, are critical areas of highly stressed components, which can cause a fatal failure of these components and thus the loss of an engine. To ensure a high quality and security level of these manufacturing processes, special monitoring techniques and systems have to be developed, in order to recognize anomalies in rotating aero engine components already during their manufacturing sequence. This paper presents recent results of an ongoing FAA funded project in collaboration with nearly all US and European aero engine manufacturers, where new process monitoring techniques are developed. Main focus of this work is set on broaching and drilling operation during the manufacture of critical aero engine components made of nickel based alloys. The most recent developments and results from laboratory as well as production testing facilities will be shown and discussed. Furthermore, possible future system designs of monitoring systems will be presented, which can lead to a so called “in-process inspection” strategy for the manufacture of the most critical aero engine components.

Automatic Tracking of the Weld Line in Radiographic Images

---Ryszard Sikora and Piotr Baniukiewicz, West Pomeranian University of Technology, Faculty of Electrical Engineering, Sikorskiego 37, 70313 Szczecin, Poland

Radiography is an important part of modern non-destructive testing. Fast and accurate x-ray converters that have been developed recently open up new possibilities for x-ray applications and make this technique more flexible than ever before. Digital radiography combines modern digital image processing algorithms with the traditional x-ray testing method. The importance of computerized systems that support or even superseding of radiologist, such as automatic radiogram analysis systems or automatic defect recognition systems, is still growing. In this work we present advanced algorithms for automatic segmentation of radiographic images of welded joints. The goal of segmentation of a radiogram is to change and simplify representation of the image into a form that is more meaningful and easier to analyze automatically. It opens possibilities to use targeted tools working on selected regions of interest. Here, we focus on detection of weld lines in real radiograms in presence of high-intensive disturbances originating from various technological objects commonly located in the radiograms (lead letters, marks, etc.). Moreover, various shapes of the weld line have been also investigated. Apart from the straight butt-welds, which are the easiest case, presented algorithm is able to detect and track skewed, bent and crossed welds as well. Extracted welds are passed for further analysis to algorithms aimed at detection of defects.
In-Die Ultrasonic and Off-line Air-Coupled Monitoring and Characterization Techniques for Drug Tablets
---James D. Stephens, Brian R. Kowalczyk, and Cetin Cetinkaya, Clarkson University, Department of Mechanical and Aeronautical Engineering, Potsdam, NY 13699, Bruno C. Hancock and Goldi Kaul, Pfizer Inc., MS 8156-006, Eastern Point Road, Groton, CT 06340; Ilgaz Akseli, Boehringer Ingelheim, GmbH, 900 Ridgebury Road, Ridgefield, CT 06877-1058

---Mechanical properties and defects of drug tablets may seriously affect their therapeutic functions. An embedded ultrasound monitoring system for tablet mechanical property monitoring during compaction and a non-contact/non-destructive air-coupled technique for determining the mechanical properties of coated drug tablets are presented. In the compaction monitoring system, the change of ToF and the reflection coefficient for the upper-punch surface interface as a function of compaction pressure has been studied. It is found that ToF in the compact increases with compaction force. The reflection coefficient also decreases with force above a certain threshold. In the air-coupled measurement approach, air-coupled excitation and laser interferometric detection are utilized and their effectiveness in characterizing the mechanical properties of a drug tablet by examining its vibrational resonance frequencies is demonstrated. The tablet is vibrated via an acoustic field of an air-coupled transducer in a frequency range sufficiently high to excite its several vibrational modes. An iterative computational procedure based on the finite element method is developed to extract the mechanical properties of the coated tablet from a subset of its measured resonance frequencies. The mechanical properties measured by this technique are compared to those obtained by a contact ultrasonic measurement method. A good agreement is found.

Ultrasonic Measurements of Polyimide Materials During Heating
---R. T. Ko2, C.W. Lee2, T. Storage1, and M. Y. Chen1, 1Air Force Research Laboratory, Wright-Patterson Air Force Base, OH 45433; 2University of Dayton Research Institute, 300 College Park, Dayton, OH 45469

---Innovative ultrasonic delay lines are being applied on polyimide neat resin for the detection of bubble formation during heating. These delay lines have certain advantageous characteristics that can enhance the detection of bubbles during the heating process of materials over the conventional curing sensors. A transition point in ultrasonic velocity during heating, which signifies the formation of bubbles, has been experimentally verified in water first and then in polyimide neat resin.
SESSION 13

NDE FOR MATERIALS – STEELS
C. Lo and N. Kishore, Co-Chairpersons
Terrill 108

3:30 PM  Micro- and Nanostructure Imaging and Characterization of Advanced Steels
---L. Batista and U. Rabe, Saarland University, Chair of Nondestructive Testing and Quality Assurance, Saarbrucken, Germany; U. Rabe and S. Hirsekorn, Fraunhofer Institute for Nondestructive Testing (IZFP), Campus E3.1, 66123, Saarbrucken, Germany

3:50 PM  Evaluation of Isothermal Aged 12Cr Steel Using Electromagnetic Acoustic Resonance

4:10 PM  Evaluation of Isothermal Aged 304H Austenitic Stainless Steel Using Ultrasound
---H.-H. Kim, H.-J. Kim, S.-J. Song, B.-J. Kim, and B.-S. Lim, School of Mechanical Engineering, Sungkyunkwan University, Suwon, Korea

4:30 PM  Core Loss Analyses of Grain-Oriented Electrical Steel Using Flux-Controlled Magnetic Barkhausen Noise Measurements
---A. A. Samimi and L. Clapham, Applied Magnetics Group, Department of Physics, Queen's University, Kingston, Ontario, K7L 3N6, Canada; T. W. Krause, Department of Physics, Royal Military College of Canada, Kingston, Ontario, Canada

4:50 PM  Acoustic Emission During Tensile Deformation of M250 Grade Maraging Steel

5:10 PM  Effects of Copper Precipitation on the Magnetic Properties of Aged Copper-Containing Ferrous Alloys
---C. C. H. Lo, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011
Micro- and Nanostructure Imaging and Characterization of Advanced Steels
---Leonardo Batista and Ute Rabe, Saarland University, Chair of Nondestructive Testing and Quality Assurance, Saarbrücken, Germany; Ute Rabe and Sigrun Hirsekorn, Fraunhofer Institute for Nondestructive Testing (IZFP), Campus E3.1, 66123 Saarbrücken, Germany

---New design concepts for the construction of advanced light-weight and crash resistant transportation systems require the development of high strength and supra-ductile steels with enhanced energy absorption and reduced specific weight. TWIP (Twinning Induced Plasticity) steels have excellent mechanical properties combining high strength levels with a large uniform elongation. This is a direct consequence of intensive mechanical twinning resulting in a high sustained degree of strain-hardening. The mechanisms and the related microstructures are, however, not well understood. In order to image the microstructure and probe local material properties, EBSD (Electron Backscattering Diffraction) and AFAM (Atomic Force Acoustic Microscopy) as well as TEM (Transmission Electron Microscopy) studies are combined. Cementite (Fe3C) is a very important phase in steels because its morphology directly controls the macroscopic mechanical properties. The majority of steels with such iron carbides contain residual stresses. The cementite phase embedded in a ferrite matrix is characterized by Atomic Force Acoustic Microscopy (AFAM) and nanoindentation studies. A Magnetic Force Microscope (MFM) coupled with an external coil providing an in-plane controlled magnetic field is employed to image the dynamic behavior of the magnetic domains in the cementite precipitates as well as the ferrite matrix of unalloyed steels.

Evaluation of Isothermal Aged 12Cr Steel Using Electromagnetic Acoustic Resonance
---Dae-Kwang Kim, Hak-Joon Kim, and Sung-Jin Song, Sungkyunkwan University, School of Mechanical Engineering, Suwon, Kyunggi, Korea; Seung-Hyun Cho, Korea Research Institute of Standard and Science, Daejeon, Korea; Joon-Soo Park, Doosan Heavy Industries and Construction Co., Advanced Process Development Team, Changwon, Gyeongnam, Korea

---12Cr steel is widely used as structural materials of high temperature in nuclear power plants. As increasing their operation times, 12Cr steel can be degraded. Isothermal aged 12Cr steels have corrosion and precipitation and these can be one of major causes fail of components using 12Cr steels. So, in this study, microstructure evaluation during isothermal aging in 12Cr steel using electromagnetic acoustic resonance (EMAR) will be performed. EMAR is a combination of the resonant spectroscopy technique and a non-contacting electromagnetic acoustic transducer (EMAT). For EMAR measurement, isothermal aged 12Cr steel specimens with variation of aging time and aging temperature were fabricated. Using the aged specimens, we will measure resonance frequency of each specimen. And then, relation between resonance frequencies and aging times and/or temperature will investigate. In this presentation, EMAR measurement results of aged 12Cr steel specimens and investigated relation will be presented.---This work was supported by the R&D program of the Korea Institute of Energy Technology Evaluation and Planning (KETEP) grant funded by the Korea government Ministry of Knowledge Economy (No.2010T100100756).
Evaluation of Isothermal Aged 304H Austenitic Stainless Steel Using Ultrasound
---Hun-Hee Kim, Hak-Joon Kim, Sung-Jin Song, Bum-Joon Kim, and Byeong-Soo Lim, School of Mechanical Engineering, Sungkyunkwan University, Suwon, Korea

---304H austenitic stainless steel is widely used as components which were operated under the high temperature and high pressure environments since 304H have excellence in weld ability and strength under high temperature. However, microstructure of these components can be changed and several phases appear in grain boundaries. These changes could be one of major factor of brittleness under high temperature condition for long period. However, a few researches have been done on how microstructural changes of precipitates affect the macroscopic mechanical properties. Therefore, it is necessary to research microstructural changes of precipitates effect on the macroscopic mechanical properties. To address such a need, in this study, we evaluated isothermal damaged 304H austenitic stainless steel specimens using ultrasound. The specimens used in this study were prepared by isothermal ageing at 750Â°C with variation in aging time. Then, we will evaluate the isothermal aged 304H austenitic stainless steel using the attenuations and velocities of ultrasound. And then, relation between attenuation of ultrasound and area fraction of precipitates will be presented in this study.---The Korea Institute of Energy Technology Evaluation and Planning (KETEP) grant funded by the Korea government Ministry of Knowledge Economy (No.2010T100100756).

Core Loss Analyses of Grain-Oriented Electrical Steel Using Flux-Controlled Magnetic Barkhausen Noise Measurements
---Arash A. Samimi and Lynann Clapham, Applied Magnetics Group, Department of Physics, Queen’s University, Kingston, Ontario, K7L 3N6 Canada; Thomas W. Krause, Department of Physics, Royal Military College of Canada, Kingston, Ontario, Canada

---The key component in electric motors that is used for flux transfer is 3% Si-Fe or electrical steel. Measurement and characterization of hysteresis and eddy current losses in Si-Fe, known as core loss, is of interest as this provides a means of optimizing motor performance for improved energy efficiency. Magnetic Barkhausen Noise (MBN) is the result of abrupt motion of domain walls over microstructural variations during magnetization of ferromagnetic steel materials. These high frequency events are associated with micro-eddy current generation, which contributes to the overall core loss. Therefore, it is a potential non-destructive method for monitoring metallurgical changes and core loss in Si-Fe steel. This study presents results obtained using novel flux-controlled MBN measurements to characterize the magnetic performance in electrical steel. The correlation between Barkhausen emissions and core loss at different flux and frequency levels is investigated in grain oriented 3% Si-Fe samples with different power losses. Results are discussed in light of domain wall models with a focus on potential applications of MBN for measurement and analyses of core loss in electrical steel.
Acoustic Emission During Tensile Deformation of M250 Grade Maraging Steel
---Tammana Jayakumar, Chandan Kumar Mukhopadhyay, Kesavan Vadivelu Rajkumar, Bhagi Purna Chandra Rao, and Baldev Raj, Indira Gandhi Centre for Atomic Research, Metallurgy and Materials Group, Kalpakkam, Tamil Nadu, India

---M250 grade maraging steel possessing excellent combination of mechanical properties is preferred as a structural material for critical applications in strategic sectors. Thermal ageing of M250 grade maraging steel produces complex variations in microstructural features, i.e., in dislocation density, intermetallic precipitation and reversion of martensite to austenite. In this investigation, acoustic emission (AE) generated during tensile deformation of M250 grade maraging steel in the solution annealed, peak aged and over aged conditions with different microstructures has been studied. Tensile tests of specimens in the solution annealed, peak aged (755K for 10 h) and over aged (750 K for 100 h) conditions were carried out at ambient temperature (298K). The AE signals generated during tensile testing were recorded by using 150 kHz resonant sensor and analyzed using different AE parameters viz., root mean square voltage, counts, energy and peak amplitude of AE events. The AE signals generated during tensile deformation were found to have good correlation with the changes in the tensile properties associated with precipitation of intermetallic phases. Higher AE generated in the peak aged condition as compared to the annealed condition has been attributed to increase in shearing of precipitates by dislocations and increased brittleness of the matrix. The decrease in the AE generated in the over-aged condition as compared to the peak aged condition has been attributed to the occurrence of deformation by Orowan looping, dissolution of precipitates and austenite reversion. Generation of AE signals in the deformation regions before and after yield and peak amplitude distribution of AE events were used to further analyze the results. AET could be successfully used to characterize the deformation behavior of solution annealed and differently aged specimens of M250 maraging steel possessing different microstructural features.

Effects of Copper Precipitation on the Magnetic Properties of Aged Copper-Containing Ferrous Alloys
---C. C. H. Lo, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, Iowa 50011

---Formation of copper precipitates induced by neutron irradiation has been identified as one of the primary cause of radiation embrittlement of reactor pressure vessel steels. Nondestructive techniques capable of detecting such damage are invaluable, in view of the probable need to extend the life of the current generation of nuclear power plants. Although magnetic properties have been shown to be sensitive to steel microstructure, a fundamental understanding is yet to be developed before these techniques can be reliably employed to detect radiation damages. In this work, the effects of copper precipitation on magnetic properties were studied using a supersaturated Fe-1wt%Cu alloy as a model system. A series of Fe-Cu samples was aged for different periods of time from 50 to 5000 minutes to produce different extents of copper precipitation in a bcc Fe matrix. Their bulk and micro-magnetic properties were characterized by performing magnetic hysteresis and Barkhausen effect measurements. The magnetic properties, including coercivity, initial permeability, Rayleigh constant and rms value of Barkhausen signals, were found to correlate with the sample hardness as a result of precipitation hardening. The empirical relationships between magnetic and mechanical properties are interpreted based on a model description of pinning of magnetic domain walls and dislocations by a network of randomly distributed copper precipitates.---This work was supported by the NSF Industry/University Cooperative Research Program of the Center for Nondestructive Evaluation.
SESSION 14

UT NONLINEAR EFFECTS AND TECHNIQUES

T. Mihara, Chairperson

Frank Livak Ballroom

3:30 PM  Scattering of Waves in Elastic Media with Heterogeneous Quadratic Nonlinearity
---G. Tang, Northwestern University, Department of Mechanical Engineering, Evanston, IL 60208; L. J. Jacobs, Georgia Institute of Technology, School of Civil and Environmental Engineering, Atlanta, GA; J. Qu, Northwestern University, Department of Mechanical Engineering, Department of Civil and Environmental Engineering, Evanston, IL 60208

3:50 PM  Two-Dimensional Analysis of Subharmonic Ultrasound at Closed Cracks by Damped Double Nodes
---K. Yamanaka, Y. Shintaku, M. Oguma, and Y. Ohara, Department of Materials Processing, Tohoku University, Sendai, Miyahi, 980-8579, Japan

4:10 PM  Subharmonic Wave Analysis in Cracks Using Developed FEM
---T. Mihara, Graduate School of Engineering, University of Toyama, Toyama, Japan; Y. Ikegami, ITOCHU Techno-Solutions Co., Tokyo, Japan; T. Furukawa, JAPEIC, Tokyo, Japan

4:30 PM  Non-Collinear Ultrasonic Beam Mixing for C-Scan Imaging of Interface Imperfections
---A. Ruiz, Instituto de Investigaciones Metalurgicas, UMSNH, Morelia, Michoacan, Mexico; W. T. Hassan, Rolls-Royce Corporation, Indianapolis, IN 46241; P. B. Nagy, School of Aerospace Systems, University of Cincinnati, Cincinnati, OH 45221

4:50 PM  Nonlinear Ultrasonic Measurements with EMATs for Detecting Pre-Cracking Fatigue Damage
---A. Cobb, M. Capps, C. Duffer, J. Feiger, and K. Robinson, Southwest Research Institute, Mechanical Engineering Division, San Antonio, TX 78238; B. Hollingshaus, Electric Power Research Institute, Fossil Operations and Maintenance, Charlotte, NC 28201

5:10 PM  Practical Approaches to Single Sided Nonlinear Measurements
---A. J. Croxford, S. R. Best, and S. A. Neild, University of Bristol, Department of Mechanical Engineering, Bristol, BS8 1TR, United Kingdom
Scattering of Waves in Elastic Media with Heterogeneous Quadratic Nonlinearity
---Guangxin Tang, Northwestern University, Department of Mechanical Engineering, Evanston, IL 60208; Laurence J. Jacobs, Georgia Institute of Technology, School of Civil and Environmental Engineering, Atlanta, GA; Jianmin Qu, Northwestern University, Department of Civil and Environmental Engineering, Evanston, IL 60208

---This paper studies the three-dimensional wave scattering by an elastic inclusion with quadratic nonlinearity in an otherwise linear elastic medium. Due to the nonlinearity of the inclusion, second order harmonic appeared in the scattered field. Under the incidence of a plane longitudinal wave, the solution to the scattered second order field is derived explicitly in terms of the Green’s function. A far field approximation of the scattered field is also obtained. The results of far field show that the scattered second harmonic field consists of a longitudinal spherical wave and a shear spherical wave. Furthermore, it is found that the amplitude of the forward scattered field is proportional to the acoustic nonlinearity parameter $\beta$ averaged over the volume of the inclusion, and the amplitude of backscattered field is proportional to a spatially weighted average of $\beta$. Finally, a method is described on how to use the statistics of the scattered fields to nondestructively obtain the statistics of $\beta$ over the inclusion such as the mean, the variance and autocorrelation length.

Two-Dimensional Analysis of Subharmonic Ultrasound at Closed Cracks by Damped Double Nodes
---Kazushi Yamanaka, Yohei Shintaku, Miyuki Oguma, and Yoshikazu Ohara, Department of Materials Processing, Tohoku University, Sendai, Miyagi, 980-8579, Japan

---Closed cracks are the most serious obstacle for safety of important structures such as power plants or air planes. The depth of such crack can be underestimated even by the most sensitive measurement tool, ultrasound. To detect closed cracks, nonlinearity of ultrasound is regarded and subharmonics is particularly useful because of their excellent selectivity for closed cracks and high temporal resolution such as in subharmonic phased array for crack evaluation (SPACE). However, in the one dimensional (1D) model so far reported, parameters relevant in real components cannot be taken into account. In this study, we propose the first two dimensional (2D) model to reproduce subharmonic generation at closed cracks using damped double nodes (DDN). Numerical simulation using finite difference time domain (FDTD) method was performed using DDN and compared with experimental waveforms and time frequency analysis based on the wavelet analysis. As a result, it was found that apparently random (chaotic) high frequency vibration is excited by large amplitude input wave without the damping. However, the damping is useful in avoiding the chaotic vibration and realizes stable subharmonics even at large amplitude input wave. The vibration waveforms of the displacement of incidence-side crack face, that of trasmission-side crack face and the crack opening displacement (COD) is calculated. Then is pushed up by, and the former cannot follow the return of the latter due to the inertia. In the following periods, this process is repeated with different percentages, causing doubling of period and formation of subharmonics. This analysis will be useful in designing and evaluating testing equipment, probes and conditions for important structures with possible extension of closed cracks.
Subharmonic Wave Analysis in Cracks Using Developed FEM
--- Tsuyoshi Mihara, Graduate School of Engineering, University of Toyama, Toyama, Japan; Yasushi Ikeyama, ITOCHU Techno-Solutions Co. Tokyo, Japan; Takashi Furukawa, JAPEIC, Tokyo, Japan

--- Subharmonic wave measurement is expected as a promising technique for the industrial NDE for industrial structures. However, the accurate mechanism of the generation of subharmonic wave at crack is not clear enough yet. We proposed a simple analytical model considering the clapping of the crack surfaces generate subharmonic wave at crack and qualitative agreement with the experiment could be obtained. According to the basic concept of previous analysis, we develop a new FEM code to simulate the accurate subharmonic wave behaviors at crack in this research. The analytical FEM code for subharmonic wave used here is a new one to develop basing on the commercial large-scale FEM code. The gap of crack of nm order can be simulated by the FEM model using double contact mesh technique. Analytical behaviors of transmitted ultrasound around crack according to the crack closure, residual stress and the amplitude of incident ultrasound are investigated comparing to the experimental behaviors.

Non-Collinear Ultrasonic Beam Mixing for C-Scan Imaging of Interface Imperfections
--- Alberto Ruiz, Instituto de Investigaciones Metalúrgicas, UMSNH, Morelia, Michoacán, México; Waled T. Hassan, Rolls-Royce Corporation, Indianapolis, IN 46241; Peter B. Nagy, School of Aerospace Systems, University of Cincinnati, Cincinnati, OH 45221

--- Non-collinear mixing has been proposed as an alternative to more conventional nonlinear ultrasonic techniques mainly because spurious system nonlinearities can be easily eliminated. This unique feature creates an opportunity to combine linear and nonlinear ultrasonic imaging into an integrated inspection system using conventional immersion scanning in spite of the very large acoustic nonlinearity of the coupling medium. We report the development of an ultrasonic immersion scanner that allows us to take both linear and nonlinear c-scans essentially simultaneously. By adjusting the incidence angles of the two mixing beams, the nonlinear sensitivity can be maximized for either bulk or interface imperfections. Although damaged areas tend to exhibit significant excess nonlinearity, in most cases the undamaged material also shows perceivable variations in nonlinearity the physical origin of which will have to be further investigated. However, excess nonlinearity from imperfectly bonded interfaces clearly originates from tightly compressed kissing bonded parts. The new configuration of the non-collinear scanner was used to generate a series of nonlinear ultrasonic c-scan images from an Inconel-Cu-Inconel interface that was gradually compressed to simulate kissing bonds of varying degree. C-scan images show that the nonlinear contrast significantly increases in regions where the linear contrast diminishes as tight contact develops at the interface.
Nonlinear Ultrasonic Measurements with EMATs for Detecting Pre-Cracking Fatigue Damage

---Adam Cobb, Matt Capps, Charles Duffer, Jim Feiger, and Kyle Robinson, Southwest Research Institute, Mechanical Engineering Division, San Antonio, TX 78238; Brian Hollingshaus, Electric Power Research Institute, Fossil Operations and Maintenance, Charlotte, NC 28201

---This paper describes a new approach for measuring material degradation using nonlinear acoustics. The importance of this measurement is that prior efforts have shown that the degree of acoustic nonlinearity increases as a function of fatigue damage accumulation. By exploiting this physical mechanism, there is the potential to develop field deployable methods for measuring the remaining life of critical components. The challenge with existing approaches for measuring acoustic nonlinearity is that primarily they have only been shown to be successful in a laboratory setting. This paper presents a potential approach for field measurement of acoustic nonlinearity that utilizes Rayleigh waves generated from electromagnetic acoustic transducers (EMATs). Rayleigh waves have unique advantages because the sound propagates along the surface, allowing for application on complex engineering structures. EMATs were used in place of traditional piezoelectric transducers because the sound is generated directly in the metallic structure. This eliminated the need for fluids for coupling the sound from the transducer to the structure, a potential source of variability. Custom EMATs were developed and nonlinearity measurements were performed on 410 stainless steel specimens that were subjected to a fatigue process. The expectation was that there would be correlation between the measured nonlinearity and the induced fatigue damage. Some experiments showed an increase in the acoustic nonlinearity of up to 700% compared to the initial value after fatigue damage was introduced. Other experiments had too much scatter and did not show this relationship consistently due to unanticipated challenges in producing repeatable measurements. Recommendations based on lessons learned from the project effort will be presented to potentially improve the repeatability of the measurement approach. If the scatter can be reduced, this EMAT-based technique could result in a field deployable prognosis tool.

Practical Approaches to Single Sided Nonlinear Measurements

---Anthony J. Croxford, Steven R. Best, and Simon A. Neild, University of Bristol, Department of Mechanical Engineering, Bristol, BS8 1TR, United Kingdom

---Harmonic measurements have been used to measure material nonlinearity for a significant period. They are attractive having simple equipment requirements and being relatively straightforward to understand. Most approaches rely on double sided measurements in a through transmission mode. While attractive from an experimental point of view the usefulness of this is limited in many industrial examples. For this reason the development of a single sided measurement would be beneficial. This paper outlines how a single sided measurement of material nonlinearity can be made. It outlines some of the difficulties in the system due to issues related to reflections. It shows through the use of simulations and experiments how the presence of damping is a positive benefit when making single sided measurements and defines a series of correction factors that can be used to describe measured nonlinearity in terms of the underlying continuous wave formulation of the nonlinear measure beta. Finally conclusions are drawn as to how practical measurements may be made.
WEDNESDAY

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**SPECIAL EVENING SESSION – 8:00 PM – Silver Maple Ballroom**
SESSION 15
NDE OF ARMOR AND ARMOR SYSTEMS
R. E. Brennan, Chairperson
Mildred Livak Ballroom

8:30 AM  Nondestructive Characterization of Transparent Laminate Systems Subject to Low Velocity Impacts
---R. E. Brennan, W. H. Green, and C. G. Fountzoulas, U. S. Army Research Laboratory, Aberdeen Proving Ground, MD 21005

8:50 AM  Analysis of Cone Cracks in Multi-Layered Transparent Panel Structures by X-Ray Computed Tomography

9:10 AM  Further Testing and Development of Simulation Models for UT Inspections of Armor
---F. J. Margetan and R. B. Thompson, Iowa State University, Center for NDE, Ames, IA 50011; N. Richter, Pratt & Whitney, East Hartford, CT 06108

9:30 AM  Determination of Grain Size in Alumina Through the Use of Scanning Acoustic Spectroscopy
---S. Bottiglieri and R. A. Haber, Rutgers University, Department of Materials Science and Engineering, Piscataway, NJ 08854

9:50 AM  Elliptical Trajectory Orientation of Lamb Wave Polarization as a Damage Localization Parameter in Metallic and Composite Structures
---J. T. Ayers, U. S. Army Research Laboratory, Vehicle Technology Directorate, Mechanics Division, RDRL- VTM, Building 517, Aberdeen Proving Ground, MD 21005-5066; N. Apetre and M. Ruzzene, Georgia Institute of Technology, Aerospace Engineering, Atlanta, GA; E. Swenson, Air Force Institute of Technology, ENY, Dayton, OH

10:10 AM  Break

10:30 AM  Correlation of Scanning Microwave Interferometry and Digital X-Ray Images for Damage Detection in Ceramic Composite Armor
---K. Schmidt and R. Goitia, Evisive, Inc., Baton Rouge, LA 70808; W. A. Ellingson, ERC Company, Indianapolis, IN; W. H. Green, Army Research Laboratory, APG, MD 21005

10:50 AM  Advances in Resonance Based NDT for Ceramic Components
---L. Hunter and L. Jauriqui, Vibrant Corporation, 5550 Midway Park Place N.E., Albuquerque, NM 87109; R. Sisneros, Magnaflux Resonance Systems

11:10 AM  Toward an Integrated System for Comprehensive Component Characterization
---D. R. Wallace, Youngstown State University, Department of Mechanical and Industrial Engineering, One University Plaza, Youngstown, OH 44555; B. D. Vukanovich, Youngstown State University, Mechanical Engineering Technology, One University Plaza, Youngstown, OH 44555; F. Persi and M. Garvey, M-7 Technologies, Inc., 1019 Ohio Works Drive, Youngstown, OH 44510

11:30 AM  Nondestructive Characterization of UHMWPE Helmet Armor Material
---C.-P. T. Chiou, F. J. Margetan, D. J. Barnard, T. Jensen, D. Eisenmann, and D. K. Hsu, Iowa State University, Center for NDE, Ames, IA 50011

11:50 AM  Nondestructive Inspection of a Composite Missile Launcher
---O. Ley, M. Butera, T. Valatka, and V. Godinez, Mistras Group, Princeton Junction, NJ 08550; S. Chung, Materials Sciences Corporation, Horsham, PA 19044; M. H. Triplett, U. S. Army Aviation and Missile Research Development and Engineering Center, Huntsville, AL

12:10 PM  Lunch
Nondestructive Characterization of Transparent Laminate Systems Subject to Low Velocity Impacts
---Raymond E. Brennan, William H. Green, and Constantine G. Fountzoulas, U.S. Army Research Laboratory, Aberdeen Proving Ground, MD 21005

---Multi-layer, multi-material transparent laminate systems are used to enhance protection efficiency for ground vehicle windshield and window applications while ensuring sufficient visibility for the operator. Impact damage caused by low velocity strikes may result in crack formation in the transparent materials or delaminations between layers, which can impair visibility and affect performance. In this effort, both conventional and novel transparent laminate systems have been nondestructively evaluated in a pre-impact, baseline state using visual inspection, cross-polarization imaging, x-ray characterization, and ultrasound characterization. After subjecting the laminate systems to a series of low velocity impact tests, the same nondestructive methods were used for characterization of the post-impact state. By combining nondestructive and destructive testing, damage mechanisms were identified at critical velocity and energy conditions to help establish damage tolerance levels for transparent protective systems. In addition to experimental testing, 2D and 3D modeling and simulation studies were concurrently performed to develop a transparent laminate system failure model. The combined effort of experimental and modeling results provided a means for comparison and downselection of transparent laminate systems based on low velocity impact damage tolerance to achieve improved visibility and protection capabilities.

Analysis of Cone Cracks in Multi-Layered Transparent Panel Structures by X-ray Computed Tomography

---Transparent and opaque materials are used by the Army in protective systems for enhancing survivability of ground vehicles, air vehicles, and personnel. Transparent materials are utilized for face shields, riot gear, and vehicle windows, in addition to other applications for sensor protection, including radomes and electromagnetic (EM) windows. Fracture from low velocity impacts limits visibility and impairs continued vehicle operations. Transparent protective systems typically consist of glass, polymeric and ceramic materials. Impact damage in a series of two different multi-layered transparent panel structure types was investigated using a number of nondestructive evaluation (NDE) methods, including phased array ultrasonic testing and x-ray computed tomography (XCT). Some of the damaged specimens exhibited multiple cone cracks in the second glass layer in front of the backing plate. The spatial characteristics of the cone cracks were analyzed using geometric data from the XCT scans (images). Physical cone attributes (e.g., cone angle) were compared to crack damage geometries generated by theoretical simulations of impact damage.
Further Testing and Development of Simulation Models for UT Inspections of Armor
---Frank J. Margetan and R. Bruce Thompson, Iowa State University, Center for NDE, Ames, IA 50011; Nathaniel Richter, Pratt & Whitney, East Hartford, CT 06108

---At last year’s QNDE conference, we discussed an approach for simulating ultrasonic pulse/echo immersion inspections of multi-layer armor panels. The simulator uses as inputs the thickness, density, velocity and attenuation of water and each armor layer. Other inspection parameters, such as transducer properties and a measured calibration signal, are also input. The output consists of a predicted UT A-scan which includes echoes from all interfaces including those arising from reverberations within layers. Such A-scans can be predicted both for unflawed panels and panels containing a large disbond at any given interface. Last year the simulator was tested against experimental results for a 5-layer composite armor panel containing fiberglass, graphite/epoxy, rubber and ceramic layers. This year we apply the simulator to metal-encapsulated ceramic armor consisting of SiC ceramic tiles fully embedded in a titanium-alloy matrix. An interesting specimen of such armor is on loan to us in which some tile/metal interfaces appear to be well bonded, while others contain disbonded areas of various sizes. Measured and predicted UT signals are compared for inspections using planar and focused transducers. We also discuss approaches for extending the simulator to predict ultrasonic C-scan images for 2D-scans over interfaces containing small isolated disbands.---This work was supported by the Army Research Laboratory.

Determination of Grain Size in Alumina Through the Use of Scanning Acoustic Spectroscopy
---Stephen Bottiglieri and Richard A. Haber, Rutgers University, Department of Materials Science and Engineering, Piscataway, NJ, 08854

---Ultrasonic nondestructive evaluation (NDE) is capable of locating large anomalous flaws within dense ceramic materials by measuring the relative drop in intensity from one bottom surface peak to the next reflected one. Another use involves obtaining time-of-flight (TOF) data which gives the time it takes a generated longitudinal or shear wave to pass through the material. TOF data can be turned into speed of sound (longitudinal or shear) and elastic properties (Poisson ratio, Young’s modulus, shear modulus, and bulk modulus). This information can be collected over large sample areas where variability of a specific property can be determined. While the location of large flaws or determination of variability in elastic properties is useful information, the next step is determining what the flaws are and why there is variability. Ultrasonic nondestructive characterization (NDC) makes use of measuring the frequency dependent attenuation of the ultrasonic pulse that is transmitted through a dense ceramic material. Attenuation coefficient spectra are causally related to the bulk material microstructure by which they are produced. Deconvolution and an understanding of the attenuation coefficient spectrum in any dense ceramic material can give microstructural information such as grain size, solid inclusion size and concentration. Attenuation mechanisms include absorption and scattering, and within each of these mechanisms exists subsets of specific types of absorption or scattering. The work presented in this paper involves developing an understanding of specific types of scattering (Rayleigh and stochastic scattering) in dense aluminum oxide (Al2O3). General terms which relate attenuation coefficient to Rayleigh and stochastic scattering will be used to predict grain size variations in Al2O3. A discussion of inherent difficulties in using such a method and possible techniques to overcome these difficulties is added.
Elliptical Trajectory Orientation of Lamb Wave Polarization as a Damage Localization Parameter in Metallic and Composite Structures
---James T. Ayers, US Army Research Laboratory, Vehicle Technology Directorate, Mechanics Division, RDRL-VTM, Bldg. 517, Aberdeen Proving Ground, MD 21005-5066; Nicole Apetre and Massimo Ruzzene, Georgia Institute of Technology, Aerospace Engineering, Atlanta, GA; Eric Swenson, Air Force Institute of Technology, ENY, Dayton, OH

---Polarization defines the phase and amplitude relationships between the various components of wave motion, and is significant in many technological applications based on wave propagation, such as optics, seismology, telecommunications and radar science. The ability to measure and quantify the polarization of ultrasonic waves has led to the development of novel non-destructive diagnostic tools, which rely on the sensitivity of polarization to surface roughness, cracks, temperature and residual stresses, among others. In particular, the following paper provides an analytical description of polarized Lamb wave components that yield an elliptical, rotated profile of the particle trajectory. The formulation includes Lamb waves generated by a circular piezoelectric disc, along with descriptions of bi-modal and single mode polarization characteristics. A technique is proposed that utilizes the elliptical orientation as a damage identification parameter for guided wave structural interrogation techniques. The technique is applied to 3D finite element models of aluminum and composite armor-like structures. This analytical formulation is compared to experimental Lamb wave polarization results, where polarized Lamb wave components are extracted from complex, homogenous aluminum specimens using a 3D Scanning Laser Doppler Vibrometry setup. The experimental results show that the proposed technique allows for improved damage characterization.

Correlation of Scanning Microwave Interferometry and Digital X-Ray Images for Damage Detection in Ceramic Composite Armor
---Karl Schmidt and Ryan Goitia, Evisive, Inc., Baton Rouge, LA 70808; William A. Ellingson, ERC Company, Indianapolis, IN; William H. Green, Army Research Laboratory, Aberdeen Proving Ground, Maryland

---Application of non-contact, scanning, microwave interferometry for inspection of ceramic-based composite armor facilitates detection of defects which may occur in manufacturing or in service. Non-contact, one-side access permits inspection of panels while on the vehicle. The method was applied as a base line inspection and post-damage inspection of composite ceramic armor containing artificial defects, fiducaries and actual damage. Detection, sizing and depth location capabilities were compared using microwave interferometry system and micro-focus digital x-ray imaging. The data demonstrate corroboration of microwave interference scanning detection of cracks and laminar features. The authors present details of the system operation, descriptions of the test samples used and recent results obtained.
Advances in Resonance Based NDT for Ceramic Components
---Lem Hunter and Leanne Jauriqui, Vibrant Corporation, 5550 Midway Park Place, NE, Albuquerque, NM 87109; Robert Sisneros, Magnaflux Resonance Systems

---The application of resonance based non-destructive testing methods has been providing benefit to manufacturers of metal components in the automotive and aerospace industries for many years. Recent developments in resonance based technologies are now allowing the application of resonance NDT to ceramic components including turbine engine components, armor, and hybrid bearing rolling elements. Application of higher frequencies and advanced signal interpretation are now allowing Process Compensated Resonance Testing to detect both internal material defects and surface breaking cracks in a variety of ceramic component. Resonance techniques can also be applied to determine material properties of coupons and to evaluate process capability for new manufacturing methods.

Toward an Integrated System for Comprehensive Component Characterization
---Darrell R. Wallace, Youngstown State University, Department of Mechanical and Industrial Engineering, One University Plaza, Youngstown, OH 44555; Brian D. Vuksanovich, Youngstown State University, Mechanical Engineering Technology, One University Plaza, Youngstown, OH 44555; Fred Persi and Michael Garvey, M-7 Technologies, Inc., 1019 Ohio Works Drive, Youngstown, OH 44510

---Modern analytical and metrological instruments offer diverse options for measurement and analysis. In the context of dimensional measurements, CMM's have become nearly ubiquitous as they have become relatively affordable, faster, and capable of ever-finer resolution. Non-contact CMM systems have reached a level of capability and maturity that enables the exploration of new paradigms for inspection. The system described in this paper, currently under development, offers a platform to integrate the capabilities of high-speed laser metrology with various other non-contact evaluation technologies. The data from these sensors may be taken directly from within the manufacturing process and may be co-registered and superimposed for levels of inference that are not presently possible with single-sensor offline techniques. The data may be archived for a comprehensive record of the manufactured component and may be integrated into a lifecycle management database for an unprecedented level of traceability. This technology offers to fundamentally challenge manufacturing paradigms that currently limit process capability, particularly for high-precision, mission-critical components. This paper presents the concept of the new technology and its anticipated benefits for defense, aerospace, and biomedical applications.
Nondestructive Characterization of UHMWPE Helmet Armor Material
---Chien-Ping T. Chiou, Frank J. Margetan, Daniel J. Barnard, Terrence Jensen, David Eisenmann, and David K. Hsu, Iowa State University, Center for NDE, Ames, IA 50011

---Ultra-high molecular weight polyethylene (UHMWPE) is a material used for fabricating helmet and body armor. Thin composite sheets consisting of four unidirectional plies of UHMWPE fibers with a [0/90] layup can be consolidated into plates or shaped armors. In this work, plate specimens approximately 0.25 inches thick, consolidated at 280°F temperature and at 1000, 2000, 3000, 4000, and 5000psi pressure were provided by South Dakota School of Mines and Technology for NDE study. Two material types SR-3124 and SR-3130 were tested. These plate specimens were examined with ultrasound, X-ray and terahertz waves. Ultrasonic through-transmission scans using both air-coupled and immersion modes revealed that the 3130 series material generally had much lower attenuation than the 3124 series, and that certain 3124 plates had extremely high attenuation. Due to the relatively low inspection frequencies used, pulse-echo immersion ultrasonic testing could not detect distinct flaw echoes from the interior. To characterize the nature of the defective condition that was responsible for the high ultrasonic attenuation, terahertz waves in the time-domain spectroscopy mode were used to image the flaws. Terahertz B-scan images obtained on the high attenuation samples clearly showed a distribution of a large number of defects throughout the volume of the interior. These defects appeared to be small planar delaminations, but their precise nature will be further characterized using X-ray CT and eventually by optical microscopy of the sectioned surface. The NDE results demonstrated the complementary role of ultrasonic and terahertz examinations---This work was supported by the Army Research Laboratory.

Nondestructive Inspection of a Composite Missile Launcher
---Odbulia Ley, Manny Butera, Thomas Valatka, and Valery Godinez-Azcuauga, Mistras Group, Princeton Junction, NJ 08550; Simon Chung, Materials Sciences Corporation, Horsham, PA 19044; M. H. Triplett, U. S. Army Aviation and Missile Research Development and Engineering Center, Huntsville, AL

---Lighter weight alternatives are being sought to replace the metallic components currently used in high performance aviation and missile systems. Benefits of lightweight, high strength carbon fiber reinforced composites in missile launchers and rocket motor cases, for example, include improved fuel economy, increased flight times, enhanced lethality and/or increased velocity. In this work, various nondestructive inspection techniques are investigated for the damage assessment of a composite missile launcher system for use in U.S. Army attack helicopters. The launcher system, which includes rails and a hardback, can be subject to impact damage from accidental tool drops, routine operation, and/or ballistic threats. The composite hardback and the launch rails both have complex geometries that can challenge the inspection process. Scanning techniques such as line scanning thermography, ultrasonic, and acousto-ultrasonics will be used and compared to determine damage detection accuracy, reliability, and efficiency. Results will also be compared with visual observations to determine if there is a correlation. The goal is to establish an inspection method that quickly and accurately assess damage extent in order to minimize service time and return the missile system back into the field.
Session 16
SESSION 16
UT PHASED ARRAYS I
R. Addison, Chairperson
Sugar Maple Ballroom

8:30 AM  Advanced Ultrasound Probes for Medical Imaging
          ---D. G. Wildes, GE Global Research, Room KW-C1317B, One Research Circle, Niskayuna, NY 12309

9:10 AM   Ultrasonic Phased Array Transducer Modeling – Issues and Solutions
          ---L. W. Schmerr, Jr.,1,2 and A. Sedov3, 1Center for NDE and the 2Department of Aerospace Engineering, Iowa State University, Ames, IA 50011; 3Department of Mechanical Engineering, Lakehead University, Thunder Bay, Ontario, Canada

9:30 AM   Ultrasonic Measurement Model for Phased Array Inspection on Side-Drilled Holes
          ---X. Zhao, C. Xu, and D. Xiao, Key Laboratory of Fundamental Science for Advanced Machining, School of Mechanical Engineering, Beijing Institute of Technology, Beijing, 100081, China

9:50 AM   Prediction of B Scope Images for Phase Array Ultrasonic Testing by Geometrical Theory of Diffraction
          ---M. Nagai, S. Lin, and H. Fukutomi, Central Research Institute of Electric Power Industry, Materials Science Research Laboratory, Yokosuka-shi, Kanagawa, Japan

10:10 AM  Break

10:30 AM  SAFT-Reconstruction in Ultrasonic Immersion Technique Using Phased Array Transducers
          ---J. Prager, J. Kitze, R. Boehm, and H.-J. Montag, Federal Institute for Materials Research and Testing, Division 8.4, Acoustical and Electromagnetic Methods, Unter den Eichen 87, D-12205, Berlin, Germany

10:50 AM  A Sparse 2D Ultrasonic Array Structure Designed Using a Conformal Mapping Technique
          ---S. N. Ramadas, J. C. Jackson, and A. Gachagan, Centre for Ultrasonic Engineering, University of Strathclyde, Glasgow, Scotland, United Kingdom; A. Tweedie, Alba Ultrasound Ltd., Glasgow, Scotland, United Kingdom

11:10 AM  Evaluation of Multi-Element Methods for Non-Destructive Testing of Complex Components
          ---S. Bannouf, S. Robert, and O. Casula, Commissariat à l’Energie Atomique, Laboratoire d’Intégration des Systemes et des Technologies, Centre de Saclay, 91191, Gif-sur-Yvette, France; C. Prada, Institut Langevin, 10 rue Vauquelin, 75231, Paris, Cedex 05, France

11:30 AM  Simulation of Ultrasonic Arrays for Industrial and Civil Engineering Applications Including Validation
          ---M. Spies and H. Rieder, Fraunhofer Institute for Industrial Mathematics, ITWM, Fraunhofer-Platz 1, 67663 Kaiserslautern, Germany; T. Orth, Salzgitter Mannesmann Forschung GmbH, Ehingerstrasse 200, 47259 Duisburg, Germany; S. Maack, Federal Institute for Materials Research & Testing, BAM, Unter den Eichen 87, 12205 Berlin, Germany

11:50 AM  Self-Adaptive Focusing for Phased-Array Inspection of Complex Composite Specimens
          ---D. L. Hopkins, G. A. Neau, and W. V. Johnson, BERCLI Corporation, 1750 Montgomery Street, Suite 151, San Francisco, CA; L. Le Ber, M2M, Les Ulis, France

12:10 PM  Lunch
Advanced Ultrasound Probes for Medical Imaging
---Douglas G. Wildes, GE Global Research, Room KW-C1317B, One Research Circle, Niskayuna, NY 12309

---Medical ultrasound probe technology has advanced significantly over the past 15 years. While conventional 1D linear, sector, and convex phased arrays are still workhorse probes for most applications, newer probe architectures and materials deliver greater imaging performance and clinical value. Multi-row 1.25D & 1.5D arrays provide improved elevation focusing and image slice thickness control. Mechanically-swept 1D arrays create 3D images of slow-moving targets (obstetrics), but 2D arrays with electronic beamforming in the probe are required for 4D (real-time 3D) imaging of fast-moving anatomy (cardiology). The trend toward higher performance, smaller size, and lower cost has enabled ultrasound to play an increasingly critical role in interventional procedures, through 45 MHz IVUS catheters, 64-element phased-array ICE catheters, and 2500-element 2D array TEE probes. New materials (high dielectric and single crystal piezoelectrics) and new acoustic designs (e.g., triple matching layers) have delivered improved sensitivity and bandwidth, improving both Doppler penetration and imaging resolution and enabling new modes such as harmonic imaging. MEMS devices (cMUTs, pMUTs) promise great improvements in performance and dramatic changes in the way probes are designed and built. The presentation will review basic principles of medical transducer design and imaging, then introduce the advanced technologies listed above.

Ultrasonic Phased Array Transducer Modeling – Issues and Solutions
---Lester W. Schmerr Jr. and Alexander Sedov, Center for NDE and the Dept. of Aerospace Engineering, Iowa State University, Ames, Iowa 50011, Department of Mechanical Engineering, Lakehead University, Thunder Bay, Ontario, Canada

---Modeling ultrasonic phased array transducers involves a number of issues, some of which are similar to those found with large, single element transducers and some which are unique to arrays. These issues include the choice of ultrasonic beam model to be employed, the appropriateness of a rigid baffle assumption, the electrical and acoustical interactions of elements, and the determination of the electrical and electromechanical behavior of each element on sound transmission and reception. Here we will discuss those issues and how they can be addressed so that phased arrays can be used in quantitative NDE measurements.---This work was supported for L.W.S. by the NSF Industry/University Cooperative Research Center at Iowa State University, and by for A.S. by the Natural Sciences and Engineering Research Council of Canada.
Ultrasonic Measurement Model for Phased Arrays Inspection on Side-Drilled Holes
---Xinyu Zhao, Chunguang Xu, and Dingguo Xiao, Key Laboratory of Fundamental Science for Advanced Machining, School of Mechanical Engineering, Beijing Institute of Technology, Beijing 100081, China

---An ultrasonic measurement model can give us a deep insight into the complex physical principle of the ultrasonic testing processes and help us evaluate the inspection results quantitatively. Recently, multi-Gaussian beam (MGB) models were increasingly adopted in the ultrasonic measurement model due to its outstanding capability in both computational efficiency and accuracy. However the paraxial MGB model will lose accuracy in the case of predicting the responses from the phased array transducer with a wide steering angle. To take care of this issue, a nonparaxial multi-Gaussian beam (NMGB) model was developed recently and some simulation examples had shown it was an accurate and efficient tool to calculate the steering and focusing beam fields radiated from the phased arrays. Then as a natural extension of this research work, in this study, a completed ultrasonic measurement model for the phased array system is developed by using this NMGB method. This provided measurement model can be used to predict the response of a side-drilled hole over a wide range of steering angles. Also the system efficiency factor for the linear phased arrays is discussed and determined by a given reference experiment. Furthermore, some comparisons for both A-scan signals and B-scan images of modeling predictions to experimental results are present to demonstrate the accuracy of this measurement model. Finally, the sensitivity versus various steering angles of linear phased arrays are investigated and explained using the provided model.

Prediction of B Scope Images for Phase Array Ultrasonic Testing by Geometrical Theory of Diffraction
---Masaki Nagai, Shan Lin, and Hiroyuki Fukutomi, Central Research Institute of Electric Power Industry, Materials Science Research Laboratory, Yokosuka-shi, Kanagawa, Japan

---A numerical method is developed to calculate B scope images obtained by the phased array technique using linear array probes. In this method, an analytical equation of echoes received by transducers is calculated based upon the geometrical theory of diffraction and the reciprocity relations. This method is able to calculate B scope images for various focal depths and active apertures in the phased array technique in a short time. B scope images and echo intensities of a specimen with a side-drilled hole (SDH) are calculated for various focal depths and active apertures in a normal beam inspection. Numerical results are compared with experimental results. Comparison shows that it is possible to predict B scope images correctly. Furthermore, B scope images obtained from a specimen with a slit while using both transverse and longitudinal angle beam inspections were also calculated. Intensities of the corner echo of the slit agree qualitatively with those obtained in experiments.
SAFT-Reconstruction in Ultrasonic Immersion Technique Using Phased Array Transducers

--- The two main preconditions for the application of the Synthetic Aperture Focusing Technique (SAFT) are: (i) a large divergence of the transducer and (ii) an exact knowledge on the sound propagation path and therewith the pulse travel time from the transducer to each pixel or voxel in the specimen. These requirements are easily fulfilled for point sources directly mounted on the surface of the specimen. However, in practical applications the finite dimension of the transducer limits its divergence. In many cases the transducer is wedge mounted and/or especially in immersion technique coupled via a water delay line. These delay paths change the point of incidence and the propagation path has to be evaluated for each pixel separately considering Fermat’s principle. Using phased array probes a sector scan can improve the divergence of the transducer. The introduced method combines the advantages of using a phased array probe in immersion technique to improve SAFT reconstruction. An algorithm is presented accounting the influence of the delay path on the reconstruction method. The applicability of the algorithm is shown by validation with simulated echo responses and with experimental results collected from a specimen with artificial flaws.

A Sparse 2D Ultrasonic Array Structure Designed Using a Conformal Mapping Technique
--- S. N. Ramadas, J. C. Jackson, and A. Gachagan, Centre for Ultrasonic Engineering, University of Strathclyde, Glasgow, Scotland, United Kingdom; A. Tweedie, Alba Ultrasound Ltd., Glasgow, Scotland, United Kingdom

--- The paper presents the application of conformal mapping as a new technique for the design of sparse array layouts. Conformal map is an angle preserving transformation and while there are a variety of interesting mapping functions available to exploit, this preliminary investigation is restricted to a square root transformation of the classical fully populated 2D layout. Extensive modeling using both Huygens™ Field prediction theory and 2D FFT is employed to study the resulting new structure. The investigations indicate clearly that the new layout efficiently breaks the periodicity in the array lattice, which allows the array structure to be scaled without introducing undesirable grating lobes. In order to investigate and compare the various design outcomes, a methodology based on a line integral algorithm was used to transform a standard matrix array layout into a Sinogram, which is a visual indicator of periodicity in the layout. A theoretical comparison against other common array designs including densely populated rectangular, hexagonal, and random 2D array configuration is presented. Moreover, a prototype 2.5MHz 2D conformal map array configuration was designed for direct contact operation in steel. The prototype device has been used to demonstrate the imaging performance of this sparse array configuration.
Evaluation of Multi-Elements Methods for Non-Destructive Testing of Complex Components
---S. Bannouf, S. Robert, and O. Casula, Commissariat à l'Energie Atomique, Laboratoire d'Intégration des Systèmes et des Technologies, Centre de Saclay, 91191 Gif-sur-Yvette, France; C. Prada, Institut Langevin, 10 rue Vauquelin, 75231 Paris, Cedex 05, France

---Ultrasonic phased array techniques are increasingly used in NDT and improve significantly the controls of industrial components with complex geometries. In this paper, we present different applications of these techniques on a realistic mock-up representing a butt weld. The control is carried out either in immersion, or in contact using a smart flexible phased-array. The conventional phased array ultrasonic techniques (electronic scanning coupled to Dynamic Depth Focusing) are compared to adaptive methods (Decomposition of the Time-reversal Operator) and synthetic imaging (Total Focusing Method). In order to image the flaw in the 3D-view of the specimen, all these techniques need the knowledge of the external and/or internal surface. In immersion, both surfaces of the mock-up are reconstructed by algorithms using surface/back-wall echoes and image segmentation. For the detection with the flexible phased-array, the surface is reconstructed thanks to the embedded profilometer and the internal shape is reconstructed by a specific real time functionality embedded in the system. The performances of detection, characterization, benefits and limitations of these techniques are discussed and evaluated on both simulated and experimental data.

Simulation of Ultrasonic Arrays for Industrial and Civil Engineering Applications Including Validation
---Martin Spies and Hans Rieder, Fraunhofer-Institute for Industrial Mathematics ITWM, Fraunhofer-Platz 1, 67663 Kaiserslautern, Germany; Thomas Orth and Salzgitter Mannesmann, Forschung GmbH, Ehingerstrasse 200, 47259 Duisburg, Germany; Stefan Maack, Federal Institute for Materials Research & Testing BAM, Unter den Eichen 87, 12205 Berlin, Germany

---Operating ultrasonic transducers as phased arrays, where each of the array elements can be pulsed with time delays, allows to control the beam shape and the sound beam direction on a large scale. Thus, phased arrays are suitable for a wide range of applications, which has correspondingly stimulated considerable interest within the NDE community. Quite recently, two-dimensional arrays have become widely available offering additional capabilities in view of a three-dimensional steering of the beam field. However, the various transducer and control parameters of such 2D-arrays require the proper evaluation of the probe characteristics. The use of efficient simulation techniques is thus inevitable, also with respect to the calculation of the delay laws especially for the inspection of complex-shaped components. In this contribution we address the beam field simulation of 2D ultrasonic arrays using the Generalized Point Source Synthesis technique (GPSS). Aiming at the inspection of cylindrical components such as pipes the influence of concave and convex surface curvatures, respectively, has been evaluated for a commercial probe. Validation has been performed using a photo-elastic visualization set-up. In civil engineering, the ultrasonic inspection of highly attenuating concrete structures has been boosted by the development of dry contact point transducers, mainly applied in array arrangements. Respective simulations for a widely used commercial probe are validated using experimental results acquired on concrete half-spheres with diameters from 200 mm up to 650 mm. The probe directivity patterns are determined three-dimensionally using a scanner system developed at BAM. The application of validated simulation techniques in account of the material parameters, such as sound attenuation, allows to gain a-priori information about the signal-to-noise conditions and thus to characterize the experimental conditions to be expected.
Self-Adaptive Focusing for Phased-Array Inspection of Complex Composite Specimens

---Deborah L. Hopkins, Guillaume A. Neau, and Wayne V. Johnson, BERCLI Corp., 1750 Montgomery St., Suite 151, San Francisco, CA; Laurent Le Ber M2M, Les Ulis, France

---Results are presented from laboratory experiments in which Self-Adaptive ULtrasound (SAUL) was used in conjunction with linear and radial arrays to achieve improved defect detection and sizing for curved composite test specimens with tight radii. For this recently available technique, the specimen shape is measured as part of the inspection and is used to adapt the focal laws in real time to create a shape-corrected B-scan. The technique shows tremendous promise for helping to overcome challenges associated with inspection of composite structures including curved and highly contoured surfaces, changes in thickness and geometry including ply dropoff, and part-to-part variation. For example, shaped arrays improve resolution for known geometries, but good results depend on accurate positioning of the probe. Measurements performed to study the effect of probe misalignment demonstrate that the SAUL technique can greatly reduce the sensitivity to probe position. In addition, experiments using self-adaptive focusing with a linear array have achieved good results for curved parts. SAUL therefore stands to increase the functionality of conventional probes thereby offering a cost-effective solution for complex geometries and for addressing the variability in parts and probe alignment that is typically encountered in production environments.
Session 17
SESSION 17
NDE FOR MICROSTRUCTURE
A. Lasseigne and D. Olson, Co-Chairpersons
Frank Livak Ballroom

8:30 AM Two-Step Formation of Closed Stress Corrosion Cracks in Ni-Based Alloy Weld Metal and its Evaluation by Subharmonic Phased Array
---Y. Ohara, S. Horinouchi, Y. Shintaku, and K. Yamanaka, Tohoku University, Department of Materials Processing, Sendai, Miyagi, Japan

8:50 AM Fatigue Damage Evaluation in a Pure Copper with Nonlinear Resonant Ultrasound Spectroscopy (NRUS)
---T. Ohtani and Y. Ishii, Shonan Institute of Technology, Department of Mechanical Engineering, 1-1-25 Tusjido-Nishikaigan, Fujisawa, Kanagawa, 251-8511, Japan

9:10 AM Ultrasonic Fatigue Process Analyzed by Using Laser Doppler Vibrometer and Continuous AE Waveform Analysis System
---M. Shiwa, Y. Furuya, and H. Yamawaki, National Institute for Materials Science, Materials Reliability Unit, Tsukuba, Ibaraki, Japan; K. Ito and M. Enoki, The University of Tokyo, Department of Materials Engineering, Tokyo, Japan

9:30 AM Inspection Challenges Associated with the Use of the Creep Strength Enhanced Ferritic Steels
---J. Henry and A. N. Lasseigne, Structural Integrity Associates, Inc., Chattanooga, TN 37421; Generation 2 Materials Technology, LLC, Tomball, TX 77098

9:50 AM Characterization of Residual Stresses in Pipelines by Nondestructive Electromagnetic Assessment
---J. E. Jackson, K. M. Koenig, and A. N. Lasseigne, Generation 2 Materials Technology, LLC, 1626 S. Cherry Street, Tomball, TX 77375

10:10 AM Break

10:30 AM High Frequency Ultrasonic Mitigation of Microbial Corrosion

10:50 AM In-Situ Repairs of Pipelines Using Metal Arc Welding Under Oil (MAW-UO) Aided by Eddy Current Crack Detection
---H. H. Almostaneer, Z. Jones, S. Liu, and D. L. Olson, Metallurgical and Materials Engineering Department, Colorado School of Mines, Golden, CO 80401

11:10 AM Utilization of Nondestructive Electrochemical Techniques in Characterizing Microbiologically Influenced Corrosion (MIC) of API-5L X65 Carbon Linepipe Steel: Laboratory Study
---F. Al-Abbas, D. L. Olson, B. Mishra, and J. R. Spear, Colorado School of Mines, 1500 Illinois Street, Golden, CO 80401; A. Kakpovbia, Saudi Aramco

11:30 AM Ultrasonic Determination of Carbon Content in Uranium Metal
---J. A. Poncelow, B. Mishra, and D. L. Olson, Colorado School of Mines, Department of Materials Science, 1500 Illinois Street, Golden, CO 80401; J. Morrell, Y-12 National Security Complex, Department of Chemistry, Oak Ridge, TN

11:50 AM Nondestructive Evaluation of Adhesively Bonded Carbon Fiber Reinforced Composite Lap Joints with Varied Bond Quality
---V. K. R. Lokesha, C. R. Murthy, and M. R. Bhat, Indian Institute of Science, Department of Aerospace Engineering, IISc, Bangalore, Karnataka, India

12:10 PM Lunch
Two-Step Formation of Closed Stress Corrosion Cracks in Ni-Based Alloy Weld Metal and Its Evaluation by Subharmonic Phased Array
---Yoshikazu Ohara, Satoshi Horinouchi, Yohei Shintaku, and Kazushi Yamanaka, Tohoku University, Department of Materials Processing, Sendai, Miyagi, Japan

---To ensure the safety of atomic power plants against massive earthquakes, accurate measurement of crack depth is needed. However, inspection of stress corrosion cracks (SCCs) is difficult in Ni-based alloy weld metal (NBAWM) because of the strong crack closure. This leads to a problem of underestimation or overlook of cracks, resulting in catastrophic accidents such as radiation leaks. For application of new inspection methods to solve this problem, and for the training/education of inspection, realistic closed SCC specimens are required, but open SCC specimens by acceleration test have been used instead. It is because formation of mm-sized closed SCCs in the high temperature pressurized water (HTPW) takes several years because of low growth rate. Here, we propose a two-step process to form closed SCCs in relatively short time of several months. The first step is to weld stainless steel plates by NBAWM. Then, the SCC was extended from the notch in K2S4O6 solution at room temperature. It took a few weeks to form open SCC with about 9 mm deep. The second step is to close the SCC by filling oxide films between the crack faces. To this end, the specimen was immersed in an autoclave with HTPW. To verify the crack closure, inspection method capable of distinguishing between open and closed cracks is needed. As an almost unique possibility, the subharmonic phased array for crack evaluation (SPACE) was employed since it has been proven to provide fundamental array (FA) and subharmonic array (SA) images, showing open and closed parts of a crack, respectively. In the FA image, the crack was imaged at 8 mm depth. On the other hand, in SA image, the crack tip was imaged at 9.5 mm depth. It is deeper than that in the FA image. This shows that the part of SCC between 8 mm and 9.5 mm was closed by the generation of oxide film between crack faces. This result will also significantly improve scientific understanding of SCCs.

Fatigue Damage Evaluation in a Pure Copper with Nonlinear Resonant Ultrasound Spectroscopy (NRUS)
---Toshihiro Ohtani and Yutaka Ishii, Shonan Institute of Technology, Department of Mechanical Engineering, 1-1-25 Tusjido-Nishikaigan, Fujisawa, Kanagawa, 251-8511, Japan

---In this paper, we describe a monitoring technique of fatigue damage in pure copper plates, JIS-C1100, under a cyclic 0-to-tension loading by the nonlinear resonant ultrasound spectroscopy (NRUS), which is a resonance-based technique exploiting the significant nonlinear behavior of damaged materials. In NRUS, the resonant frequency of an object is studied as a function of the excitation level. As the excitation level increases, the elastic nonlinearity is manifest by a shift in the resonance frequency. NRUS exhibits high sensitivity to microstructural change of damaged materials. We use an electromagnetic acoustic transducer (EMAT) to monitor NRUS of bulk shear wave propagating in the thickness direction of the sample. The EMAT operates with the Lorentz-force mechanism and is the key to establish a monitoring for microstructural change during fatigue with high sensitivity. Furthermore, use of EMAT makes contactless transduction possibility. We also monitor the change of linear ultrasonic characterizations, shear-wave attenuation and velocity. NRUS exhibits much larger sensitivity to the damage accumulation than the velocity. It rapidly increases from 60% of fatigue life to the fracture. The attenuation shows the peak at 70% of the life. These are no clear independence on the stress amplitude. The NRUS evolution as creep progress is related to the microstructure change, especially, dislocation mobility. This is supported by TEM observation for dislocation structure. This technique has potential to assess the damage advance and to predict the fatigue life of metals.
Ultrasonic Fatigue Process Analyzed by Using Laser Doppler Vibromater and Continuous AE Waveform Analysis System

---M. Shiwa, Y. Furuya, and H. Yamawaki, National Institute for Materials Science, Materials Reliability Unit, Tsukuba, Ibaraki, Japan; K. Ito and M. Enoki, The University of Tokyo, Department of Materials Engineering, Tokyo, Japan

---Non-linear ultrasonic parameter b and acoustic emission (AE) signals during ultrasonic fatigue testing were analyzed by using Laser Doppler Vibrometer (LDV) and continuous AE waveform analysis system (CWM). Notched specimens of a high-strength low alloy steel were prepared for the ultrasonic fatigue testing with an exciting vibration frequency of 20 kHz. The detected surface velocity was the longitudinal direction at the end of specimen with frequency range from 200 Hz to 500 kHz. The slopes of b parameter based on a long range FFT were changing, which is related to the breaking cycles. However, the resonant frequency and b of non broken specimens were stable during fatigue testing. AE Events of each broken specimens were detected before the increasing b parameter based on a short range FFT in broken samples. The b parameter is probably attributed to the growth and transformation of dislocation dipole substructures formed in micro cracks during fatigue.

Inspection Challenges Associated with the Use of the Creep Strength Enhanced Ferritic Steels

---J. Henry and A. N. Lasseigne, Structural Integrity Associates, Inc., Chattanooga, TN 37421; Generation 2 Materials Technology, LLC, Tomball, TX 77098

---A new class of ferritic alloys developed for use in the Power and Petrochemical industries offer substantially improved strength at elevated temperatures, making it possible in many high temperature applications to eliminate or reduce the use of the more costly and fatigue-sensitive austenitic stainless alloys. As should be expected, however, this improved creep strength comes at a cost: these alloys depend for their improved strength on a specific condition of microstructure that is developed through a tightly controlled regimen of heat treatment. Any deficiencies in the processing of these alloys during either welding or heat treatment can result in disruption of the required condition of microstructure and, thereby, loss of enhanced strength. The sensitivity of these materials to all aspects of thermal processing creates a particular challenge for quality control and inspection, because the specific features of the microstructure that are most critical to the elevated temperature strength of the alloy cannot be measured directly by traditional non-destructive inspection techniques, such as ultrasonic testing, eddy-current testing, hardness testing, or metallographic replication. As a result, there have been substantial numbers of components fabricated from these materials that have been processed improperly and subsequently placed in service because the available inspection techniques were not sufficiently sensitive to detect the effects of the processing errors on the material microstructure. It is for this reason, that recent successful efforts using advanced field-hardened electromagnetics capable of sensing subtle changes in the electronic properties of a material represents a potential quantum leap in inspection technology. This paper will discuss the unique assessment problems posed by the advent of the creep strength-enhanced ferritic steels and how those problems are addressed by advanced electromagnetic microstructural characterization technology.
Characterization of Residual Stresses in Pipelines By Nondestructive Electromagnetic Assessment
---J. E. Jackson, K. M. Koenig, and A. N. Lasseigne, Generation 2 Materials Technology, LLC, 1626 S. Cherry Street, Tomball, TX 77375

---Nondestructive tools are being developed to quantitatively assess pipeline steels for residual stress from the exterior of the pipeline and through structural coatings. Residual stress is a critical factor that determines the cracking susceptibility of pipeline steels, but existing methods for measuring mechanical damage in pipeline steels are incapable of accurately quantifying the residual stress levels. Re-rounding and other phenomena can alter the residual stress and shape of dents, so that a larger gouge or dent does not necessarily signify worse damage than a smaller gouge or dent. Therefore it is more important to focus on the actual residual stress levels induced by damage. Knowledge of the residual stress levels associated with mechanical damage provides an accurate means to assess the severity of the damage and improve the pipeline integrity, ultimately reducing the amount of unnecessary removal and repair applications. The unique use of electromagnetic testing sensors will allow for through-thickness pipeline integrity assessment. The results of preliminary analysis from in-situ residual stress measurements on simulated mechanically damaged pipeline steel are compared with finite element and other stress estimation techniques.

High Frequency Ultrasonic Mitigation of Microbial Corrosion

---Microbiologically Influenced Corrosion (MIC) is a major problem in oil industry facilities, and considerable effort has been spent to mitigate it. More environmentally benign methods are under consideration as alternatives to biocides, among which are ultrasonic techniques. In this study, a high frequency ultrasonic (HFUT) technique was used as a mitigation method for MIC. The killing percentages of the HFUT were higher than 99.8% and their corrosivity on steel was reduced by more than 50%. The practice and result will be discussed.
In-Situ Repairs of Pipelines Using Metal Arc Welding Under Oil (MAW-UO) Aided by Eddy Current Crack Detection

---Hamad H. Almostaneer, Zack Jones, Stephen Liu, and David L. Olson, Metallurgical and Materials Engineering Department, Colorado School of Mines, Golden, CO 80401

---Metal arc welding under oil (MAW-UO) is a new process designed to make in-situ internal repairs of in-service oil industry pipelines, tanks and vessels without the need to evacuate the service from the containing fluid. High nickel alloy welding wires were used to produce a tough, relatively soft, austenitic weld metal; with reduced weld metal hardness, porosity, residual strain, and cracking susceptibility. Eddy current sensors were able to detect cracks under oil which then can be repaired in-situ using MAW-UO. The in-situ under oil cracks detection and arc weld repair will be described.

Utilization of Nondestructive Electrochemical Techniques in Characterizing Microbiologically Influenced Corrosion (MIC) of API-5L X65 Carbon Linepipe Steel: Laboratory Study

---Faisal Al-Abbas, David Olson, Brajendra Mishra, and John R. Spear, Colorado School of Mines, 1500 Illinois Street, Golden, CO 80401; Anthony Kakpovbia, Saudi Aramco

---Nondestructive electrochemical techniques were used to investigate the microbiologically influenced corrosion (MIC) by Sulfate Reducing Bacteria (SRB) corrosion of API 5L X65 linepipe steel widely used in hydrocarbon transporting pipelines. These techniques included Electrochemical Impedance Spectroscopy (EIS), open circuit potential (OCP) and linear polarization resistance (Rp). OCP trend showed anodic polarization of 67 mV between the biotic media with reference to abiotic media. These shifts were attributed to the cathodic side reactions produced by the metabolic activity of SRB. Through circuit modeling, EIS results were used to interpret the real time interactions between the electrode, biofilm and solution interfaces. The results revealed two time constants in the biotic media which were attributed to the corrosive activity of the microorganism that formed biofilm and a porous iron sulfide layers on the metal surface over time. Moreover, FESEM images validated the EIS results, which confirmed biofilm development on the metal substrate. Corrosion products were characterized by X-ray diffraction (XRD) which identified the presence of different sulfide and oxide constituents that included FeS and Mackinawite and FeOOH.
Ultrasonic Determination of Carbon Content in Uranium Metal
---Jonathan A. Poncelow, Brajendra Mishra, and David L. Olson, Colorado School of Mines, Department of Materials Science, 1500 Illinois Street, Golden, CO 80401; Jonathan Morrell, Y-12 National Security Complex, Department of Chemistry, Oak Ridge, TN

---A nondestructive method to determine the solute content of carbon in polycrystalline uranium by ultrasonic techniques is currently being developed. The problem is approached by considering first theories developed in the field of physical acoustics applicable to variation in attenuation and elasticity with respect to interstitial and second-phase contents. Attention is given to the physical metallurgy of uranium, specifically phase stability and the effects of carbon concentration on physical properties. Experimental verification of theory is provided using Resonant Ultrasound Spectroscopy (RUS) and pulse-echo time of flight measurements, the former yielding elastic moduli and quality factors and the latter supplying attenuation and velocity information.

Nondestructive Evaluation of Adhesively Bonded Carbon Fiber Reinforced Composite Lap Joints with Varied Bond Quality
---Vijaya Kumar Ravandur Lokesha, Challa Ramalinga Murthy, and Modbidri Ramachandra Bhat, Indian Institute of Science, Department of Aerospace Engineering, IISc, Bangalore, Karnataka, India

---Adhesive bonding is widely used to execute assemblies in a variety of structures including automobile and aerospace. The quality and reliability of these bonded joints must be ensured during service. In this context nondestructive evaluation of these bonded structures plays an important role. In fact till today while bond quality is usually assessed, determination of strength of a joint is still a topic of extensive research. In order to move towards this objective, evaluation of adhesively bonded composite single lap shear joints has been attempted using different experimental techniques. A series of tests were performed on different sets of specimen prepared according ASTM D 5868 standard for lap shear adhesion for fiber reinforced plastic bonding. Unidirectional carbon fiber reinforced plastic substrates were joined using AV138M/HV 998 two part epoxy adhesive system. Different sets of specimens with varied bond quality were obtained by induced degradation in the adhesive layer with Poly Vinyl Alcohol. The bonded area of the specimen was subjected to ultrasonic testing and subsequently loaded till failure to obtain their bond strengths. Acoustic emission data was obtained during the process of loading the adhesive joint. Shear Strain at different stages of failure was measured using Digital image correlation technique. Some of the results obtained from these experiments are discussed in this paper.
Session 18
SESSION 18
NEW EDDY CURRENT PROBES AND TECHNIQUES
S. Udpa and L. Udpa, Co-Chairpersons
Silver Maple Ballroom

8:30 AM  Development and Modeling of High Resolution Eddy Current Imaging Using an Electro-
Mechanical Sensor
---J. Welter and M. P. Blodgett, Air Force Research Laboratory, Materials and Manufacturing
Directorate, Dayton, OH 45433; M. R. Cherry, S. Sathish, and R. Reibel, University of Dayton
Research Institute, Structural Integrity Division, Dayton, OH 45433

8:50 AM  Validation of Potentials and Limitations of a High-Frequency Eddy Current System in
Frequency-Sweep Mode
---S. Hillmann, H. Heuer, and N. Meyendorf, IZFP, Dresden, Germany; J. G. Calzada, A. T.
Cooney, and B. C. Foos, Air Force Research Laboratory, WPAFB, Dayton, OH 45433

9:10 AM  Novel Rotating Field Probe for Inspection of Tubes
---J. Xin, N. Lei, L. Udpa, and S. S. Udpa, Michigan State University, Department of Electrical and
Computer Engineering, Lansing, MI 48824-1226; E. Tarkleson, Michigan State University,
Department of Mechanical Engineering, Lansing, MI 48824

9:30 AM  EC-GMR Detection of Subsurface Defects at Steel Fastener Sites in Multilayer Structures
---G. Yang1 and Z. Zeng2, Member, IEEE, Y. Deng3, Member, IEEE; X. Liu and L. Udpa1, Fellow,
IEEE, A. Tamburrino1,4, Member, IEEE and S. S. Udpa1, Fellow, IEEE; 1Department of Aeronautics,
Xiamen University, Xiamen, Fujian 361005, China; 2Department of Electrical &
Computer Engineering, Michigan State University, East Lansing, Michigan 48824; 3Department of
Aeronautics, Xiamen University, Xiamen, Fujian 361005, China; 4Department of Electrical
Engineering, Bioengineering and Radiology, University of Colorado Denver, Denver CO, 80217-
3364; 5University of Cassino, Daeimi, 43-03043, Italy, Association EURATOM/ENEA/CREATE

9:50 AM  High-Resolution Imaging with Two-Axis Orthogonal Magneto-Resistive Sensor Based Eddy
Current Probe
---B. Wincheski, NASA Langley Research Center, Research and Technology Directorate, Mail
Stop 231, Hampton, VA 23681; J. Simpson and J. P. Seebo, Lockheed Martin, Hampton, VA 23681

10:10 AM  Break

10:30 AM  Modeling of New Eddy Current Probes in Steam Generator Inspection
---N. Lei, G. Yang, L. Udpa, and S. S. Udpa, Michigan State University, 2120 Engineering Building,
East Lansing, MI 48824; A. Z. Zeng, Xiamen University, Department of Aeronautics, Xiamen,
Fujian 361005, China

10:50 AM  Methods for Shielding a Flexible PCB Made Eddy Current Array Probe Against Edge Effects
---B. Lepage, Olympus NDT Canada INC., 505, boul. du Parc-Technologique, Quebec, G1P 4S9,
Canada

11:10 AM  Model-Based Studies of the Split D Differential Eddy Current Probe
---R. D. Mooers, University of Dayton Research Institute, Structural Integrity Division, Dayton,
OH 45402; J. S. Knopp and M. P. Blodgett, Material and Manufacturing Directorate, AFRL/RXLP,
Wright Patterson, OH 45433

11:30 AM  Characterization of Wet Conductive Coatings During Curing Using Eddy Current Techniques
---S. Hillmann, H. Heuer, and N. Meyendorf, Fraunhofer Institute for Nondestructive Testing
(IZFP), Dresden, Germany; J. G. Calzada, A. T. Cooney, and B. C. Foos, Air Force Research
Laboratory, WPAFB, Dayton, OH 45433

11:50 AM  Modeling Eddy Current Detection of Edge Cracks on Chamfered Edges
---N. Nakagawa and B. F. Larson, Iowa State University, Center for NDE, 1915 Scholl Road,
Ames, IA 50011; D. Raulerson, United Technologies, Pratt & Whitney, West Palm Beach, FL 33410

12:10 PM  Lunch
Development and Modeling of High Resolution Eddy Current Imaging Using an Electro-Mechanical Sensor
---John Welter and Mark P. Blodgett, Air Force Research Laboratory, Materials and Manufacturing Directorate, Dayton, OH 45433; Matthew R. Cherry, Shamachary Sathish, and Richard Reibel, University of Dayton Research Institute, Structural Integrity Division, Dayton, OH 45433

---Typical eddy current probes are based on measuring the impedance change of a coil excited by an AC current when the coil is placed above a conductive sample. These types of probes are limited in spatial resolution to the dimensions of the coil, and coil diameter is limited by operating frequency. Because of this, the highest resolution available with these probes is on the order of 100 um. While detecting the impedance change of the probe has limited spatial resolution, various methods of detecting the change in magnetic field in and around the coil have been shown to improve the resolution of a standard coil. These methods have improved the resolution in eddy current imaging to 25 nm. To date, the resolutions achievable by modern eddy current technology have failed to encompass the 100nm-100 um range, which would be ideal for microstructure characterization of conductive materials. In this paper, a new probe is presented that is based on the electromechanical design to fill this resolution gap. The new probe is designed and developed with a sharpened magnetic tip attached to the membrane of an electret microphone. The magnet is actuated by an external coil with a low current AC voltage. The motion of the magnet produces eddy currents in a conductive sample, which then result in a damping force on the magnet. The results of the experimental measurements demonstrate that this probe has spatial resolution that is much higher compared with the measurements using the external excitation coil only. A governing equation for the probe is presented that treats the magnet as a magnetic dipole and uses the eddy current forces as a damping term in the equation of motion for the membrane. The equation is solved with finite differences and the resolution is indeed shown to be on the order of the tip diameter.

Validation of Potentials and Limitations of a High-Frequency Eddy Current System in Frequency-Sweep Mode
---Susanne Hillmann, Henning Heuer, and Norbert Meyendorf, Fraunhofer Institute for Nondestructive Testing (IZFP), Dresden, Germany; Juan G. Calzada, Adam T. Cooney, and Bryan C. Foos, Air Force Research Laboratory, WPAFB, Dayton, OH 45433

---Eddy Current techniques can provide a fast and precise opportunity to characterize the thickness of thin conducting surface layers. To characterize very thin conductive layers on a conducting substrate, low penetrations depths at high measurement frequencies are required. Equally high measurement frequencies are needed to characterize materials with very low electrical conductivity. For the characterization of the thickness of multi-layer-systems or layer-substrate-systems with very low variations of electrical conductivity, the multi-frequency approach can be a promising solution. Fraunhofer-IZFP Dresden has developed a prototype system for high-frequency Eddy Current measurements using frequencies up to 100MHz. The system is configured to permit the sweeping of numerous measurement frequencies in a large frequency range to acquire a frequency depending profile of the Eddy Current measured. This approach allows characterization of very thin layers, in the micrometer range, and to characterize layers with very thin electrical conductivity, around 1% IACS. To investigate the limitations of such high-frequency Eddy Current systems, experiments are performed using an extensive sample concept. These samples consist of substrates with low, medium and high electrical conductivity that are coated with layers of low, medium and high electrically conductive layers having different layer thicknesses. In addition, some samples are produced as double-layer-systems. This article shows experimental results of the described sample concept related to frequency depending conductivity profiles and frequency response locus in the complex impedance plane. The article discusses results and displays options as well as limitations of Frequency-Sweep Mode Eddy Current measurements with frequencies of up to 100MHz.
Novel Rotating Field Probe for Inspection of Tubes
---J. Xin, N. Lei, L. Udpa, and S. S. Udpa, Michigan State University, Department of Electrical and Computer Engineering, Lansing, MI 48824-1226; E. Tarkleson, Michigan State University, Department of Mechanical Engineering, Lansing, MI 48824

---Inspection of tubular test samples are needed in several industries such as natural gas transmission pipelines and steam generator tubes in nuclear power plants. In the nuclear industry, steam generator tube inspection using eddy current techniques has evolved over the years from a simple bobbin coil, to rotating probe coil (RPC) and array probe, in an attempt to improve the speed and reliability of inspection. The RPC probe offers the best spatial resolution but involves complex mechanical rotation. This paper presents a novel design of eddy current inspection based on rotating fields produced by three identical coils excited by a balanced three-phase supply. The sensor thereby achieves rotating probe functionality by electronic means and eliminates the need for mechanical rotation. The field generated by the probe is largely radial that result in induced currents that flow circularly around the radial axis rotating around the tube at synchronous speed effectively producing induced eddy currents that are multidirectional. The probe will consequently be sensitive to cracks of all orientations in the tube wall. The finite element method (FEM) computational results of the rotating fields and induced currents will be presented. A prototype probe will be built to validate simulation results.

EC-GMR Detection of Subsurface Defects at Steel Fastener Sites in Multilayer Structures
---G. Yang, Z. Zeng, Y. Deng, X. Liu, L. Udpa, A. Tamburrino, and S. S. Udpa; 1Department of Electrical & Computer Engineering, Michigan State University, East Lansing, Michigan 48824; 2Department of Aeronautics, Xiamen University, Xiamen, Fujian 361005, China; 3Departments of Electrical Engineering, Bioengineering and Radiology, University of Colorado Denver, Denver CO, 80217-3364; 4University of Cassino, Daeimi, 43-03043, Italy, Association EURATOM/ENEA/CREATE

---Eddy current testing methods combined with magnetoresistive (MR) sensors have seen increasing applications in recent times in the inspection of deep embedded cracks under fastener heads (CUF) in multi-layer structures. An inspection system based on eddy current excitation and giant-magnetoresistive (EC-GMR) pick-up sensors has been developed and shown to provide improved detectability of 2nd and 3rd layer defects around Aluminum fastener heads. This paper presents the feasibility study of detecting cracks under steel fasteners using tangential components Bx and By of the induced magnetic field. Data fusion using image data of normal and tangential field measurements further enhances the probability of detection of cracks under steel fasteners. The proposed approach is investigated using normal and tangential components generated using a numerical finite element (FE) model and validated using experimental measurements.
High-Resolution Imaging with Two-Axis Orthogonal Magneto-Resistive Sensor Based Eddy Current Probe
---Buzz Wincheski, NASA Langley Research Center, Research and Technology Directorate, Mail Stop 231, Hampton, VA 23681; John Simpson and Jeffrey P. Seebo, Lockheed Martin, Hampton, VA 23681

---Recently, high-resolution eddy current imaging has been sought for applications including sensory material characterization and the analysis of intermittent contact along compression boundaries and fatigue cracks. As the spatial resolution of eddy current imaging is typically limited by the size of the eddy current coil, new methods for minimization of the drive field and sensor pickup area have been investigated. For this a two-channel magneto-resistive sensor with an embedded single strand eddy current inducer has been fabricated and tested. The solid-state magneto-resistive sensor provides high sensitivity measurement of the magnetic field across a spatial area of approximately 0.5 x 0.5 mm. The induction wire is embedded directly into the sensor face to minimize spacing between the drive source and sensor while also protecting the source from mechanical damage. Simultaneous two channel imaging in orthogonal directions helps to further improve the spatial resolution by removing artificial elongation of imaged defects along the direction of the induction wire. Lastly, a rapid scanning technique has been implemented to enable high resolution imaging of relatively large areas in modest times. Applications of the probe for high-resolution imaging of sensory materials, compression boundaries and fatigue cracks are presented. Finite element modeling of the probe is also presented and compared with experimental measurements with good agreement.

Modeling of New Eddy Current Probes in Steam Generator Inspection
---Naiguang Lei, Guang Yang, Lalita Udpa, and Satish S. Udpa, Michigan State University, 2120 Engineering Building, East Lansing, MI 48824; A Zhiwei Zeng, Xiamen University, Department of Aeronautics, Xiamen, Fujian 361005, China

---Computational models serve an important role in NDE applications for enabling effective use of the technology. The solution of simulation models provide valuable insight into the underlying physics, help visualize the field/flaw interaction, help optimize sensor design and develop algorithms for interpreting the measured signals. This paper presents a simulation model for predicting defect signals in Steam Generator tube inspections using a number of commercial eddy current probes used in industry. These probes range from simple bobbin probes to ferrite core plus point probes and array probes. The model, based on finite element analysis, uses reduced vector potential formulation and novel strategies for modeling ferrite core probes. Experimental validation of model predictions for a number of probe and defect geometry will be presented.
Methods for Shielding a Flexible PCB Made Eddy Current Array Probe Against Edge Effects
---Benoit Lepage, Olympus NDT Canada INC., 505, boul. du Parc-Technologique, Quebec, Quebec, G1P 4S9, Canada

---Probe shielding has been used in combination with eddy current and eddy current array sensors for improving detection of defects located near a components edges for a while. Conventional methods to provide such shielding are not suitable for coils etched on a printed circuit board. This paper describes an innovative shielded coil design suitable for highly flexible printed circuit board eddy current array probes. The benefits of the new design will be demonstrated for the inspection of dovetails, where detection of near edges defects is critical.

Model-Based Studies of the Split D Differential Eddy Current Probe
---Ryan D. Mooers, University of Dayton Research Institute, Structural Integrity Division, Dayton, OH 45402; Jeremy S. Knopp and Mark P. Blodgett, Material and Manufacturing Directorate, AFRL/RXL, Wright Patterson, OH 45433

---Differential eddy current probes generally have an advantage over absolute probes in that they are highly sensitivity to defects and intrinsically invariant to gradual changes in geometry and material properties. They enhance the detection of defects due to reduction of signal variations due to alignment issues in the measurements. These probes are commonly used in aerospace and power generation industries. Prior research on differential coils has focused primarily on bobbin coils or those composed entirely of circular coils. Very little modeling studies of the split-D type of differential coils have been presented in the literature. This paper presents results from computational models for split-D differential probe configurations. Two commercially available eddy current modeling packages, ECSIM and VIC-3D®, are used to model a standard reflection differential pencil probe. This study will provide a comparison between the results obtained from the two approaches, and provide direction for future benchmarking and model validation investigations.
Characterization of Wet Conductive Coatings During Curing Using Eddy Current Techniques
---Susanne Hillmann, Henning Heuer, and Norbert Meyendorf, Fraunhofer Institute for Nondestructive Testing (IZFP), Dresden, Germany; Juan G. Calzada, Adam T. Cooney, and Bryan C. Foos, Air Force Research Laboratory, WPAFB, Dayton, OH 45433

---Carbon fiber composites are increasingly used for shell surfaces in the aircraft industry. Aircraft shell structures must be furnished with lightning protection. Until now this is realized by integrating copper mesh onto the shell surface. In order to reduce the weight of this lightning protection solution, materials and processes for spraying electrically conductive paints on airplanes have been developed. These complex conductive coatings require an exact process control to achieve the demanded properties. Wet conductive coatings can dispense non-uniformly on the surface, for example due to uneven contours of the airplane structure. Especially for the aircraft industry, it is important to find a compromise between layers that are too thick, resulting in more weight, and layers that are too thin, resulting in insufficient lightning protection. Furthermore it is required to achieve a homogeneous conductivity of the coating to avoid critical local current densities in the event of a lightning strike. To monitor the spraying and drying process and respective film thickness and conductivity, a solution is required. The method presented here is an Eddy Current based solution, which could enable a fast and precise characterization of the conductive coating thickness during the drying process of the wet coatings when the conductivity is marginal and highly variable. This article shows experimental results of Eddy Current measurements of wet conductive coatings during the drying process. In addition, recorded drying curves are discussed and approaches to implement the technique into practical testing instruments and systems are presented.

Modeling Eddy Current Detection of Edge Cracks on Chamfered Edges
---Norio Nakagawa and Brian F. Larson, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011; David Raulerson, United Technologies, Pratt & Whitney, West Palm Beach, FL 33410

---This paper presents the results of an eddy current NDE modeling project, aiming to validate model predictions against experiment. The study specifically involves a set of scallop-shaped titanium alloy samples, with top and bottom chamfered edges. Each sample contains an artificially grown fatigue crack either on one of the chamfered edges or between the two. A custom probe was designed and built to scan the edge samples. Experiments showed symmetric four-prong impedance deflections with repeatable peak-to-peak signals from a subset of the sample set. We thus used this subset and the peak-to-peak vertical voltage deflections to test the model. The computational task was carried out by a numerical eddy current simulation model based on the boundary element method, with CAD models of the edge inspection probe and square plate geometry of top and bottom chamfers as input. The model internally generated a mesh of an ideally tight crack to simulate each of the cracks, where the surface length is known, while the depth and exact location are unknown and thus assumed. As a conclusion, we will present the computed impedance signals that reproduce the characteristic four-prong crack indications. We will also present a correlation plot between the predicted and measured peak-to-peak deflections. The correlation plot exhibits morphological effects, similar to those we presented previously based on flat-surface crack specimens. A possible impact of the result on the model-assisted probability of detection studies will be discussed.
SESSION 19
UT PHASED ARRAYS II
M. Spies, Chairperson
Sugar Maple Ballroom

1:30 PM  Shape Adaptive Beam Steering Technique for Phased Array Ultrasonic Testing

1:50 PM  Determination of Shape Profile by the SAFT for Application of Phased Array Technique to Complex Geometry Surface
---M. Nagai, S. Lin, and H. Fukutomi, Central Research Institute of Electric Power Industry, Materials Science Research Laboratory, Yokosuka-shi, Kanagawa, Japan

2:10 PM  Ultrasonic Phased Array Detection of Cracks in Deepwater Fastener Nuts
---G. P. Pires, Petrobras’ Research and Development Center (CENPES), Materials Equipments and Corrosion Department (TMEC), 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; V. Lupien, Acoustic Ideas Inc., Wakefield, MA 01880

2:30 PM  Turbine Rotor Inspection Using Phased Array Method

2:50 PM  The Development of a 2D Ultrasonic Array System for the In Situ Inspection of Single Crystal Turbine Blades
---C. J. L. Lane and T. K. Dunhill, Rolls-Royce plc, GP 4-1-4, NDE Laboratory, Bristol, BS34 7QE, United Kingdom; B. W. Drinkwater and P. D. Wilcox, University of Bristol, Department of Mechanical Engineering, BS8 1TR, United Kingdom

3:10 PM  Break

3:30 PM  Investigation of Ultrasonic Array Measurements to Refine Weld Maps of Austenitic Steel Welds
---Z. Fan and M. J. S. Lowe, Imperial College, Department of Mechanical Engineering, London, SW7 2AZ, United Kingdom

3:50 PM  Quantitative Ultrasonic Testing of Acoustically Anisotropic Materials Verified on Austenitic and Dissimilar Weld Joints
---S. Pudovikov, A. Bulavinov, and C. Boller, Fraunhofer Institute of Non-Destructive Testing IZFP, Campus E3.1, Saarbrücken, 66123 Germany

4:10 PM  The Effect of Beam Directivity on the Inspection of Anisotropic Materials Using Ultrasonic Arrays
---C. J. L. Lane, Rolls-Royce plc, GP 4-1-4, NDE Laboratory, Bristol, BS34 7QE, United Kingdom; P. D. Wilcox, University of Bristol, Department of Mechanical Engineering, BS8 1TR, United Kingdom

4:30 PM  Characterization of Composite Material Using Ultrasonic Arrays
---C. Li, D. Pain, P. D. Wilcox, and B. W. Drinkwater, University of Bristol, Department of Mechanical Engineering, University Walk, Bristol, BS8 1TR United Kingdom

4:50 PM  Design and Development of High Frequency Matrix Phased-Array Ultrasonic Probes
---J. K. Na and R. L. Spencer, Edison Welding Institute, NDE Group,1250 Arthur E. Adams Drive, Columbus, OH 43221
Shape Adaptive Beam Steering Technique for Phased Array Ultrasonic Testing
---Setsu Yamamoto, Jun Senboshi, and Makoto Ochiai, Toshiba Corporation, Power and Industrial Systems Research and Development Center, Yokohama, Kanagawa, Japan; Tadahiro Mitsuhashi, Hiroyuki Adachi, and Satoshi Yamamoto, Toshiba Corporation, Isogo Engineering Center, Yokohama, Kanagawa, Japan

---We have developed a phased array ultrasonic testing (PAUT) technique which is suitable for use on complex surface profiles such as a nozzle of a pressure vessel or a part deformed by welding. In this paper, the development of a shape adaptive beam steering technique employing a flexible coupling gel under dry conditions is described. Firstly the synthetic aperture focusing technique (SAFT) was employed to measure complex surface profiles. Comparing the time-of-flight (TOF) to SAFT, the measurement error of surface profiles with a radius-of-curvature of 60mm was reduced from 0.9mm to less than 0.05mm. Delay time calculation code for as-built profiles was developed. Considering the geometric relationship between ideal beam paths in test objects and actual surface profiles, the element to be used and delay time for each element are properly calculated with the code. Using the above method, the measurement error of crack tips under the curved surface was reduced from over 4mm to less than 1mm. Secondly we developed a coupling gel which has the flexibility to contact to the complex surfaces with characteristics similar to water. Comparing the immersion technique with the gel, the sensitivity rate was more than 95% and the difference of crack sizing accuracy was less than 1mm.

Determination of Shape Profile by the SAFT for Application of Phased Array Technique to Complex Geometry Surface
---Masaki Nagai, Shan Lin, and Hiroyuki Fukutomi, Central Research Institute of Electric Power Industry, Materials Science Research Laboratory, Yokosuka-shi, Kanagawa, Japan

---Creep damage in the heat affected zone of welded high-chromium pipes is a crucial problem in ultra-super critical power plants. The ultrasonic phased array technique is a powerful tool for detection of creep damage. In order to detect the damage near the surface at earlier stages, it is necessary to transmit the ultrasonic wave with the appropriate refraction angle. Consequently, it is expected that creep damage can be detected over the weld metal while the weld exits. In such a case, in order to control the ultrasonic beam orientation after transmission through complicated interfaces, it is necessary to measure the surface profile of the specimen. In this paper, a method to reconstruct surface profiles of the specimens is proposed by means of the synthetic aperture focusing technique (SAFT). Surface profiles of the simulated crown of a butt welding specimen and the fillet of a nozzle welding specimen with side-drilled holes (SDHs) that were obtained using the proposed method agree well with the actual shapes. Moreover, the positions of indications for SDHs displayed in side views were in excellent agreement with their actual positions.
Ultrasonic Phased Array Detection of Cracks in Deepwater Fastener Nuts
---Gustavo P. Pires, Petrobras' Research and Development Center (CENPES), Materials Equipments and Corrosion Department (TMEC), Rio de Janeiro, RJ, Brazil; Joao M. A. Rebello, Federal University of Rio de Janeiro, Department of Metallurgical and Materials Engineering - COPPE/UFRJ, Rio de Janeiro, RJ, Brazil; Vincent Lupien, Acoustic Ideas Inc., Wakefield, MA 01880

---This work explores the versatility of ultrasonic phased arrays for detecting cracks in fastener nuts in a deepwater environment using a remotely operated vehicle (ROV). The use of an ROV imposes limitations on the movements allowed for the probe, such that the entire volume of the nut must be ultrasonically accessible using only one or two of its lateral faces. Ensuring volumetric coverage of the nut is insufficient to allow detectability of cracks; inspection solutions must also guarantee that the rays return to the probe after interacting with the crack. Using phased arrays with electronically moving apertures, beam steering and extensive use of multiple reflections from the hexagonal geometry, it is possible to fulfill these requirements, which we demonstrate using several simulation tools. In our first approach, sixty degree linear scanning is used both in transmission and pulse echo mode. In our second approach, we improve the detectability by controlling the angle of arrival at every inspection location for near perpendicular incidence to expected crack orientations. Finally, a full matrix capture scanning followed by a reconstruction algorithm is used. The different approaches are tested both by simulations and experiments and an inspection strategy is outlined.

Turbine Rotor Inspection using Phased Array Method

---Turbine rotors are subject to high stresses due to the high operational speeds and exposure to varying and high temperatures. The highest stressed areas are located around the centerline of solid rotors and around the bore surface for bored rotors. Siemens uses NDE methods to check the integrity of the rotors for continued service. These NDE methods include visual, magnetic particle and ultrasonic inspections to detect any indications at both the surface and the volume of the rotor. The current method for the ultrasonic inspection uses a conventional probe with a number of wedges to scan the volume of the rotor for any radial axial flaws such as inclusion and cracks. The new method, based on phased array technique reduces the number of wedges and the inspection time. The phased array allows a multiple beam angles to be performed simultaneously and thus more accurate flaw sizing. The new phased array method is based on DGS for sizing of flaws. In-house software has been developed to allow the 3D visualization of the ultrasonic data, signal processing and data analysis. This paper describes the developed phased array technique and the practical trials used to evaluate it in the laboratory and in the field.
The Development of a 2D Ultrasonic Array System for the In Situ Inspection of Single Crystal Turbine Blades

Christopher J. L. Lane and Tony K. Dunhill
Rolls-Royce plc, GP 4-1-4, NDE Laboratory, Bristol, BS34 7QE, United Kingdom; Bruce W. Drinkwater and Paul D. Wilcox, University of Bristol, Department of Mechanical Engineering, BS8 1TR, United Kingdom

Modern jet-engine turbine blades are cast from single crystals of nickel-based superalloys because of the excellent mechanical properties that these materials exhibit at high temperatures. However, the anisotropic behavior of single crystals causes difficulties when using ultrasound to inspect these components for defects that could potentially initiate in-service. This paper describes the development of a 2D ultrasonic array system for the in situ inspection of these components. The problems associated with the inspection of anisotropic single crystal materials such as the directional dependence of the ultrasonic velocity, beam directivities in anisotropic media and the variation in the crystallographic orientation, are all addressed in this paper. In addition, constraints regarding access to the inspection location within the engine are discussed. Finally, the defect detection sensitivity and sizing capability of the developed system is evaluated.

Investigation of Ultrasonic Array Measurements to Refine Weld Maps of Austenitic Steel Welds

Zheng Fan and Mike J. S. Lowe, Imperial College, Department of Mechanical Engineering, London, SW7 2AZ, United Kingdom

It is challenging to inspect austenitic welds non-destructively using ultrasonic waves because ultrasonic beams are deviated due to spatially varying anisotropy of the material. Models have been developed to predict the propagation of ultrasound in such welds, and most of them assume that the inhomogeneity of the material which can also be described as the weld map is already known. However, in reality weld maps may vary according to allowable variations in the manufacturing, thus it becomes necessary to develop a method to measure weld maps in order to perform accurate inspections in welds. This work investigates the idea of using ultrasonic array measurements to refine weld maps of inhomogeneous and anisotropic welds. Two models have been studied, both of which use a small number of key parameters to describe the weld map. Numerical modelling, based on ray-tracing techniques and also the finite element method, has been carried out to simulate measurements of selected ultrasonic array signals through the weld. An inverse model based on a genetic algorithm has been developed to iterate the key parameters in the model of the weld map with the results obtained from the simulated ultrasonic array measurements.
Quantitative Ultrasonic Testing of Acoustically Anisotropic Materials Verified on Austenitic and Dissimilar Weld Joints
---Sergey Pudovikov, Andrey Bulavinov, and Christian Boller, Fraunhofer Institute of Non-Destructive Testing IZFP, Campus E3.1, Saarbrücken, 66123 Germany

---A Sampling Phased Array developed by Fraunhofer IZFP allows the acquisition of A-scans for individual transducer elements of a transducer array combined with image reconstruction techniques based on synthetic focusing algorithms. This considers propagation of sound from each pixel of an image to the individual sensing transducer element. For anisotropic media, where the sound beam is deflected and the sound path is not known a-priori, a new phase adjustment technique called “Reverse Phase Matching” has been implemented. A ray tracing algorithm additionally allows acoustic wave propagation to be modeled and propagation time of sound to be calculated by taking anisotropy and inhomogeneity of an austenitic or dissimilar weld structure into account. This allows propagation of sound in an anisotropic structure to be determined and can be used for 2D and 3D real time image reconstruction. With the “Gradient Elastic Constant Descent Method” (GECDM) an iterative algorithm has been additionally implemented being essential for examining inhomogeneous anisotropic media having unknown elastic constants. Combining all the methods allows unknown elastic constants to be determined and provides reliable and efficient quantitative flaw detection. Validation of a ray-tracing algorithm and the GECDM-method has been achieved through experiments.

The Effect of Beam Directivity on the Inspection of Anisotropic Materials Using Ultrasonic Arrays
---Christopher J. L. Lane, Rolls-Royce plc, GP 4-1-4, NDE Laboratory, Bristol, BS34 7QE, United Kingdom; Paul D. Wilcox, University of Bristol, Department of Mechanical Engineering, BS8 1TR, United Kingdom

---The beam directivity from an ultrasonic transducer in isotropic materials is well documented. However, beam directivities in elastically anisotropic materials and their effect on ultrasonic NDE inspection has been investigated far less extensively. In this paper, analytical and numerical finite element models are developed to predict the beam directivity in a single crystal nickel-based superalloy. This material is highly anisotropic and is used widely in the gas-turbine industry. The developed models are used to investigate the effect of the crystallographic orientation on the beam directivity. In turn, the effect of beam directivity on defect detection sensitivity and characterization capability using an ultrasonic array is demonstrated. It is shown that the effect is particularly important for the accurate sizing of small defects.
Characterization of Composite Material Using Ultrasonic Arrays
---Chuan Li, Damien Pain, Paul D. Wilcox, and Bruce W. Drinkwater, University of Bristol, Department of Mechanical Engineering, University Walk, Bristol, BS8 1TR United Kingdom

---Recent years have seen a rapid expansion in the use of carbon fiber composites in the aerospace and automotive sectors. It is vital to have appropriate NDE approaches to utilize the full potential of these components. This paper presents ultrasonic array post-processing techniques to improve the quantitative imaging of carbon fiber composite laminates. The particular challenge addressed is the inspection of relatively thick sections which present the most critical imaging conditions. Extensions to the Total Focusing Method array post-processing techniques are described and a new algorithm is developed that is tailored for application to the anisotropic and non-homogeneous nature of a composite laminate. The effects of the anisotropic material properties are included by using the velocity profiles extracted via the most appropriate experimental method. The non-homogenous laminar structure results in high levels of backscatter meaning that high incident angles contribute little to the image, other than the addition of noise. The correct choice of angular aperture is shown to produce significant signal-to-noise enhancements. The scattering from the laminar structure is also highly frequency dependent and so the frequency of a Gaussian filter also strongly influences image signal-to-noise. Both angular aperture and frequency filter characteristics are varied to optimize the array imaging of a 19mm thick carbon fiber composite containing various defects. The imaging results obtained demonstrate the effectiveness of the developed techniques in terms of signal-to-noise of up to 12dB, relative to standard imaging. As a final step the images are corrected to compensate for amplitude loss due to attenuation and scattering. The result of this process is that defects of equal size produce the same amplitude in the image at different depths. Results from this collection of image enhancements techniques are described and their relative merits discussed.

Design and Development of High Frequency Matrix Phased-Array Ultrasonic Probes
---Jeong K. Na and Roger L. Spencer, Edison Welding Institute, NDE Group, 1250 Arthur E. Adams Drive, Columbus, OH 43221

---High frequency matrix phased-array (MPA) probes have been designed and developed for more accurate and repeatable assessment of weld conditions of thin sheet metals commonly used in auto industry. Unlike the line focused ultrasonic beam generated by a linear phased-array (LPA) probe, a MPA probe can form a circular shaped focused beam in addition to the typical beam steering capabilities of phased-array probes. CIVA based modeling and simulation methods have been used to design the probes in terms of various probe parameters such as number of elements, element size, overall dimensions, frequency etc. Challenges associated with the thicknesses of thin sheet metals have been resolved by optimizing these probe design parameters. A further improvement made on the design of the MPA probe proved that a three-dimensionally shaped matrix element can provide a better performing probe at a much lower probe manufacturing cost by reducing the total number of elements and lowering the operational frequency. This three dimensional probe naturally matches to the indentation shape of the weld on the thin sheet metals and hence a wider inspection area with the same level of spatial resolution obtained by a two-dimensional flat MPA probe operating at a higher frequency. The two aspects, a wider inspection area and a lower probe manufacturing cost, make this three-dimensional MPA sensor more attractive to the current auto manufacturers demanding a quantitative nondestructive inspection method.
Session 20
SESSION 20

PROBABILITY OF DETECTION

E. Lindgren and E. Medina, Co-Chairpersons
Mildred Livak Ballroom

1:30 PM  Distinguishing Between Uncertainty and Variability in Nondestructive Evaluation
---M. Li, Applied Statistics Laboratory, GE Global Research, Niskayuna, NY 12309; F. W. Spencer, SFHire, 13812 Haines Avenue NES, Albuquerque, NM 87112; W. Q. Meeker, Iowa State University, Center for NDE and Department of Statistics, Ames, IA 50011

1:50 PM  Modeling Multivariate POD Curves

2:10 PM  Demonstration of Model-Assisted Probability of Detection (MAPOD) Evaluation Methodology for Eddy Current NDE
---J. C. Aldrin², H. A. Sabbagh³, E. H. Sabbagh³, R. K. Murphy³, J. S. Knopp¹, and E. A. Lindgren¹, ¹U.S. Air Force Research Laboratory, Wright-Patterson AFB, OH 45433; ²Computational Tools, Gurnee, IL 60031; ³Victor Technologies, Bloomington, IN 47407

2:30 PM  Probabilistic Collocation Method for NDE Problems with Uncertain Parameters with Arbitrary Distributions
---J. S. Knopp and M. P. Blodgett, Air Force Research Laboratory, Material and Manufacturing Directorate, Dayton, OH 45433; M. R. Cherry, University of Dayton Research Institute, Structural Integrity Division, Dayton, OH 45433

2:50 PM  Transfer Function Model Assisted Probability of Detection for Lap Joint Multi Site Damage Detection
---M. Bode, J. Newcomer, and S. Fitchett, Sandia National Laboratories, Airworthiness Assurance NDI Validation Center, Albuquerque, NM 87106

3:10 PM  Break

3:30 PM  Transfer Function Approach Based on Simulation Results for the Determination of POD Curves
---F. Jenson and E. Lakovleva, CEA, LIST, F-91191 Gif-sur-Yvette, France; N. Dominguez, EADS, Innovation Works Department, 18 rue Marius Terce, 31025 Toulouse, France (Please note: S. Demeyer will present this work.)

3:50 PM  Simulation-Assisted POD of a Phased Array Ultrasonic Inspection in Manufacturing
---N. Dominguez¹, F. Jenson², V. Feuillard³, and P. Willaume⁴, ¹European Aeronautic Defence and Space Company (EADS), Innovation Works Dept., Toulouse, France; ²CEA LIST, ³PHIMECA, ⁴PHIMECA

4:10 PM  POD Generated by Monte Carlo Simulation Using a Meta-Model Based on the simSUNDT Software
---G. Persson, P. Hammersberg, and H. Wirdelius, Chalmers University of Technology, Advanced Nondestructive Testing, Goteborg, Sweden

4:30 PM  Simulation of Ultrasonic Scattering from Inclusions Using Laser Engravings in Glass Samples
---J. Menges, J. Bamberg, and H.-U. Baron, MTU Aero Engines GmbH, Dachauer Str. 665, 80995 Munich, Germany; F. Schubert, Fraunhofer IZFP-Dresden, Maria-Reiche-Str. 2, 01109 Dresden, Germany

4:50 PM  Fluorescent Penetrant Inspection Probability of Detection
Distinguishing Between Uncertainty and Variability in Nondestructive Evaluation
---Ming Li, Applied Statistics Laboratory, GE Global Research, Niskayuna, NY 12309; Floyd W. Spencer, SF Hire, 13812 Haines Avenue NES, Albuquerque, NM 87112; William Q. Meeker, Iowa State University, Center for NDE and Department of Statistics, Ames, IA 50011

---In nondestructive evaluation (NDE), measurement outputs usually involve different sources of variability such as operator variation, flaw-morphology variation, setup and calibration variation, environmental related variations, and measurement error. If an appropriate experiment is conducted, it is possible to estimate the separate effects of different sources of variability. These sources of variability imply that POD itself is random depending, for example, on the operator assigned to do the inspection. Traditional POD analysis has focused on the estimation of the mean of the POD distribution (i.e., estimating a POD averaged over only the different sources of variability reflected in the data), also providing an associated 95% lower confidence bound to reflect statistical uncertainty (i.e., uncertainty due to limited data). Focusing on mean POD obscures the process variability and has the potential to provide an overly optimistic impression of POD when there is considerable variation. An alternative, commonly used in other areas of statistical analysis, such as product reliability, is to make inferences on a lower quantile of the distribution. In this paper, we emphasize the important difference between mean POD and quantile POD and provide guidance about when they should be used.

Modeling Multivariate POD Curves
---Pablo U. Bartholo, Joao M. A. Rebello, and Luis M. M. Tavares, Federal University of Rio de Janeiro - Department of Metallurgical and Materials Engineering - COPPE/UFRJ - P.O. Box 68505 CEP 21941-972, Rio de Janeiro RJ, Brazil; Sergio D. Soares, PETROBRAS R&D Center - Rio de Janeiro/RJ, Brazil

---The reliability of a nondestructive testing technique determines the limit of detectable flaws as a function of a number of variables, including their length and height. Although it is common to calculate probability of detection (PoD) curves as a function of only one of these geometrical variables – typically length or height – there is considerable benefit to consider these two variables simultaneously. Whereas in the single-variable PoD a single curve is estimated from the data, through a bivariate PoD a surface needs to be used to describe the probability of detection as a function of the two explaining variables. The paper describes the methodology used for estimating the multivariable PoD curve of the conventional ultrasonic technique in API X70 pipes containing defects of different types and sizes. It was found that this methodology is a powerful tool in reliability analyzes. The technique is able to provide curves of equal probability of detection as a function of length and height of flaw. This is particularly meaningful when comparing the PoD results with significance flaw’s sizes based in the fracture mechanics analyses view point. This methodology represents a powerful tool for establishing all acceptance level criteria comparison of different detection techniques for inspection.
Demonstration of Model-assisted Probability of Detection (MAPOD) Evaluation Methodology for Eddy Current NDE

---John C. Aldrin2, Harold A. Sabbagh3, Elias H. Sabbagh3, R. Kim Murphy3, Jeremy S. Knopp1, and Eric A. Lindgren1, 1U.S. Air Force Research Laboratory, Wright-Patterson AFB, OH 45433; 2Computational Tools, Gurnee, IL 60031; 3Victor Technologies, Bloomington, IN 47407

---Progress is presented on the development and demonstration of a model-assisted probability of detection (MAPOD) methodology for nondestructive evaluation. The application of eddy current NDE techniques for the inspection of titanium structures for fatigue cracks is explored. Necessary components for a successful MAPOD evaluation include: (1) a rigorous initial factor evaluation prior to the POD study, (2) Bayesian methods to appropriately incorporate quality prior data and knowledge in the evaluation, (3) the calibration and validation of models that address measurement signal and noise, (4) efficient uncertainty propagation methods, and (5) software tools to facilitate the analysis using both experimental and simulated data. Experimental results are presented comparing crack and EDM notch flaw responses with simulation. Progress and challenges are also presented concerning the use of numerical models to represent material-related measurement noise due to anisotropy, grain structure and surface roughness. The MAPOD evaluation process is performed for a variety of case studies with increasing measurement model complexity, highlighting the benefit of leveraging more accurate models in order to mitigate variation in the model fit and ideally minimize experimental test sample requirements. Lastly, software tools are introduced that facilitate the MAPOD evaluation for input factors with varying and uncertainty properties.

Probabilistic Collocation Method for NDE Problems with Uncertain Parameters with Arbitrary Distributions

---Jeremy S. Knopp and Mark P. Blodgett, Air Force Research Laboratory, Material and Manufacturing Directorate, Dayton, OH 45433; Matthew R. Cherry, University of Dayton Research Institute, Structural Integrity Division, Dayton, OH 45433

---In order to quantify the reliability of NDE systems, large amounts of experiments are performed to develop a probability of detection (POD) curve for the system. These POD studies require a substantial amount of experimentation which can sometimes be cost prohibitive. To expedite the process of developing these curves, highly precise numerical models are used in conjunction with NDE sensors to understand the uncertainties associated with the inspections. Numerical models are also used in stochastic inversion methods such as Bayesian inversion, which provide a means of characterizing system properties with uncertainties. A strong basis has been developed in the modeling and simulation community for deterministic forward models in NDE, but to fully incorporate these models in model-assisted probability of detection (MAPOD) studies or stochastic inversion schemes, the models must be treated in a stochastic sense. A method of taking random inputs to a “black box” forward model and developing the full probability distribution function (PDF) of the response has been proposed. This method, called the probabilistic collocation method (PCM), takes random inputs to a forward model and uses orthogonal polynomials to construct a surrogate model in the area of the expected values of the inputs which is solved much quicker than the original forward model. In the NDE community, this method has only been used with inputs of known, named distributions. In this work, inputs of arbitrary distribution were used and the orthogonal polynomials for these inputs were developed with a recursion relationship that has been shown to produce orthogonal polynomials with respect to a given, continuous function. A concise code was written to make testing the method and incorporating it into MAPOD studies and inversion schemes relatively easy. The routine was tested with academic problems as well as eddy current problems.
Transfer Function Model Assisted Probability of Detection for Lap Joint Multi Site Damage Detection  
---Michel Bode, Justin Newcomer, and Stephanie Fitchett, Sandia National Laboratories, Airworthiness Assurance NDI Validation Center, Albuquerque, NM 87106

---The use of the Transfer Function (TFx) approach to Model Assisted Probability of Detection (MAPOD) is explored in this paper. A complete specimen set encompassing lap joint sections with multiple site damage underwent inspections using linear array ultrasonic shear waves for crack-type defects at lower skin, lower rivet row holes. Four types of specimens represent the quadrants of a 2 by 2 matrix with structure type and defect types on the 2 axis. Structure types were rivet flat plates (simple-simulated) and retired 727 lap joints (complex-real). Defect types were EDM notches (simulated) and fatigue cracks (real). Probability of Detection (POD) curves were generated in each quadrant for each of the multiple inspectors that participated. For each inspector, POD curves from three quadrants were used to predict a curve in the fourth quadrant, which represents actual in-service cracking on real airplane structures. Data from multiple inspectors was used to assess the component in the transfer function process that can be attributed to inspector to inspector variability.

Transfer Function Approach Based on Simulation Results for the Determination of POD Curves  
---Frederic Jenson and Ekaterina Lakovleva, CEA, LIST, F-91191 Gif-sur-Yvette, France; Nicolas Dominguez, EADS, Innovation Works Department, 18 rue Marius Terce, 31025 Toulouse, France

---POD curves estimations are based on statistical studies of empirical data which are obtained thru costly and time consuming experimental campaigns. Currently, cost reduction of POD trials is a major issue. A proposed solution is to replace some of the experimental data required to determine the POD with model based results. Following this idea, the concept of Model Assisted POD (MAPOD) has been introduced first in the US in 2004 through the constitution of the MAPOD working group. One approach to Model Assisted POD is based on a transfer function which uses empirical data and models to transfer POD measured for one specific application to another related application. The objective of this paper is to show how numerical simulations could help to determine such transfer functions. A practical implementation of the approach to a high frequency eddy current inspection for fatigue cracks is presented. Empirical data is available for the titanium alloy plates. A model based transfer function is used to assess a POD curve for the inspection of aluminium components.
Simulation-Assisted POD of a Phased Array Ultrasonic Inspection in Manufacturing
---N. Dominguez, F. Jenson, V. Feuillard, and P. Willaume, 1European Aeronautic Defence and Space Company (EADS), Innovation Works Dept., Toulouse, France; 2CEA LIST, 3PHIMECA

---The concept of Probability of Detection (POD) is generally used to quantitatively assess performances and reliability of NDT operations for in-service operations related to damage tolerant designs. Application of the POD approach as a metric for manufacturing NDT assessment would also be relevant but the very expensive cost of such campaigns generally prevents us from doing so. However the increase in NDT simulation capability and maturity opens the field for POD demonstrations for manufacturing NDT with the help of simulation. This paper presents the example of an automated phased array ultrasonic testing procedure of Electron Beam Weldings on helicopter rotative parts, as part of the PICASSO European project. POD is calculated by using the uncertainty propagation approach in CIVA. The peculiarity of uncertainties in automated NDT compared to in-service manual operations is discussed and raises questions on appropriate statistics to be used for this kind of data. Alternative estimation techniques like Box-Cox transformation or quantile regression are proposed and evaluated.

POD Generated by Monte Carlo Simulation Using a Meta-Model Based on the simSUNDT Software
---Gert Persson, Peter Hammersberg, and Hakan Wirdelius, Chalmers University of Technology, Advanced Nondestructive Testing, Goteborg, Sweden

---In order to quantify the inspection reliability of a NDE procedure the methodology of probability of detection (POD) has been developed since the 1980’s. The method reduces the number of necessary defects but still require a large number of both costly and time consuming inspections. This study address the development of a procedure for generating stochastic simulation of POD based on synthetic data by fitting a multi-parameter prediction model to the NDT simulation software simSUNDT. The validation of this developed methodology for POD generation is based on a qualified ultrasonic procedure dating from 1996, UT-01. It specifies ultrasonic inspection and qualification of personnel within Swedish nuclear power plants. In 2005 these qualifications were comprised as POD curves for both fatigue and stress corrosion cracks. In this paper it was feasible to identify the most influential parameters and to test the effect of their interaction and variability with different distributions. The dissimilar distributions of tilt and skew angles for real fatigue and stress corrosion cracks that was identified within the study have physical explanations. It was achievable to identify statistic distributions that made it possible to reconstruct experimentally based POD curves.
Simulation of Ultrasonic Scattering from Inclusions Using Laser Engravings in Glass Samples
---Johanna Menges, Joachim Bamberg, and Hans-Uwe Baron, MTU Aero Engines GmbH, Dachauer Str. 665, 80995 Munich, Germany; Frank Schubert, Fraunhofer IZFP-Dresden, Maria-Reiche-Str. 2, 01109 Dresden, Germany

---This paper presents a simple alternative for the analysis and valuation of ultrasonic scattering from arbitrary formed inclusions in materials. The basis for this are glass samples. Their sound velocity (longitudinal and transversal) can be adjusted by the composition of the glass so that it will be similar to the sound velocity of e.g. titanium alloy Ti6246. The propagation of the sound fields in both materials is then comparable. Using laser engraving arbitrary formed three dimensional structures/voids can be built in glass. The surface of the structures consists of many micro cracks. By varying the micro crack concentration the sound transmission and reflection can be adjusted. By this means the ultrasonic scattering of impurity inclusions can be simulated. For verification different laser engraved voids (spheres, cylinders and ellipsoids) were built up in glass samples. They were inspected using focused ultrasonic probes. For comparison a titanium sample (Ti6246) containing carbide and quartz inclusions was produced. Additionally the experimental situations were simulated using model calculations. Experimental and simulation results show that the correlation of ultrasonic scattering between laser engravings in glass samples and inclusions in titanium is good. Given that the production of glass samples with laser engravings is inexpensive, fast and reproducible, they offer a practical method to perform POD analysis.

Fluorescent Penetrant Inspection Probability of Detection
---Surendra Singh, Jim Ohm, Andy Kinney, Robert Hogan, Scott Sullivan, and Urban Kramer, MCOE and MSEA, Honeywell Aerospace, Phoenix, AZ 85034

---This work describes Fluorescence Penetrant Inspection (FPI) results in seventeen pre-flawed specimens Ni having sixty seven cracks with size from 0 to 0.360 inch for calculating Probability of Detection (POD) data. In this study, we calculated POD data using hit and miss. We also measured the length of each detected crack measured Honeywell approved pin gages, and these data were used for calculating Measurement System Evaluation (MSE), Gage Repeatability and Reproducibility (R&R), and ANOVA -Analysis of Variance. Each operator measured length three times for each detected crack. In total, there were eight hundred four measurements were completed. This work based on the MIL HBK 1823 had five sections: 1) anomalies type along with shape, size, locations, and distribution; 2) Design of Experiment (DOE) for optimizing FPI response; 3) samples set selection; 4) determination of MSE, R&R, ANOVA, and Component of Variance (COV); and 5) calculating POD data.
Session 21
Wednesday, July 20, 2011

SESSION 21
STRUCTURAL HEALTH MONITORING
J. Aldrin and T. Michaels, Co-Chairpersons
Silver Maple Ballroom

1:30 PM  Principal Challenges in Predicting Guided Wave Behavior in NDT
---D. K. Stoyko, K. Aadeogun, and N. Popplewell, The University of Manitoba, Department of Mechanical and Manufacturing Engineering, 15 Gillson Street, Winnipeg, Manitoba, R3T 5V6, Canada; B. Hao, Lakehead University, Department of Mechanical Engineering, Thunderbay, Ontario, P7B 5E1, Canada

1:50 PM  Fatigue Crack Detection Via Load-Differential Guided Wave Methods
---S. J. Lee, J. E. Michaels, X. Chen, and T. E. Michaels, School of Electrical and Computer Engineering, Georgia Institute of Technology, Atlanta, GA 30332-0250

2:10 PM  Thickness Reduction Evaluation Using a SH-EMAT Tomographic Imaging Technique
---Y. Kim, Pusan National University, Mechanical Engineering & Technology Research Information Center, Busan, South Korea; Y. Cho, Pusan National University, School of Mechanical Engineering, Busan, South Korea; I. Park, Seoul National University of Science and Technology, Department of Mechanical Engineering, Seoul, South Korea

2:30 PM  Application of Mellin Transform Features for Robust Ultrasonic Guided Wave Structural Health Monitoring

---J. C. Aldrin*, E. A. Medina*, J. Santiago, E. A. Lindgren¹, C. Buynak¹, and J. S. Knopp¹, ¹U.S. Air Force Research Laboratory, Wright-Patterson AFB, OH 45433; *Computational Tools, Gurnee, IL 60031; *Radiance Technologies, Inc., Wright-Patterson AFB, OH 45433

3:10 PM  Break

---V. Godinez-Azcuaga and R. Fustos, Mistras Group Inc., Princeton Junction, NJ 08550; D. J. Inman and J. Farmer, Virginia Tech, Department of Mechanical Engineering, Blacksburg, VA 24060

3:50 PM  High Performance Wireless Sensors System for Structural Health Monitoring
---G. Dib, J. Xin, P. R. Paladhi, and L. Udpa, Michigan State University, Electrical and Computer Engineering Department, 2200 Engineering Building, East Lansing, MI 48824; E. Tarkleson, Michigan State University, Mechanical Engineering Department, East Lansing, MI 48824

4:10 PM  High Temperature Integratable Ultrasonic Transducers
---M. Kobayashi, J. Veilleux, K.-T. Wu, and S. E. Kruger, Industrial Materials Institute - NRC, 75, Boul.de Mortagne, Boucherville, QC J4B 6Y4, Canada

4:30 PM  Active-Passive Structural Health Monitoring Using Flexible Piezocomposite Sensors

4:50 PM  Effective AE Sources Location of Damages in the Wind Turbine Blade
---D.-J. Yoon and B.-H. Han, Korea Research Institute of Standards and Science, Center for Safety Measurement, Daejeon, Korea
Principal Challenges in Predicting Guided Wave Behavior in NDT

--- Darryl K. Stoyko, Kazeem Adeogun, and Neil Popplewell, The University of Manitoba, Dept. of Mechanical and Manufacturing Engineering, 15 Gillson Street, Winnipeg, Manitoba, R3T 5V6, Canada; Bai Hao, Lakehead University, Department of Mechanical Engineering, Thunderbay, Ontario, P7B 5E1, Canada

---Three principal challenges and currently feasible solutions to non-destructively assessing the health of a structure by using ultrasonic guided waves are described. Although more universally applicable, comments are illustrated throughout by using the 3-dimensional example of a uniform, isotropic, and linear steel pipe having a through hole. Computer predictions and corresponding experimental measurements needed for their corroboration are examined. The former is more amenable to assessing trends and answering "what if?" questions whereas the latter is likely closer to reality. The first challenge is to significantly curtail computer run times. It has been met by clustering personal computers that were donated rather than being discarded by industry. A combination of parallel and distributed computing may be used, with configuration choices made by utilizing empirical computer performance data. Transporting the software to other computer platforms is eased by employing computer generated code. The second challenge, when comparing computed and experimental data, is to introduce the imperfect measurement chain’s effect. The chain encompasses transducers (plus ancillary electronic equipment like amplifiers) and, if used, the couplant between them and the structure of concern. Beeswax is a convenient couplant that is also versatile. However, a beeswax layer’s dynamic behavior is influenced by its thickness and uniformity. A batch manufacturing process is described that largely overcomes such variations. The third challenge arises when post-processing short duration signals emanating from a transient excitation. A standard exponential time window is used to ameliorate data leakage after which a simple temporal curve fit has been found to effectively calculate the values and, just as importantly, uncertainties in cut-off frequencies. Cut-off frequencies may be employed to measure, for example, material and dimensional properties.

Fatigue Crack Detection Via Load-Differential Guided Wave Methods

---Sang Jun Lee, Jennifer E. Michaels, Xin Chen, and Thomas E. Michaels, School of Electrical and Computer Engineering, Georgia Institute of Technology, Atlanta, GA 30332-0250

---Detection of fatigue cracks originating from fastener holes is an important application for structural health monitoring (SHM) of civil, mechanical and aerospace structures, but their detection via ultrasonic guided waves can be problematic when cracks are tightly closed in the absence of applied tensile loads. Proposed here are load-differential guided wave methods, which compare signals at one load to those at another load at the same damage state. The main advantage of such methods is that cracks can be detected and localized by analyzing current signals obtained from different loading conditions without using baseline data from the damage free state. The efficacy of the proposed load-differential methods is examined using data from fatigue tests of multiple specimens with different numbers of both fastener holes and induced fatigue cracks. Data were acquired with a spatially distributed array of piezoelectric discs by recording ultrasonic signals as a function of applied uniaxial load at intervals through each fatigue test. Various features from residual signals between two different loading conditions at the same damage state are examined for detection of fatigue cracks. In addition, load-differential guided wave images are generated from residual signals via delay-and-sum imaging methods, and these images are analyzed in terms of their ability to localize fatigue cracks.
Thickmess Reduction Evaluation Using a SH-EMAT Tomographic Imaging Technique
---Yongkwon Kim, Pusan National University, Mechanical Engineering & Technology Research Information Center, Busan, South Korea; Younho Cho, Pusan National University, School of Mechanical Engineering, Busan, South Korea; Ikkeun Park, Seoul National University of Science and Technology, Department of Mechanical Engineering, Seoul, South Korea

---A guided ultrasonic wave technique is considered for monitoring the integrity of plate-like and pipe-like structures. To inspect structures that are prone to thickness reduction, a network of many transducers is constructed to produce guided wave signals. In the case of piezoelectric transducers, complex signals are received due to the dispersive effect of guided waves. These waves contain multiple modes because of the difficulty in generating single-mode waves. In order to overcome these problems, a technique using an electromagnetic acoustic transducer (EMAT) which generates SH plate waves is proposed for evaluating thickness reduction in a structure. Thickness reduction is evaluated by measuring the time of flight of guided ultrasonic wave modes. Artificial defects with various shapes and thickness reduction ratios were machined and the results of our evaluation are reported. The results show that the tomography image generated displays the thickness reductions and has the ability to identify the size of the damage to the structure. This shows the efficacy of our technique for thickness reduction evaluation.

Application of Mellin Transform Features for Robust Ultrasonic Guided Wave Structural Health Monitoring
---Joel B. Harley and Jose M.F. Moura, Carnegie Mellon University, Department of Electrical and Computer Engineering, Pittsburgh, PA 15213; Yujie Ying, James H. Garrett, Lucio Sobelman, and Irving J. Oppenheim, Carnegie Mellon University, Department of Civil and Environmental Engineering, Pittsburgh, PA 15213

---In the design of structural health monitoring systems, the use of guided wave ultrasonic techniques has become popular due to their capability for detecting damage over long distances. However, guided wave-based systems are sensitive to environmental and operational conditions. This leads to false-positive results for most conventional detection methods. In this paper, we investigate the capabilities of the Mellin transform (MT) for detecting damage under variable environmental conditions. The MT is chosen due to its unique relationships with scaling operations and wave velocity. In an experiment, we measured guided waves between two permanently attached piezoelectric transducers across a steel pipe under continuously varying pressure. To simulate damage, we placed a mass scatterer on the pipe. From the measurements, we extracted MT related features and used machine learning algorithms to classify when the mass was on the pipe. Our results demonstrate the MT features to detect, on average, the mass with a 91.7% accuracy while similar Fourier transform features detect it with only a 68.9% accuracy. We also discuss how the MT achieves robustness against variations in wave velocity and how this relates to the effects of many environmental conditions, such as pressurization.
Demonstration Study for Reliability Assessment of Structural Health Monitoring Systems Incorporating Model-assisted Probability of Detection (MAPOD) Approach
---John C. Aldrin\(^2\), Enrique A. Medina\(^1\), Jose Santiago\(^3\), Eric A. Lindgren\(^1\), Charles Buynak\(^1\), and Jeremy S. Knopp\(^1\), \(^1\)U.S. Air Force Research Laboratory, Wright-Patterson AFB, OH 45433; \(^2\)Computational Tools, Gurnee, IL 60031; \(^3\)Radiance Technologies, Inc., Wright-Patterson AFB, OH 45433

---To support effective deployment of Structural Health Monitoring (SHM) systems to enable Condition Based Maintenance for structures, SHM systems must be the subject of verification and validation evaluation congruent with the level of reliability that the system must achieve in detecting, localizing, and/or quantifying structural health degradation. This paper describes the development of a validation protocol and presents a demonstration study on an SHM system incorporating vibration methods. Protocol steps emphasize the importance of assessing the key application characteristics and evaluating the significant factors that control performance and reliability. As well, a critical aspect of the protocol is that by addressing variability and uncertainty in the model evaluation and minimizing unexplained error in the representation, less experimental data will be required to address the total unknowns in the evaluation. For the demonstration, the key factors were assessed through controlled studies of (a) loading and unloading, (b) fastener torque, (c) boundary condition variation, (d) temperature variation and temperature gradients, (e) sensor bond quality and operation performance, (f) ambient noise and (g) sensitivity to the flaw growth. The design and results of the full validation study are presented, highlighting general protocol feasibility while identifying remaining challenges for broad use.

---Valery Godinez-Azcuaga and Richard Fustos, Mistras Group Inc., Princeton Junction, NJ 08550; Daniel J. Inman and Justin Farmer, Virginia Tech, Department of Mechanical Engineering, Blacksburg, VA 24060

---This paper presents the most recent advances in the development of a wireless sensor node for steel and concrete bridges structural health monitoring. The project includes the development and deployment of a 4-channel acoustic emission wireless node powered by structural vibration and wind energy harvesting modules. This node is part of an ambitious five-year cross-disciplinary project, which includes a series of tasks that encompassed a variety of developments such as ultralow power AE systems, energy harvester hardware and especial sensors for passive and active acoustic wave detection. Key studies on acoustic emission produced by corrosion on reinforced concrete and by crack propagation on steel components to develop diagnosis tools and models for bridge prognosis are also a part of the project activities. It is important to mention that the impact of this project extends beyond the area of bridge health monitoring. Several wireless prototype nodes have been already requested for applications on offshore oil platforms, composite ships, combat deployable bridges and wind turbines.---This project is sponsored through the NIST-TIP Grant #70NANB9H007.
High Performance Wireless Sensors System for Structural Health Monitoring
---Gerges Dib, Junjun Xin, Pavel Roy Paladhi, and Lalita Udpa, Michigan State University, Electrical and Computer Engineering Department, 2200 Engineering Building, East Lansing, MI 48824; Eric Tarkleson, Michigan State University, Mechanical Engineering Department, East Lansing, MI 48824

---Continuous structural health monitoring (SHM) uses permanently mounted sensor networks on critical locations of a structural component. In-situ wired sensors require a large amount of cabling for power and data transfer, which can drive up costs of installation and maintenance. Hence the need for developing wireless sensors for SHM. The major obstacles preventing the widespread use of wireless sensor networks (WSN) for SHM is the availability of portable, low cost, low powered, low footprint, and high SNR based instrumentation. This paper presents a wireless sensor system that could be interfaced with piezoelectric transducers for the identification of anomalous events using ultrasonic techniques. Power aware algorithms are used to coordinate the actuator-sensor network interaction with a central processing server, where appropriate signal processing techniques are used to quantify the damage in terms of severity.

High Temperature Integratable Ultrasonic Transducers
---Makiko Kobayashi, Jocelyn Veilleux, Kuo-Ting Wu and Silvio E. Kruger, Industrial Materials Institute - NRC, 75, Boul.de Mortagne, Boucherville, QC J4B 6Y4, Canada

---This paper reports recent development on high temperature ultrasonic sensor assemblies with piezoelectric films fabricated by the sol-gel route. Sol-gel composite piezoelectric films show high potential for ultrasonic monitoring of structures at high temperatures, as they have the capability to endure thermal shock, can be integrated to complex geometry, have reasonable signal strength at high temperature, have suitable operation frequency and are broadband. The film composition, the configuration and the fabrication parameters can be optimized for operation temperature or other practical operational and installation conditions. Recent progress of ultrasonic sensor systems using sol-gel composite materials are reported.
Active-Passive Structural Health Monitoring Using Flexible Piezocomposite Sensors

--Structural health monitoring (SHM) is fast becoming a reliable and economical solution for condition based maintenance of large structures like bridges, pipelines, storage tanks, aircrafts etc. Piezoelectric sensors are traditionally used to acquire data from the structures and analyze it to identify the state of the structure. Piezoelectric sensors in their raw ceramic form are brittle and cannot conform to the complex shapes of different structures. Flexible Macro fiber composites are developed as an alternative to these sensors. Making a 2-2 piezocomposite with the piezoelectric and epoxy phases gives it a desired degree of flexibility and also their piezoelectric properties can be tailored to a desired application. Using these sensors it is possible to monitor a structure with both passive and active approaches. Acoustic emission (AE) is a passive technique that can give information about any defect onset in a structure and its growth. Using triangulation techniques the location of the defect can be accurately located. Guided wave tomographic approaches can be used to actively locate and size the defects on the structure. In this paper, we present a hybrid active-passive approach to structural health monitoring. A steel plate is monitored with several sensors permanently mounted on it, a corrosion defect is introduced and its growth is monitored.

Effective AE Sources Location of Damages in the Wind Turbine Blade
---Dong-J. Yoon and Byeong-Hee Han, Korea Research Institute of Standards and Science, Center for Safety Measurement, Daejeon, Korea

---Acoustic emission technology was used for monitoring the integrity of large structures like a huge wind turbine blade. It was aimed to find a symptom of damage propagation before catastrophic failure through a continuous monitoring. In this study, we have done a practical study to monitor and assess the damage sources from a full scale wind turbine blade using new developed source location method. And also we have tried to enhance a source location algorithm for damage identification more exactly on the real blade. First, it was focused to classify the activities of acoustic emission events generated from the glass fiber reinforced plastic (GFRP) structures such as a wind blade. Secondly, this study aims to identify and locate the damages from blade bonding interfaces, since it was known that it is very difficult to find an exact location of damage source on the composite material structures. In this work, conventional piezo-electric acoustic emission sensor was attached on or embedded inside blade. The activities of AE signals generated from external artificial sources was evaluated and located by new developed source location algorithm. The results show that new suggested source location algorithm was much higher performance than conventional source location method.
Session 22
1:30 PM  
NDE Models Using Meshless Methods on Graphics Processing Unit
---Y. Deng1,2,4, X. Liu1, C. Bardel3, and L. Udpa3, 1Department of Electrical Engineering, University of Colorado Denver, Denver, CO 80217; 2Department of Bioengineering, University of Colorado Denver, Aurora, CO 80045; 3Department of Electrical and Computer Engineering, East Lansing, MI 48824; 4Colorado Translational Research Imaging Center (C-TRIC), Aurora, CO 80045

1:50 PM  
Study of the Direct Solution of Snell’s Equation for Application in GP-GPU Computing
---J. Dziewierz and T. Gachagan, University of Strathclyde, Centre for Ultrasonic Engineering, 204 George Street, Glasgow G1 1XW, United Kingdom

2:10 PM  
A Simple Direct Problem Solver for Non-Destructive Inspection of Conductive Plates

2:30 PM  
Estimation of Erosion/Corrosion Rate in Pipe Walls by Cross-Correlation Technique
---F. Honarvar and F. Salehi, K. N. Toosi University of Technology, Faculty of Mechanical Engineering, Tehran, Iran; V. Safavi and A. N. Sinclair, University of Toronto, Department of Mechanical and Industrial Engineering, 5 King’s College Road, Toronto, Ontario, M5S 3G8, Canada

2:50 PM  
Hidden Heterogeneous Materials Recognition in Pulsed Thermography
---Z. Zeng1,2, N. Tao1, L. Feng1, Y. Li1, C. Zhang1*, 1Department of Physics, Capital Normal University, Beijing 100048, China, Beijing Key Laboratory for Terahertz Spectroscopy and Imaging, Key Laboratory of Terahertz Optoelectronics, Ministry of Education, China; 2Institute of Physics and Electronic Engineering, Chongqing Normal University, 400047, China

3:10 PM  
Break

3:30 PM  
Simulation of the Variation of Ultrasonically Monitored Thickness Due to the Effects of Roughness
---A. Jarvis and F. Cegla, Imperial College London, Mechanical Engineering Department, Exhibition Road, London, SW7 2AZ, United Kingdom

3:50 PM  
Ultrasound Data Processing for Detection of Laminar Imperfections in Welded Pipes
---C. Imbert, Olympus NDT, 505, boul.du Parc-Technologique, Quebec City, Quebec G1P459, Canada (Please note: E. Grondin will present this work.)

4:10 PM  
AutoNDE: A 3D Visualization and Analysis System for Automatic Non-Destructive Examination of Rotor Using Ultrasound

4:30 PM  
Pulsed Thermography Image Processing for Damage Growth Monitoring
---M. Genest, Institute for Aerospace Research, National Research Council Canada, 1200 Montreal Road, Building M-14, Ottawa, Ontario, K1A OR6, Canada

4:50 PM  
Frequency Modulated Thermal Wave Imaging
---S. Tuli and K. Chatterjee, Indian Institute of Technology, Centre for Applied Research in Electronics, Delhi, India
NDE Models Using Meshless Methods on Graphics Processing Unit

--- Y. Deng\textsuperscript{1,2,4}, X. Liu\textsuperscript{1}, C. Bardel\textsuperscript{3}, and L. Udpa\textsuperscript{3}, \textsuperscript{1}Department of Electrical Engineering, University of Colorado Denver, Denver, CO 80217; \textsuperscript{2}Department of Bioengineering, University of Colorado Denver, Aurora, CO 80045; \textsuperscript{3}Department of Electrical and Computer Engineering, East Lansing, MI 48824; \textsuperscript{4}Colorado Translational Research Imaging Center (C-TRIC), Aurora, CO 80045

--- Integrity and safety of structures operating in extreme conditions such as very low or high temperatures, vacuum or pressures up to 15,000 psi and other harsh environments is very critical. Hence there is a crucial need to track and detect hidden tight cracks and corrosion at their early stage using advanced NDE sensors. Computational models that simulate the underlying physics is extremely invaluable for optimizing the sensor design. Three dimensional (3-D) computational models based on finite element analysis typically require exorbitant computational resources including memory and execution time, particularly if probe motion is involved. Recently, we have witnessed a trend to use graphics processing unit (GPU) for implementing computational models. This paper presents GPU-based modeling of tight cracks and corrosion interacting with multi-frequency electromagnetic energy. An innovative numerical solver based on meshless methods is developed and implemented on GPUs. Initial results of 3-D electromagnetic computational models indicate significant improvement in computation time of the models.

Study of the Direct Solution of Snell’s Equation for Application in GP-GPU Computing

--- Jerzy Dziewierz and Tony Gachagan, University of Strathclyde, Centre for Ultrasonic Engineering, 204 George Street, Glasgow G1 1XW, United Kingdom

--- Recent developments in General Purpose Graphics Processing Units (GP-GPU) open up the possibility to implement complex sound processing algorithms to work in real time. Such techniques are generally considered impractical for real-time system operation under the current architectures used. In this work, an algorithm to calculate refraction point of the ray crossing an interface is presented to demonstrate the advantages of implementing algorithms using GP-GPU. Due to the specifics of GP-GPU architecture, traditional iterative solver performance is low. Therefore, a direct, single-step approach is used. Detailed study of numerical accuracy is required to ensure correctness. Main applications of this technique include augmenting imaging algorithms such as Total Focusing Method with through-water or through-wedge support. Other applications include calculating focal laws and acoustic beam simulation. Study findings are presented along with a comparative benchmark of the proposed new implementation approach.
A Simple Direct Problem Solver for Non-Destructive Inspection of Conductive Plates
---Helena G. Ramos, Artur Ribeiro, Dário Pasadas, and Tiago Rocha, Instituto de Telecomunicações, Instituto Superior Técnico, UTL, Lisboa, Portugal

---This paper presents a simple algorithm to preview the spatial variation of the voltage detected by an eddy current probe when an metallic plate with machined round hole defects is scanned. The direct problem is formulated in terms of complex potentials and the method of conformal mapping is used to transform the domain with a round hole into a simpler domain in which the solution can be computed. The magnetic field perturbation due to the defect was determined. The consideration of the conformal mapping is possible because, in a limited area, the applied magnetic field is uniform and the resultant electric field can be considered as the gradient of a scalar potential in that region. To prove the validity of the model the simulation work was followed by a real experiment. A planar probe with a magnetic sensor based on giant magneto-resistors was implemented to impose a uniform time-variable electric field over a limited region of the plate. Then, the magnetic field at the sample surface vicinity was determined and a good agreement was achieved between the model and experimental data. Due to its simplicity, the algorithm constitutes a very good tool to test inversion algorithms. Moreover, the achieved results point out a direction to explore for the inversion problem solution.

Estimation of Erosion/Corrosion Rate in Pipe Walls by Cross-Correlation Technique
---Farhang Honarvar and Farzaneh Salehi, K. N. Toosi University of Technology, Faculty of Mechanical Engineering, Tehran, Iran; Vahid Safavi and Anthony N. Sinclair, University of Toronto, Department of Mechanical and Industrial Engineering, 5 King’s College Road, Toronto, Ontario, M5S 3G8, Canada

---In industrial plants, most pipelines are subject to erosion and/or corrosion due to the presence of aggressive agents, turbulence, or high fluid velocity; changes in process parameters can cause significant changes in the pipe wall erosion/corrosion rate. Quick detection of such changes by continuous monitoring of the erosion/corrosion rate of the pipe wall can help arrest rapid increases in the erosion/corrosion rate before significant damage is done. In this paper, we apply enhanced cross-correlation techniques to ultrasonic signals for improved rapid estimation of fine changes in erosion/corrosion rate. The technique is applied to experimental data obtained from a test rig designed for simulating accelerated corrosion in pipes. The results of the new approach are compared with results obtained from a model-based estimation method and the relative merits/underlying assumptions of the two techniques are compared. Changes in corrosion rate on the order of 20 microns/year or more can be detected by either technique within 5 days; smaller step changes can be identified if a longer period is available for data collection. The new approach is computationally fast, and can be readily incorporated in industrial ultrasonic measurement systems.
Hidden Heterogeneous Material Recognition in Pulsed Thermography
---Tao Zeng, Li Feng, Zhi Zhang, Lichun Ning, Cunlin Yue, and Zhi Zeng, Capital Normal University, Department of Physics, Room 124, Jiaosan Building, 105 Xisanhuan North Road, Beijing, 100048 China (PRC)

---Pulsed thermography has been proven to effectively identify fluid ingress in aerospace honeycomb parts while inspecting large areas in a fast manner. Water, hydraulic oil and excess glue between skin and core may have similar appearance in the infrared image sequences, it is useful to detect what kind of ingress it is. In this study, a simple structure was used to simulate the fluid ingress in a honeycomb part, a 20mm thick steel slab was machined four 1.1mm depth and four 2mm depth circular flat-bottom holes with 25mm diameter at the same side. All holes were filled with different materials: water, oil, air and wax to simulate fluid ingress and excess glue. An algorithm was proposed to first find each hole based on fundamental imaging processing technologies, and then it is based on temporal thermal diffusive properties to automatically recognize what kind of fluid ingress it is in each hole. It was verified with the experimental results of different quantities of fluid ingress and several different flash power levels.

Simulation of the Variation of Ultrasonically Monitored Thickness Due to the Effects of Roughness
---Andrew Jarvis and Frederic Cegla, Imperial College London, Mechanical Engineering Department, Exhibition Road, London, SW7 2AZ, United Kingdom

---In ultrasonic thickness monitoring using permanently installed sensors, random signal variations due to coupling changes and manual operation are largely reduced. However, effects on the signal due to roughness introduced by corrosion and erosion processes cannot be removed. Ultrasonic scattering by rough surfaces is an extensive topic within literature; however, many models rely heavily on approximations limiting their applications. In this paper, a semi-analytical mesh-free model is presented which can simulate scattering of acoustic waves in two-dimensions while accounting for the effects of shadowing and multiple reflections at the surface. The absence of mode conversion at oblique angles of incidence make this approach valid for SH wave scattering from 2.5D surfaces. The mathematical framework is based on the Discrete Point Source Method (DPSM) which has been adapted for use in two dimensions. Comparisons are made with the Finite Element Method (FEM) showing very good agreement while incurring large decreases in computational requirements. A statistical analysis is then carried out using the model to study the effects of backwall roughness on the shape of reflected pulses. Standard methods for calculating the time of flight are then applied to the reflected pulses and conclusions are drawn on the stability of each method.
Ultrasound Data Processing for Detection of Laminar Imperfections in Welded Pipes
---Christophe Imbert, Olympus NDT, 505, boul.du Parc-Technologique, Quebec City, Quebec G1P459, Canada (Please note: this poster will be presented by E. Grondin.)

---In a recent Phased Array inspection system, Olympus NDT has implemented dedicated ultrasound data processing to fulfill the API requirements (referred to as ISO 10124) for detection of laminar imperfections in welded pipes. In this system, acquisition of ultrasound data is done using a standard pulse echo inspection technique. The standard ultrasonic inspection head for full body inspection of welded pipe includes one or several water wedges in which a linear Phased Array probe is mounted perpendicularly to the pipe surface. Once the pipe is in rotation, each water wedge is laid on the pipe sequentially and translated along the full pipe length following a helical movement. Then, ultrasound acquisition data is accurately mapped in a two dimensional grid using a reference signal for each revolution combined with radial and axial positions provided by encoders. Based on this data mapping, areas of each laminar imperfection are characterized in size and orientation, merged and sorted according to different acceptance levels. As described in the standards, severity level is related to the location of laminar imperfections, three locations are considered; pipe body, pipe ends and heat affected zone. Different reference pipes have been designed to validate the processing algorithms. Obviously, for such requirements, a basic alarm processing based on amplitude threshold of a detection gate cannot be applied anymore, and needs to be replaced by advanced image processing tools combining amplitude and spatial coordinates of the indications. This innovative data processing introduces a more powerful and reliable defect evaluation method for inspection systems in the welded or seamless pipe manufacturing industry.

AutoNDE: A 3D Visualization and Analysis System for Automatic Non-Destructive Examination of Rotor Using Ultrasound
---Jingdan Zhang, Guozhen Li, Moritz Knorr, Peter Faltin, Shaohua S. K. Zhou, and Dorin Comaniciu, Siemens Corporate Research, Siemens AG, 755 College Road East, Princeton, NJ 08540; M. El-Mahjoub Rasselkorde, Waheed A. Abbasi, and Mike J. Metala, Siemens Energy, Inc., Pittsburgh, PA 15239-2246

---A turbine rotor is a rotating component of a generator and its reliability is a major concern. To promote operational safety, the highly stressed areas around the center line of rotors are inspected regularly using ultrasound. In order to improve inspection accuracy and reliability, automatic scanning systems have been developed to capture and archive all inspection data. For a typical inspection, a large amount of digitized ultrasound data, e.g. more than 1GB, are acquired. Analysis based on 1D plots or 2D images is time-consuming as it has difficulty in exploring 3D information. We present a software system named AutoNDE to visualize and analyze ultrasound data in 3D. AutoNDE first reconstructs 3D volumes with a regular grid from raw ultrasound waveforms based on time-of-flight and the sampling theorem. Then AutoNDE leverages the volume rendering technique from medical imaging to present comprehensive 3D information of the data, enabling engineers to analyze data effectively and reliably. To facilitate data analysis, AutoNDE further implements a set of handy tools, including on-screen measurement, overlay of CAD model, and high-resolution volume reconstruction. The performance of AutoNDE is demonstrated on both boresonic inspection using conventional probes and solid rotor inspection using phased array.
Pulsed Thermography Image Processing for Damage Growth Monitoring

---Marc Genest, Institute for Aerospace Research, National Research Council Canada, 1200 Montreal Road, Building M-14, Ottawa, Ontario, K1A OR6, Canada

---In recent years, infrared (IR) thermography has evolved from an emerging nondestructive testing (NDT) technique to a viable approach for both as-manufactured and in-service inspections in the aerospace industry. One of the drawbacks of thermography techniques is that no standard signal processing has been universally adopted by specialists and that different algorithms yield different defect sizing results. Additionally, the data interpretation is not as intuitive as with other NDT techniques. In this paper, an image processing algorithm based on a combination of the most commonly used signal processing techniques in pulsed thermography (derivative processing, pulsed phase thermography and principal component analysis) is applied to monitor the progression of impact damage sites during the full-scale testing of a composite test article. It is demonstrated that the algorithm can be used to monitor damage during a loading sequence. Over the duration of first phase of the test program, although there was no damage growth, the processed pulsed thermography images showed that the standard deviation of the measurements was only ~0.08 inches, which is equivalent to only two camera pixels for the system used.

Frequency Modulated Thermal Wave Imaging

---Suneet Tuli and Krishnendu Chatterjee, Indian Institute of Technology, Centre for Applied Research in Electronics, Delhi, India

---Pulsed thermography (PT), being simple and fast, remains one of the most popular thermographic NDE techniques. However, it has two intrinsic limitations: peak power is limited by the electronics and the flash lamp's capacity, and that it may damage the sample surface due to the intense instantaneous heat. An alternative method that addresses these limitations of PT is suggested and named Frequency modulated thermal wave imaging (FMTWI). An impulse can be thought of as a superposition of waves having all frequencies whose phases match constructively. In FMTWI, the phase relations are adjusted over a bandwidth (B) in such a way, that a chirp (frequency modulated) signal of duration T and with much reduced peak power is produced. FMTWI, while retaining all characteristics of lock-in thermography, has the added advantage of overcoming the blind frequency problem. The further advantage of FMTWI is that it can be processed by matched filtering (pulse compression). An impulse is converted to a chirp using a filter whose B and T are decided based on the sample and help optimize input power. The resultant chirp heating is applied on the sample and its response is passed through a matched inverse filter to get back the result of pulsed heating. The FMTWI technique is applied on a reference piece of CFRP material having back-drilled holes, and results obtained are compared with pulsed thermography.
Special Evening Session
Wednesday, July 20, 2011

SPECIAL EVENING SESSION
Silver Maple Ballroom

8:00 PM Opportunities and Challenges of using QNDE in Earthquake Hazard Assessment
---S. Sritharan, Iowa State University, Department of Civil, Construction, and Environmental Engineering, 376 Town Engineering Building, Ames, IA 50011
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<td>Digital Signal Processing of Guided Waves</td>
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<td>Adhesive Bonds, Coatings, and Interfaces</td>
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### Sessions 23A and 23B
Thermography and Thermosonics II and UT Phased Arrays III
Sugar Maple Ballroom

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### Session 24
Digital Signal Processing of Guided Waves
Mildred Livak Ballroom

### Session 25
X-Ray NDE
Silver Maple Ballroom

### Session 26
Adhesive Bonds, Coatings, and Interfaces
Frank Livak Ballroom

### Session 27 – POSTERS – 1:30 – 3:10 PM – Mount Mansfield Room

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### Session 28
Guided Wave Applications and Systems
Sugar Maple Ballroom

### Session 29
New Techniques and Applications
Mildred Livak Ballroom

### Session 30
Laser Ultrasonics
Silver Maple Ballroom

### Session 31
Benchmark Validation NDE
Frank Livak Ballroom

### 3:10 PM
COFFEE BREAK

### 5:30 PM
ADJOURN
Sessions 23A and 23B
Thursday, July 21, 2011

SESSION 23A
THERMOGRAPHY AND THERMOSONICS II
X. Han, Chairperson
Sugar Maple Ballroom

8:30 AM Automating Data Analysis During the Inspection of Boiler Tubes Using Line Scanning Thermography
---O. Ley, S. Momeni, J. Ostroff, and V. Godinez-Azcua, Mistras Group, 195 Clarksville Road, Princeton Junction, NJ, 08550

8:50 AM Simulation of the Vibrational Response of a Turbine Blade Under Thermosonic Excitation
---G. Bolu, A. Gachagan, and G. Pierce, University of Strathclyde, Centre of Ultrasonic Engineering, Glasgow, United Kingdom; T. Barden, Rolls-Royce plc, Bristol, United Kingdom

9:10 AM Further Study of Coupling Materials in Sonic Infrared Imaging NDE on Aluminum Samples
---Y. Song and X. Han, Wayne State University, Department of Electrical and Computer Engineering, Detroit, MI 48202

9:30 AM Thermographic Signal Reconstruction for Vibrothermography
---S. D. Holland, Iowa State University, Center for NDE, 1915 Scholl Road, 111 ASC II, Ames, IA 50011

9:50 AM Application of Sonic IR Imaging in Civil Structure Health Assurance
---Q. He and X. Han, Wayne State University, Department of Electrical and Computer Engineering, 5050 Anthony Wayne Dr., #3123, Detroit, MI 48202

10:10 AM Break

SESSION 23B
UT PHASED ARRAYS III
R. Addison, Chairperson
Sugar Maple Ballroom

10:30 AM Effect of Roughness on Imaging and Characterizing Rough Crack-Like Defect Using Ultrasonic Arrays
---J. Zhang, B. W. Drinkwater, and P. D. Wilcox, University of Bristol, Department of Mechanical Engineering, University of Bristol, University Walk, Bristol, BS8 1TR, United Kingdom

10:50 AM Detection and Characterization of Near Surface and Surface-Breaking Defects Using Ultrasonic Arrays
---A. Velichko, P. D. Wilcox, and B. W. Drinkwater, University of Bristol, Department of Mechanical Engineering, Bristol, United Kingdom

11:10 AM Detection and Sizing Capabilities of Phased-Array Ultrasonic Technique to Inspect Electro Fusion Joints in Polyethylene Pipes
---M. Lozev, BP America, 150 W. Warrenville Road, MC 700-2C, Naperville, IL 60563; R. L. Spencer, E. I. Todorov, and P. White, Edison Welding Institute, Columbus, OH 43221-3585

11:30 AM Emulation of POD Curves from Synthetic Data of Phased Array Ultrasound Testing
---P. Hammersberg, G. Persson, and H. Wirdelius, Chalmers University of Technology, Advanced Nondestructive Testing, Goteborg, Sweden

11:50 AM Non-Linearly Phased 2-D Array Transducers Arranged on a Cylindrical-Polar Grid for Real-Time Guided Wave Mode Control and Steering
---H. Kannajosyula, C. J. Lissenden, and J. L. Rose, The Pennsylvania State University, Engineering Science and Mechanics, 212 EES Building, University Park, PA 16802
Automating Data Analysis During the Inspection of Boiler Tubes Using Line Scanning Thermography

---Obdulia Ley, Sepand Momeni, Jason Ostroff, and Valery Godinez-Azcuaga, Mistras Group, 195 Clarksville Road, Princeton Junction, NJ, 08550

---Failures in boiler waterwalls can occur even though a relatively small amount of corrosion and loss of metal have been experienced. Waterside tube corrosion is generally caused by the existence of contaminants in the boiler feedwater. This study presents our efforts towards the applications of Line Scanning Thermography (LST) for the analysis of thinning in waterwall tubing. LST utilizes a line heat source to thermally excite the surface to be inspected and an infrared detector to record the transient surface temperature increase observed due to the presence of voids, thinning or other defects. In water wall boiler tubes the defects that can be detected using LST correspond to corrosion pitting, hydrogen damage and wall thinning produced by inadequate burner heating or problems with the water chemistry. In this paper we discuss how the LST technique is implemented to determine thickness from the surface temperature data, and we describe our efforts towards developing a semiautomatic analysis tool to speed up the time between scanning and repairs. We compare the density of data produced by the common techniques used to assess wall thickness and the data produced by LST.

Simulation of the Vibrational Response of a Turbine Blade Under Thermosonic Excitation

---Gabriel Bolu, Anthony Gachagan, and Gareth Pierce, University of Strathclyde, Centre of Ultrasonic Engineering, Glasgow, United Kingdom; Tim Barden, Rolls-Royce plc, Bristol, United Kingdom

---The vibrational energy generated within a component during a thermosonic test is non-uniform. This could potentially lead to a defect being undetected if the vibrational energy at the defect location is below the detection threshold. The aim of this study is to develop a methodology, using a combination of vibration measurements and finite element analysis (FEA), to model the vibrational energy within a turbine blade in a typical thermosonic inspection scenario. First, using a laser vibrometer, the steady-state vibration response (i.e. frequency response) at several locations on a blade was measured. Next, the prominent peaks in the frequency spectra of the measured vibration data were used to tailor the excitation function for the finite element modeling approach. With good correlation between the measured and simulated vibration response at these locations on the blade, this forcing function approach was used to simulate the vibration response across the whole blade. Finally, the predicted displacement field is used to determine the vibrational energy at every point on the blade. This data is mapped onto the CAD representation of the blade, thereby highlighting areas on the blade that are below the defect detection threshold.
Further Study of Coupling Materials in Sonic Infrared Imaging NDE on Aluminum Samples
--- YuYang Song and Xiaoyan Han, Wayne State University, Department of Electrical and Computer Engineering, Detroit, MI 48202

--- Sonic Infrared (IR) Imaging has been proving as a very promising NDE technology even though it has not been around for very long. This technology uses acoustic/ultrasound excitation externally and infrared imaging to identify defects in materials. Coupling materials are typically employed between the sound transducer and a target. It has been talked by this research group that this coupling have shown importance in SonicIR. We have learned that coupling materials affect the vibration and heating in cracks. Systematic study has been done quantitatively by the authors over some selected coupling materials through experimental study on aluminum samples. We will present our results in this presentation.

Thermographic Signal Reconstruction for Vibrothermography
--- Stephen D. Holland, Iowa State University, Center for NDE, 1915 Scholl Road, 111 ASC II, Ames, IA 50011

--- In vibrothermography, also known as thermosonics or sonic infrared, cracks or delaminations are found from the heat given off in response to vibration. Finding cracks requires identifying and localizing pulsed surface and subsurface heat sources from a time sequence of infrared images. Traditionally this identification involves manually stepping through and studying the individual images within the sequence. Careful observation of the heating and subsequent cooling is needed to distinguish cracks from false indications. We present an algorithm that reduces the entire time sequence to a single static plot. The plot uses only a few coefficients per pixel to reconstruct the original sequence; this is possible because the reduction is based on a physical model. As a result, the algorithm also reduces noise and improves sensitivity. A single false-color image summarizes all the information from the entire sequence, simplifying the task of identifying cracks.
Application of Sonic IR Imaging in Civil Structure Health Assurance
---Qi He and Xiaoyan Han, Wayne State University, Department of Electrical and Computer Engineering, 5050 Anthony Wayne Dr., #3123, Detroit, MI 48202

---Sonic Infrared (Sonic IR) Imaging is a novel NDE technology. It employs an ultrasonic transducer to excite samples with a short pulse of 15 - 40 kHz sound. This short pulse of high power sound will excite the crack and cause the crack surfaces to rub and generate heat. An Infrared camera is used to detect the temperature change caused by the friction heating and therefore 'sees' the crack. We have seen promising results with Sonic IR imaging on both metal and composite structures including turbine discs, turbine blades and airplane fuselage panels. We have also explored new applications with Sonic IR technology. In this paper, the authors would like to present results of Sonic IR imaging technology applied on large size civil engineering structures and its potential of being used as a structure health monitoring technology.

Effect of Roughness on Imaging and Characterizing Rough Crack-Like Defect Using Ultrasonic Arrays
---Jie Zhang, Bruce W. Drinkwater, and Paul D. Wilcox, University of Bristol, Department of Mechanical Engineering, University of Bristol, University Walk, Bristol, BS8 1TR, United Kingdom

---All naturally occurring crack-like defects in solid structures are rough to some degree, which can affect defect inspection and characterization. Based on the simulated array data for various rough cracks and the total focusing method imaging algorithm, the effect of roughness on defect imaging and characterization is discussed. The array data was simulated by using the forward model combining with scattering matrices for various rough cracks, which were extracted by using the Kirchhoff model. The scattering matrix describes the scattering field of a scatterer from all possible incident and scattering directions, and it can be distinct as the coherent and diffuse fields. It is shown that roughness can be either beneficial or detrimental to the detectability of a crack-like defect, depending on the defect characteristics such as length, roughness, correlation length, orientation angle, and array inspection configuration. It is also shown that roughness can cause the underestimation of length of rough crack-like defects by using the image based approach.
Detection and Characterization of Near Surface and Surface-Breaking Defects Using Ultrasonic Arrays

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

---Detection and characterization of near surface and surface breaking defects is still a major challenge for non-destructive evaluation. The use of ultrasonic arrays 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. 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. In the current paper, an efficient Finite Element procedure is used for predicting the far-field scattering matrix of an arbitrary-shaped scatterer which is located near a free surface in an otherwise homogeneous isotropic half-space. The data provided by this model is then used for simulating an ultrasonic array response for different near surface and surface breaking defects. Special processing techniques for defect localization and characterization are discussed. Example results for a 1D array (2D defects) and a 2D array (3D defects) are presented and its practical application to the volumetric inspections of a thin section are discussed.

Detection and Sizing Capabilities of Phased-Array Ultrasonic Technique to Inspect Electro Fusion Joints in Polyethylene Pipes

---Mark Lozev, BP America, 150 W. Warrenville Road, MC 700-2C, Naperville, IL 60563; R. L. Spencer, E. I. Todorov and P. White, Edison Welding Institute

---Comprehensive ultrasonic modeling and simulation tools were used to develop and optimize Phased Array ultrasonic technique for nondestructive evaluation of Electro Fusion joints in polyethylene gas distribution pipelines. Advanced detection, imaging, and sizing capabilities of the techniques were destructively validated. Good agreement between ultrasonic simulations predictions, experimental ultrasonic results, and destructive testing was achieved. Using the developed Phased Array ultrasonic procedures planar flaws in the fusion zone (represented by implanted aluminum disks) as small as 1 mm were detectable. Probability of detection (a90/95) of 6 mm was attained by an operator having several years of Phased Array ultrasonic experience and at least 3 months experience inspecting polyethylene pipelines Electro Fusion joints. 95% lower limit against under-sizing of 8 mm was demonstrated by the best operator. Electro Fusion cold joints were classified reliably with Phased Array ultrasonic technique by measuring the depth of the heat affected zone.
Emulation of POD Curves from Synthetic Data of Phased Array Ultrasound Testing

---Peter Hammersberg, Gert Persson, and Hakan Wirdelius, Chalmers University of Technology, Advanced Nondestructive Testing, Goteborg, Sweden

---The reliability of the non-destructive techniques (NDT) used for flaw detection is traditionally quantified using statistical methods such as experimental determined probability of detection (POD). Qualification of inspection procedures then inevitably requires a significant amount of experimental verification for each application. The intention is therefore to have an optimized experimental phase combined with much more efficiently retrieved simulated data. The ultrasonic phased array technique enables reduced inspection time combined with higher detection efficiency with a prospective to increase the economic value of the inspections. This project thus includes the modeling of a phased array probe and the implementation of it into an existing simulation tool (simSUNDT). Although an individual simulation is not that time consuming it will be impossible to render a statistical amount of calculations by using the simSUNDT software for studies of multi-parameter variability. This has encouraged the development of a procedure for generating POD based on synthetic data from a multi-parameter emulation model of the simulator by computer experiments. With the emulation model POD curves comparing conventional and phased array technique were generated with Monte Carlo simulation by introducing variations in the control parameters in the phased array system with physical interpretation.

Non-Linearly Phased 2-D Array Transducers Arranged on a Cylindrical-polar Grid for Real-time Guided Wave Mode Control and Steering

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

---Ultrasonic guided wave mode control and steering using phased array transducers (PAT) is studied. It is shown that periodicity of the wave-numbers selected by phased array transducers with elements arranged in a rectangular grid may result in unintended large side-lobes. To overcome this problem, a phased array transducer with elements arranged on a cylindrical-polar grid is proposed as an alternative. To calculate the phase delays the PAT is visualized as a spatio-temporal filter. Each radial row of the PAT is excited with a different phase delay. This results in the wave-number bands to constructively interfere only in the vicinity of the desired wavenumber and angle of propagation. Numerical calculations are presented to show the conditions which affect the presence of sidelobes when the proposed PAT and method of delay calculation are used. Finite element simulations are presented to demonstrated to study the performance of the new PAT. Experimental verification of the predictions are suggested.
Session 24
SESSION 24
DIGITAL SIGNAL PROCESSING OF GUIDED WAVES
J. Michaels, Chairperson
Mildred Livak Ballroom

8:30 AM Guided Wave Imaging of Part-Thickness Defects in Large Structures
---P. Fromme, University College London, Department of Mechanical Engineering, Torrington Place, London, WC1E 7JE, United Kingdom

8:50 AM Guided Wave Imaging for Crack Detection and Quantification
---L. Yu, University of South Carolina, Department of Mechanical Engineering, 300 South Main St. A211, Columbia, SC 29208

9:10 AM Adaptive Dispersion Compensation for Guided Wave Imaging
---J. S. Hall and J. E. Michaels, School of Electrical and Computer Engineering, Georgia Institute of Technology, 777 Atlantic Dr. NW, Atlanta, Georgia 30332-0250

9:30 AM Ultrasonic Wave-Based Defect Localization Using Probabilistic Modeling
---M. D. Todd and E. B. Flynn, University of California San Diego, Department of Structural Engineering, 9500 Gilman Drive 0085, La Jolla, CA 92093-0085; P. D. Wilcox, B. W. Drinkwater, and A. J. Croxford, University of Bristol, Department of Mechanical Engineering, Bristol, United Kingdom; S. M. Kessler, Metis Design Inc., Boston, MA

9:50 AM Guided Wave Localization of Damage Via Sparse Reconstruction
---R. M. Levine, J. E. Michaels, and S. J. Lee, Georgia Institute of Technology, School of Electrical and Computer Engineering, 777 Atlantic Dr., NW, Atlanta, GA 30332-0250

10:10 AM Break

10:30 AM Long Term Stability Analysis of a Guided Wave SHM System for Platelike Structures
---V. Attarian, F. Cegla, and P. Cawley, Imperial College London, Mechanical Engineering, Exhibition Road, South Kensington, London, SW7 2AZ, United Kingdom

10:50 AM Flaw Detection and Characterization Using Lamb Wave Tomography and Pattern Classification
---M. K. Hinders and C. A. Miller, College of William & Mary, Applied Science Department, Williamsburg, VA, 23187-8795

11:10 AM Isolation of Crack-Induced Standing Wave Energy from Laser Scanned Ultrasonic Image
---Y.-K. An, B. J. Park, and H. Sohn, KAIST, Department of Civil and Environmental Engineering, Daejeon, Korea

11:30 AM Guided Wave Permanently Installed Pipeline Monitoring System
---A. Galvagni and P. Cawley, Imperial College, Department of Mechanical Engineering, Exhibition Road, London, SW7 2AZ, United Kingdom

11:50 AM On the Interpolation of Ultrasonic Guided Wave Signals
---J. E. Michaels, J. P. Zutty, and T. E. Michaels, Georgia Institute of Technology, School of Electrical and Computer Engineering, 777 Atlantic Dr., NW, Atlanta, GA 30332-0250; R.-J. Liou, National Pingtung Institute of Commerce, Department of Computers and Communications, Pingtung, Taiwan

12:10 PM Lunch
Guided Wave Imaging of Part-Thickness Defects in Large Structures
---Paul Fromme, University College London, Department of Mechanical Engineering, Torrington Place, London, WC1E 7JE, United Kingdom

---Distributed guided ultrasonic wave array systems allow for the efficient structural health monitoring (SHM) of large structures, such as aircraft or ship hulls. Permanently attached sensor arrays have been applied for the detection and imaging of corrosion and fatigue damage. A hybrid model has been developed for the efficient prediction of the sensitivity of guided waves array systems to detect through thickness and part-through fatigue cracks in plate structures. The influence of the orientation of the crack relative to the transducer elements has been predicted from localized 3D Finite Element simulations and verified experimentally. The directivity pattern of the scattered guided wave field has been shown to depend on the defect orientation and on the ratio of the characteristic defect size and depth to wavelength. Using the hybrid model, detection and imaging capabilities can be predicted for various defect depths, and the sensor layout and signal processing optimized. This has been demonstrated from laboratory experiments. Notches of increasing depth were machined into an aluminium plate and imaged using distributed sensors for the A0 Lamb wave mode. Based on the model predictions the sensitivity for shallow defects has been optimized, and the minimum imaged defect depth found.

Guided Wave Imaging for Crack Detection and Quantification
---Lingyu Yu, University of South Carolina, Department of Mechanical Engineering, 300 South Main St. A211, Columbia, SC 29208

---Embedded non-destructive evaluation (e-NDE) based on ultrasonic guided waves excited through permanently attached piezoelectric thin wafer sensors has been growing in recent years. The guided wave array imaging has shown its incredible capability to map the structure and give a visual indication of damage presence. The imaging approaches usually rely on the use of reflections or scattering waves to indicate the structural discontinuity caused by the damage. The arrays can be configured with sensors physically close to each other, transmitting and receiving waves in pulse-echo mode; they can also be arranged separated from each other and used in pitch-catch mode. In this study, we first studied guided wave excitation on isotropic plates and the capability to use piezoelectric thin wafer sensors to selectively excite a certain mode in the structure. Mode selection will be studied to choose the appropriate mode for detecting through-the-thickness damage, typically holes and cracks. Then several algorithms for imaging with the sparse arrays working in pitch-catch mode were developed. The algorithms were applied to isotropic specimens including thin aluminum plates with hole and crack damage. Image post processing was developed to assess the damage and yield estimations of location and size.
Adaptive Dispersion Compensation for Guided Wave Imaging
---James S. Hall and Jennifer E. Michaels, School of Electrical and Computer Engineering, Georgia Institute of Technology, 777 Atlantic Dr. NW, Atlanta, Georgia 30332-0250

---Ultrasonic guided waves offer the potential for a fast and reliable method of interrogating large, plate-like structures. Sparse arrays of permanently attached, inexpensive piezoelectric transducers have thus been proposed as a cost-effective means of applying ultrasonic guided waves for structural health monitoring (SHM) applications. Guided wave data recorded from a sparse array of transducers are often analyzed and interpreted through the use of guided wave imaging algorithms, such as conventional delay-and-sum imaging or the more recently applied minimum variance imaging. Both imaging algorithms perform reasonably well using envelope-detected signals, but can exhibit significant performance improvements when phase information is used. However, the use of phase information inherently requires knowledge of the dispersion relations, which are often not known to a sufficient degree of accuracy for high quality imaging since they are very sensitive to environmental conditions such as temperature, pressure, and loading. This work seeks to perform improved imaging with phase information by leveraging adaptive dispersion estimates obtained from in situ measurements. Sparse array data from both simulations and experiments are used to validate the proposed approach.

Ultrasonic Wave-Based Defect Localization Using Probabilistic Modeling
---Michael D. Todd and Eric B. Flynn, University of California San Diego, Department of Structural Engineering, 9500 Gilman Drive 0085, La Jolla, CA 92039-0085; Paul D. Wilcox, Bruce W. Drinkwater, and Anthony J. Croxford, University of Bristol, Department of Mechanical Engineering, Bristol, United Kingdom; Seth M. Kessler, Metis Design Inc., Boston, MA

---This work presents a new approach to defect localization for ultrasonic guided wave structural health monitoring applications. The approach is rooted in constructing a minimally-informed (lowest order possible) statistical model of the guided wave process. Unknown or uncertain model parameters, such as scattered wave amplitude, are assigned non-informative Bayesian prior distributions and integrated out of the a posteriori probability calculation. This is somewhat akin to a maximum likelihood estimate weighted by any prior information. The premise of this localization approach is straightforward: the most likely defect location is the point on the structure with the maximum a posteriori probability of actually being the location of damage (i.e., the most probable location given a set of sensor measurements). Using an ensemble of measurements from two instrumented plates with multiple stiffening stringers and other geometric features, the performance of the a posteriori estimate is compared to that of what were found to be the two most effective previously-reported algorithms. The MAP estimate proved superior in nearly all test cases and was particularly effective in localizing damage using very sparse arrays of as few as three transducers.
Guided Wave Localization of Damage via Sparse Reconstruction
---Ross M. Levine, Jennifer E. Michaels, and Sang Jun Lee, Georgia Institute of Technology, School of Electrical and Computer Engineering, 777 Atlantic Dr., NW, Atlanta, GA 30332-0250

---Ultrasonic guided waves are frequently applied for structural health monitoring and nondestructive evaluation of plate-like metallic and composite structures. Spatially distributed arrays of fixed piezoelectric transducers can be used to detect damage by recording and analyzing all pairwise signal combinations. By subtracting pre-recorded baseline signals, the effects due to scatterer interactions can be isolated. Given these residual signals, techniques such as delay-and-sum imaging are capable of detecting flaws, but do not exploit the expected sparse nature of damage. It is desired to determine the location of a possible flaw by leveraging the anticipated sparsity of damage; i.e., most of the structure is assumed to be damage-free. Unlike least-squares methods, L1-norm minimization techniques favor sparse solutions to inverse problems such as the one considered here of locating damage. Using this type of method, it is possible to exploit sparsity of damage by formulating the imaging process as an optimization problem. A model-based damage localization method is presented that simultaneously decomposes all scattered signals into location-based signal components. The method is first applied to simulated data to investigate sensitivity to both model mismatch and additive noise, and then to experimental data recorded from an aluminum plate with artificial damage. Compared to delay-and-sum imaging, results exhibit a significant reduction in both spot size and imaging artifacts when the model is reasonably well-matched to the data.

Long Term Stability Analysis of a Guided Wave SHM System for Platelike Structures
---Vatche Attarian, Fred Cegla, Peter Cawley, Imperial College London, Mechanical Engineering, Exhibition Road, South Kensington, London, SW7 2AZ, United Kingdom

---Maintenance of safety critical structures is essential for continued operation and development of aging infrastructure. Research suggests guided waves may well facilitate structural health monitoring (SHM) for damage in platelike structures. Past laboratory studies have shown sufficient signal-to-coherent-noise ratio (SNR) may be obtained, even in the presence of temperature changes, for detection and localization of through holes (<10mm) over reasonable areas (>1m2). However, any practical SHM system must ultimately be robust and operate reliably in realistic environments for extended time periods. This paper is concerned with the long term stability of guided wave SHM data acquired in outdoor UK weather. Five ruggedized transducers, permanently installed on an anodized Aluminum plate, were used to periodically record signals monitoring S0 Lamb wave propagation for varying combinations of transmitters and receivers. Quantitative assessment of acquired signals indicated that transducers remained robust for at least 4 months (acquisition is continuing). Temperature compensation with a baseline signal database collected in an environmental chamber and imaging allowed visualization of coherent noise distribution over the structure. Background variations in these images of the plate were analyzed to assess system stability. Results and trends in statistical measures of SNR over the acquisition period are discussed in this work.
Flaw Detection and Characterization Using Lamb Wave Tomography and Pattern Classification

--- Mark K. Hinders and Corey A. Miller, College of William & Mary, Applied Science Department, Williamsburg, VA, 23187-8795

--- Lamb waves are often used in NDE and structural health monitoring because their multimodal properties allow for interaction with many types of flaws. By collecting Lamb wave measurements in an array of pitch-catch positions around a given area, Lamb wave tomography allows for the generation of a reconstructed image that accurately locates and sizes flaws. However, these images often cannot predict the severity or type of flaw when they are severe enough that scattering effects dominate. Pattern classification routines provide an alternative means for processing ultrasonic waveforms in order to predict flaw severity. Lamb wave tomography is first used to localize a flaw. Waveforms from ray paths that cross the suspected flaw area are automatically identified, and the dynamic wavelet fingerprint technique is used to generate feature vectors from these complex multi-mode ultrasonic signals. This combination of tomography and pattern classification allows for the prediction of flaw severity in plate-like samples with defects of varying depths. Here an aluminum plate with a rectangular thinning milled at 17 different depths is scanned sequentially in order to provide a training data set for pattern classification with the performance of several standard classifiers compared.

Isolation of Crack-Induced Standing Wave Energy from Laser Scanned Ultrasonic Image

--- Yun-Kyu An, Byeong Jin Park, and Hoon Sohn, KAIST, Department of Civil and Environmental Engineering, Daejeon, Korea

--- In this study, a new standing wave energy (SWE) imaging technique is developed so that a crack in a metallic structure can be detection from ultrasonic wavefield images obtained by a laser scanning system. First, a noncontact laser ultrasonic scanning system is developed so that ultrasonic waves on a target structure can be generated and measured using two independent laser sources. Using this scanning system, an ultrasonic wavefield image with high spatial and temporal resolutions is constructed. The interaction of propagating ultrasonic waves with a crack is theoretically studied, and the creation of standing waves due to crack formation is confirmed. Then, the energy of the crack induce standing waves is isolated from the constructed wavefield image using the proposed image processing technique, allowing the identification and localization of the crack. In this way, reference-free crack detection, which can identify a crack without comparing the “current” data with the “past” baseline data obtained from an intact condition of a target structure, is realized. The effectiveness of the proposed technique is experimentally investigated using data obtained from a plate-like structure.
Guided Wave Permanently Installed Pipeline Monitoring System
---Andrea Galvagni and Peter Cawley, Imperial College, Department of Mechanical Engineering, Exhibition Road, London, SW7 2AZ, United Kingdom

---Ultrasonic guided waves are routinely used to inspect pipes. The advantage of this technique is that it enables a fully-volumetric screening of several meters of pipe from a single transducer location, resulting in substantial time and cost savings. However, it suffers from limitations such as relatively low damage sensitivity and difficulties in dealing with intricate pipe networks; furthermore, for a pipe that is buried, submerged or at height it may still prove difficult and expensive to routinely gain access to even a single location. The use of permanently attached sensors can overcome these limitations since access needs to be obtained only once during installation and they enable the use of baseline subtraction, so that any reading from a sensor can be compared to previous readings thereby allowing tracking and trending of signal changes. This paper discusses the advantages of baseline subtraction in the context of guided wave pipeline inspection as well as methods to address the unique challenges that this application presents in terms of compensating for signal changes due to effects other than the growth of damage. It is shown that the use of baseline subtraction allows significant damage sensitivity improvements, particularly in the vicinity of large reflectors.

On the Interpolation of Ultrasonic Guided Wave Signals
---Jennifer E. Michaels, Jason P. Zutty, and Thomas E. Michaels, Georgia Institute of Technology, School of Electrical and Computer Engineering, 777 Atlantic Dr., NW, Atlanta, GA 30332-0250; Ren-Jean Liou, National Pingtung Institute of Commerce, Department of Computers and Communications, Pingtung, Taiwan

---The application of ultrasonic guided wave methods to both nondestructive evaluation (NDE) and structural health monitoring (SHM) methods is becoming more prevalent as techniques to handle their multi-modal and dispersive nature are developed. There are several applications where it would be not only convenient but perhaps essential to interpolate arrays of measured guided wave signals. One application is that of linear and rectangular spatial arrays acting as receivers, where it may be useful to interpolate signals in between array elements. Another application is interpolation of signals acquired as a function of a non-spatial variable such as temperature or applied load; this situation arises in SHM applications where it is desired to construct a baseline that is well-matched to the signal of interest. This problem is closely related to that of time domain up-sampling whereby signals are resampled at a higher rate, which can readily be performed using conventional methods when the Nyquist criterion is satisfied. In the spatial domain, there is an analogous spatial Nyquist criterion, and if it is satisfied, spatial signals can also be similarly up sampled. In this paper we show examples of several interpolation algorithms in multiple domains, and evaluate the efficacy of each for different sampling rates using both synthetic and experimental data. We derive a Nyquist-like criterion for which conventional interpolation can be successfully achieved in the temperature and loading domains, and illustrate results for both types of experimental data. We then make concluding remarks regarding both the usefulness and limitations of guided wave signal interpolation for various NDE and SHM applications.
Session 25
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| 8:30 AM| Concepts for Evaluation of Image Quality in Digital Radiology  
| 8:50 AM| Estimation of Depth of Flaw in Propellant Grains by Digital X-Ray Radiography  
---B. Ghose and D. K. Kankane, High Energy Materials Research Laboratory, DRDO, Pune, Maharashtra, PIN-411021, India |
| 9:10 AM| Enhanced Estimation of Wall Thinning in Different Shape Specimens by Optimizing Scattering Using Digital X-Ray Radiography  
---T. Saravanan, J. Phip, T. Jayakumar, and B. Raj, Indira Gandhi Centre for Atomic Research, Metallurgy and Materials Group, Kalpakkam, Tamil Nadu, India; S. K. Yellapu, National Institute of Technology, Department of Physics, Tiruchirapalli, Tamil Nadu, India |
| 9:30 AM| Simulation Supported POD for RT Test Case - Concept and Modeling  
---C. Gollwitzer, C. Bellon, U. Ewert, and G.-R. Jaenisch, BAM Federal Institute for Materials Research and Testing, Radiology, Berlin, Germany; Quentin Mistral, SNECMA, Quality Department, Moissy Cramayel, France |
| 9:50 AM| CIVA 10 RX Module Validation in a Nuclear Context  
---D. Tisseur, F. Buyens, and B. Rattoni, CEA LIST, CEA Saclay 91191 Gif sur Yvette Cedex, France; G. Cattiaux and T. Sollier, IRSN/DSR/SAMS, B.P.17 92262 Fontenay-Aux-Roses, France |
| 10:10 AM| Break                                                                                                                                    |
| 10:30 AM| Recent Extensions to XRSIM: An X-ray Radiography Simulation Tool: Applications and Comparison to Experiment  
---J. Gray and S. Wendt, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011 |
| 10:50 AM| X-Ray Computed Tomography Modelling for NDT and Experimental Validation  
---M. M. Costin and S. Legoupil, French Alternative Energies and Atomic Energy Commission, Department of Imaging & Simulation for Non-Destructive Testing, Image, Tomography & Data Processing Laboratory, 91191 Gif-sur-Yvette Cedex, France; A. Leveque, French Alternative Energies and Atomic Energy Commission, Department of Imaging & Simulation for Non-Destructive Testing, IT Development Laboratory, 91191 Gif-sur-Yvette Cedex, France |
| 11:10 AM| A Mask Iterative Hard Thresholding Algorithm for Sparse X-Ray CT Image Reconstruction with Known Object Contour  
---A. Dogandzic, R. Gu, and K. Qiu, Iowa State University, ECpE Department, 3119 Coover Hall, Ames, IA 50011 |
| 11:30 AM| Process Integrated Casting Inspection Using Radiography and Computerized Tomography  
| 11:50 PM| Lunch                                                                                                                                    |
Concepts for Evaluation of Image Quality in Digital Radiology
---Uwe Zscherpel, Uwe Ewert, and Mirko Jechow, BAM Federal Institute for Material Research and Testing, Division 8.3, Unter den Eichen 87, Berlin, D-12205, Germany

Concepts for digital image evaluation are presented for Computed Radiography (CR) and Digital Detector Arrays (DDAs) used for weld inspection. The precise DDA calibration yields an extraordinary increase of contrast sensitivity up to 10 times in relation to film radiography. Restrictions in spatial resolution caused by pixel size of the DDA are compensated by increased contrast sensitivity. First CR standards were published in 2005 to support the application of phosphor imaging plates in lieu of X-ray film, but they need already a revision based on experiences reported by many users. One of the key concepts is the usage of signal-to-noise (SNR) measurements as equivalent to the optical density of film and film system class. The first standard draft for digital radiographic inspection of welds is discussed (ISO/DIS 17636-2). Imaging plates are limited in the achievable contrast sensitivity by their structural noise. The increase of exposure dose improves the contrast-to-noise ratio (CNR) in the low dose range, but reaches a maximum at higher dose values. The optimum parameters for best Equivalent Penetrameter Sensitivity (EPS) are different from the typical values of film radiography and depend on the maximum achievable signal-to-noise ratio, basic special resolution and specific contrast of the detector.

Estimation of Depth of Flaw in Propellant Grains by Digital X-Ray Radiography
---Bikash Ghose and D. K. Kankane, High Energy Materials Research Laboratory, DRDO, Pune, Maharashtra, PIN-411021, India

X-Ray radiography is widely used as Non Destructive Evaluation (NDE) tool for detection of flaws in propellant grains. Many times it is not sufficient only to detect the flaws like blow holes, voids, cracks, agglomerates etc. present in the propellant grains but it is necessary to characterize those flaws. The presence of flaws is needed to be characterized in terms of their location, shape, size and orientation. The complete characterization of flaws present in the propellant grains helps to judiciously decide the acceptability of the grains with the existing flaws. The location of blow hole in a cylindrical object like propellant grain / motor can be found out by methods mentioned by other researchers. Size of flaw can be estimated knowing the magnification factor for the flaw which can be evaluated after estimating the exact location. The information about the depth of flaw is difficult to be known from the single radiograph. Moreover the information regarding the depth of flaw is very critical and crucial in terms of correct evaluation of the grain for its acceptability. The depth information can be found out by Computerized tomography (CT) system. However in absence of sophisticated CT system there is a need to devise a methodology for estimation of depth of flaw from a single digital radiograph. This paper describes a method to estimate the depth of flaw from the single radiograph obtained from digital radiography system. The corresponding mathematical formulation has been derived which has few independent variables that to be evaluated before it can estimate the depth of unknown flaw. The independent variables can be easily found out from the same radiograph with input about the specimen detail. The formulation has been validated with wide variation in the thickness of propellant grain. The result obtained from the formulation is closely matched with the actual one.
**Enhanced Estimation of Wall Thinning in Different Shape Specimens by Optimizing Scattering Using Digital X-Ray Radiography**

--- Thangavelu Saravanan, John Philip, Tammana Jayakumar, and Baldev Raj, Indira Gandhi Centre for Atomic Research, Metallurgy and Materials Group, Kalpakkam, Tamil Nadu, India; Sai Krishna Yellapu, National Institute of Technology, Department of Physics, Tiruchirapalli, Tamil Nadu, India

--- The effect of scattering on achievable defect sensitivity for different object to detector distance (ODD) and specimen geometry is studied using Monte-Carlo simulation available in CIVA package and the results are compared with digital radiography experimental data. Monte-Carlo simulation results show that the amount of scattered photons at the detector decreases with increase in ODD. The defect sensitivity for a given ODD for two different geometries-flat plate and cylindrical pipe - using simulation studies is found to be 1% and 1.5% respectively which is in good agreement with the experimental results. Experiments were carried out using a 10mm thick SS 316 plate and a 100mm OD carbon steel pipe of thickness 10mm, which have EDM notches with different depths from 0.1 to 0.5mm. Under identical conditions, radiography exposures of these specimens were taken for different ODD. In the case of plate geometry, the normalized signal to noise ratio (SNRn) was measured as 75 and 135 for ODD of 100 and 500mm respectively. Similarly, for pipe geometry, the SNRn for the corresponding ODDs are 57 and 130 respectively. In both the cases, the SNRn saturates for the 500mm ODD. At 500mm ODD, the minimum wall thinning measured in the case of plate and pipe geometry are found to be 1% and 1.5% respectively, whereas it was > 2%, without ODD optimization. It has been found from simulation and experimental studies that the scattering effect is stronger in curved geometries, which is attributed to the large scattering volume and thickness variations in pipe geometry, leading to reduced defect sensitivity.

--- Simulation Supported POD for RT Test Case - Concept and Modeling

--- Christian Gollwitzer, Carsten Bellon, Uwe Ewert, and Gerd-Ruediger Jaenisch, BAM Federal Institute for Materials Research and Testing, Radiology, Berlin, Germany; Quentin Mistral, SNECMA, Quality Department, Moissy Cramayel, France

--- Computer simulation of radiography is applicable for different purposes in NDT such as for qualification of NDT systems, optimization of radiographic parameters, feasibility analysis, model-based data interpretation, and training of NDT/NDE personnel. Within the framework of the European project PICASSO the radiographic simulator aRTist (analytical Radiographic Technique inspection simulation tool) developed by BAM has been extended for reliability assessment of film and digital radiography. NDT of safety relevant components of aerospace industry requires the proof of probability of detection (POD) of the inspection. Modeling tools can reduce the expense of such extended, time consuming NDT trials, if the result of simulation fits to the experiment. A concept has been developed as well as extensions to the simulation tool for calibration of the radiographic model and for reliability investigations, completed by a user interface for planning automatic simulations with varying parameters. Furthermore, an automatic image analysis procedure is included to evaluate the defect visibility. The radiographic modeling from 3D CAD of aero engine components and quality test samples are compared as precondition for real trials. The analytic simulation tool includes the description of the radiation source, the interaction of radiation with parts, and the detection process with special focus to film and digital industrial radiography. This enables the evaluation and optimization of film replacement for application of modern digital equipment for economical NDT and defined POD.
CIVA 10 RX Module Validation in a Nuclear Context
---D. Tisseur, F. Buyens, and B. Rattoni, CEA LIST, CEA Saclay 91191 Gif sur Yvette Cedex, France; G. Cattiaux and T. Sollier, IRSN/DSR/SAMS, B.P.17 92262 Fontenay-Aux-Roses, France

---X-ray/gamma ray radiography is a commonly used nondestructive evaluation method. CIVA platform is a well-known NDE software developed by CEA LIST. A new gamma/X-ray radiography simulation module is now integrated in the CIVA 10 software platform. This module is based on a combination of radiographic NDE codes SINBAD developed by CEA-LETI and MODERATO developed by EDF R&D. For several years, a research program funded by the French Institute for Radioprotection and Nuclear Safety (IRSN) studies gamma/X-ray simulation tools for evaluating NDE methods in the nuclear context. In this context, IRSN in partnership with CEA LIST, has started in 2010 a program over several years for the validation of CIVA RX module. The aim of this paper is to present preliminary results of CIVA RX tools validation. The study consists in a cross comparison between experimental and simulation results. These have been carried out on different objects (stepwedge, dissimilar weld mock up, IQI) with different sources (60Co and 450kV) and a radiographic film in conformity with NF EN 584-1 standard to compare the response to optical density, IQI perceptivity and defaults detectability. Simple objects have been first studied and results show a good accuracy between experiment and simulation.

Recent Extensions to XRSIM: An X-ray Radiography Simulation Tool: Applications and Comparison to Experiment
---Joe Gray and Scott Wendt, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

---We report on recent extensions of XRSIM, an x-radiography simulation program. Improvement in the approximations used to adhere to limited computational resources in the past are no longer needed allowing accurate modeling of blurring processes, such as geometric unsharpness, undercut effects, and even scattering to be accurately modeled. The increasing demands to incorporate complex geometry into the simulations can now be met with emerging computational resources, especially gpu computing. As with any model the results are only as good as the inputs to the model and the ability to extract from high resolution 3DCT scans details of complex geometries has greatly improved. We present as an example of these improvements and extensions optimization of an inspection design and a determination of key variables controlling sensitivity and will comparison the results to experimental data.
X-Ray Computed Tomography Modelling for NDT and Experimental Validation
---Marius M. Costin and Samuel Legoupil, French Alternative Energies and Atomic Energy Commission, Department of Imaging & Simulation for Non-Destructive Testing, Image, Tomography & Data Processing Laboratory, 91191 Gif-sur-Yvette Cedex, France; Arnaud Leveque, French Alternative Energies and Atomic Energy Commission, Department of Imaging & Simulation for Non-Destructive Testing, IT Development Laboratory, 91191 Gif-sur-Yvette Cedex, France

---CIVA is a simulation software for NDT/NDE applications initially developed for ultrasonic and Eddy current techniques. A recent development is the X-ray module which computes the forward projections and the latest feature is the reconstruction of projection data, which completes the computed tomography (CT) process. The CT modeling allows estimating the influence of several parameters such as the X-ray energy, the detector response, mechanical misalignments or the detection limits and the metrological performances of the system. The projection data is computed with a hybrid algorithm combining analytical and Monte Carlo calculations for a realistic modelling of noise and scattering. The reconstruction is performed with our implementation of the FDK (Feldkamp-Davis-Kress) algorithm. This work presents an experimental validation of the X-ray CT module performed with a SkyScan 2011 nano-tomograph. We simulate the CT procedure for this device and we compare the simulated data to the experimental data. The sample used for simulation is a CAD object extracted from the experimental data reconstructed with the proprietary software of the CT device. We show through a 3D study that the CT images obtained by simulation are in good agreement with the experimental images.

A Mask Iterative Hard Thresholding Algorithm for Sparse X-Ray CT Image Reconstruction with Known Object Contour
---Aleksandar Dogandzic, Renliang Gu, and Kun Qiu, Iowa State University, ECpE Department, 3119 Coover Hall, Ames, IA 50011

---We develop a mask iterative hard thresholding algorithm (mask IHT) for sparse X-ray computed tomography (CT) image reconstruction with known object contour. The measurements follow an underdetermined linear model common in the compressive sampling literature. We assume that the contour of the object that we wish to reconstruct is known and that the signal outside the contour is zero. We first propose a constrained residual squared error minimization problem that incorporates both the geometric information (i.e. the knowledge of the object's contour) and the signal sparsity constraint. We then propose our mask IHT algorithm that aims at solving this minimization problem and guarantees monotonically non-increasing residual squared error. If we remove the hard thresholding operator, our mask IHT scheme becomes an iterative Landweber algorithm that imposes only the geometric contour constraint and yields the minimum-norm solution of the underlying linear system. We compare the proposed mask IHT and minimum-norm schemes with existing large-scale sparse signal reconstruction methods via numerical simulations and demonstrate that, by exploiting both the geometric contour information of the underlying image and the sparsity of its wavelet coefficients, we can reconstruct this image using a significantly smaller number of measurements than the existing methods. We will apply the proposed methods to reconstruct images from real X-ray CT measurements of an industrial object and demonstrate their superior performance compared with the existing approaches.---This work was supported by the NSF Industry-University Cooperative Research Program, Center for Nondestructive Evaluation (CNDE), Iowa State University.
Process Integrated Casting Inspection Using Radiography and Computerized Tomography
---Steven Oeckl, Roland Gruber, Werner Schön, Markus Eberhorn, Thomas Stocker, and Thomas Wenzel, Fraunhofer Institute for Integrated Circuits IIS, Department Process Integrated Inspection Systems, Dr.-Mack-Str. 81, 90762 Fürth, Germany

---Automatic two-dimensional (2D) X-ray inspection of cast parts is a standard quality control measure in foundries today. Typically 100 percent detection of defects in all areas of a cast part is necessary to prevent failure due to material defects. But a 2D projection of a defect does not yield sufficient information on the defect's location in the part or its extent. This lack of information often leads to an unnecessary scrapping of parts which can significantly reduce a foundry's output. Until recently system cost and processing speed of a Computerized Tomography (CT) system capable of computing three-dimensional (3D) images prevented its widespread use except for special applications, e.g. offline inspection of prototypes in the lab. With the steady advances in processing speed in conjunction with a new detector design and optimized 3D image processing algorithms, it is now possible to integrate a CT system into the process, offering 3D reconstruction, fully automatic defect detection and measurement in the cast part in less than 30 seconds per part. Using 3D reconstruction of the entire part including all defects, yields precise knowledge of flaw properties, location and distribution in the part. This information is vital for improving foundry throughput without sacrificing part quality. In this contribution we show the performance, limitations and necessary boundary conditions of both methods, i.e. 2D X-ray inspection and 3D Computerized Tomography. We discuss the results by the means of real data from automobile industry.
Session 26
SESSION 26
ADHESIVE BONDS, COATINGS, AND INTERFACES
B. Maxfield, Chairperson
Frank Livak Ballroom

8:30 AM An EMAT Based Shear Horizontal (SH) Wave Technique for the Adhesive Bond Inspection
---K. Arun, R. Dhayalan, K. Balasubramaniama, and B. Maxfield, Indian Institute of Technology
Madras, Centre for Nondestructive Evaluation, Chennai, Tamil Nadu, INDIA; P. Peres and
D. Barnoncel, bAstrium Space Transportation, EADS, Av du Général Niox – BP 20011, FRANCE

8:50 AM Bond Integrity of a Half Space on a Plate Wave Guide
---J. H. Bostron and J. L. Rose, The Pennsylvania State University, Graduate Program in
Acoustics, University Park, PA 16802

9:10 AM Stiffener Bond Line Monitoring Using Ultrasonic Shear Guided Waves
---Z. Fan, Imperial College London, Department of Mechanical Engineering, London, United
Kingdom; M. Castaings, Université de Bordeaux, Institut de Mécanique et d'Ingénierie de Bordeaux
(I2M), UMR CNRS 5295, Talence, France; M. J. S. Lowe, Imperial College London, Department of
Mechanical Engineering, London, United Kingdom; P. Fromme, University College London,
Department of Mechanical Engineering, London, United Kingdom; C. Biateau, Univ. de Bordeaux,
Institut de Mécanique et d'Ingénierie de Bordeaux (I2M), UMR CNRS 5295, Talence, France

9:30 AM Multiple Frequency Amplitude and Phase C-Scan Bond Testing for Composite Structures
---J. Habermehl, Olympus NDT, 505, boul. du Parc-Technologique, Quebec G1P4S9, Canada

9:50 AM A Hybrid Analytical and a Wavestructure Based Analysis for Ultrasonic Guided Wave
Interaction with a Waveguide Transition
---P. Puthillath, C. J. Lissenden, and J. L. Rose, Pennsylvania State University, Engineering
Science and Mechanics, University Park, PA 16802; J. M. Galan, Universidad de Sevilla, Escuela
Superior de Ingenieros, Sevilla, Spain

10:10 AM Break

10:30 AM Ultrasonic Testing of Adhesive Bonds of Thick Composites with Applications to Wind
Turbine Blades
---S. K. Chakrapani¹, V. Dayal¹, R. Krafka¹, and A. Eldal¹; ¹Department of Aerospace Engineering
and Center for NDE, Iowa State University, Ames Iowa 50010

10:50 AM Laser Generated Ultrasounds in Metals and Thin Films
---C. McKee, B. Culshaw, G. Thursby, A. Cleary, and I. Armstrong, University of Strathclyde,
Department of Electronic and Electrical Engineering, 204 George Street, Glasgow, G1 1XW
Scotland, United Kingdom

11:10 AM Simulation of Nonspecular Reflection at the Rayleigh Angle for Evaluation of Thin Coating
Layers
---H.-J. Kim, S. J. Kim, and S.-J. Song, Sungkyunkwan University, School of Mechanical
Engineering, Suwon, Korea; S.-D. Kwon, Andong National University, Department of Physics,
Andong, Korea

11:30 AM Laser Ultrasound Technique Application in Material Characterization of Thermally Sprayed
Nickel Aluminum Alloy System Coatings
---C.-H. Yeh, C.-H. Yang, and C.-Y. Su, National Taiwan University of Technology, Graduate
Institute of Manufacturing Technology, Taipei, Taiwan (R.O.C); W.-T. Hsiao, Industrial Technology
Research Institute, Material and Chemical Research Laboratories, Hsinchu, Taiwan (R.O.C.)

11:50 AM Lamb Wave Propagation in a Restricted Geometry Composite Pi-Joint Specimen
---J. L. Blackshire, Air Force Research Laboratory, AFRL/RXLP, WPAFB, OH 45433-7817;
S. Soni, Department of System & Engineering Management, AFIT, WPAFB, OH 45433-7817

12:10 PM Lunch
An EMAT Based Shear Horizontal (SH) Wave Technique for the Adhesive Bond Inspection
---K. Arun, R. Dhayalan, Krishnan Balasubramaniama, and Bruce Maxfield, Indian Institute of Technology Madras, Centre for Nondestructive Evaluation, Chennai, Tamil Nadu, INDIA; Patrick Peres and David Barnoncel, bAstrium Space Transportation, EADS, Av du Général Niox – BP 20011, FRANCE

---The evaluation of Adhesively bonded structures has been a challenge over several decades of its applications, particularly in the aerospace industry. While several techniques have been proposed for the detection of disbonds and cohesive weakness, the detection of interfacial weakness (also sometimes called as kissing bonds) have been somewhat elusive. Different techniques have been proposed which includes the NDT modalities covering Ultrasonics, Thermal Imaging, Shearography, etc., all with some degree of success. The ultrasonic methods including shear and guided ultrasonic waves have also been explored for the detection of interfacial bond quality. In this paper, a new guided wave technique using a reverberation signal, from within a lap joint, is shown to hold promise for the detection of interfacial weak bonds. It was also determined that the Shear Horizontal (SH) wave modes could discriminate between adhesive and cohesive weakness defects in both Aluminum-Epoxy-Aluminum as well as Composite-Epoxy-Composite lap joint case studies. The SH modes using the Periodic Permanent Magnets (PPM) based Electro-Magnetic Acoustic Transducers (EMATs) were designed to generate specific modes. This has been demonstrated using both Finite Element Models as well as experiments. A hybrid multi physics FEM model was used in the simulation of the generation and reception of the SH guided wave modes and the interaction with interfacial and cohesive weak bonds. It was found that the guided SH wave modes reverberate within the lap joints and were determined to be affected by weakness in the interface between the substrate and the epoxy bond. The experimental results correlate well with the simulations.

Bond Integrity of a Half Space on a Plate Wave Guide
---Jason H. Bostron and Joseph L. Rose, The Pennsylvania State University, Graduate Program in Acoustics, University Park, PA 16802

---Bond integrity is of interest to researchers in non-destructive evaluation because it is used as an indicator when assessing the health of structures in a variety of applications. For example, debonding of a coating on a metal plate allows moisture to be introduced to the plate surface. Moisture will encourage the development of corrosion and degrade the structural integrity of the plate. By studying bond integrity, one has advance notice of corrosion development, as opposed to looking at plate thickness, which monitors the progression of corrosion. In this study, we examine the bond integrity of a half space on a plate waveguide to find features correlated with bond integrity. Analytical and finite element models are developed to describe wave propagation. Guided waves are propagated in the plate across a bonded region in a pitch-catch mode. Local stiffness of the half space at the plate surface is decreased to simulate weakened bond strength. As bond strength is weakened, several possible indicators of bond strength are examined, including group velocity, amplitude ratios of output/input of different modes, and frequency content. Mode and frequency selection optimization to solve a particular problem is discussed.
Stiffener Bond Line Monitoring Using Ultrasonic Shear Guided Waves

---Zheng Fan, Imperial College London, Department of Mechanical Engineering, London, United Kingdom; Michel Castaings, Université de Bordeaux, Institut de Mécanique et d'Ingénierie de Bordeaux (I2M), UMR CNRS 5295, Talence, France; Michael J.S. Lowe, Imperial College London, Department of Mechanical Engineering, London, United Kingdom; Paul Fromme, University College London, Department of Mechanical Engineering, London, United Kingdom; Christine Biateau, Université de Bordeaux, Institut de Mécanique et d'Ingénierie de Bordeaux (I2M), UMR CNRS 5295, Talence, France

---Adhesively bonded stiffeners are employed in aerospace applications to increase structural stiffness. The potential of shear guided wave modes for the verification of adhesion and bond line thickness in difficult to access regions has been investigated. The properties of guided wave modes propagating along a T-shaped stiffener bonded to an aluminum plate were calculated using the Semi-Analytical Finite Element (SAFE) method. Shear modes were identified as well suited with energy concentrated at the stiffener and bond line, limiting energy radiation into the plate and thus achieving increased inspection length. The influence of bond line properties and thickness was investigated from SAFE calculations and a significant influence of the epoxy shear (Coulomb) modulus on the phase velocity found. Experiments were conducted during the curing of an epoxy adhesive, bonding a stiffener to the plate with bond strength and stiffness increasing over time. The excited shear mode was measured using a laser interferometer. The measured phase velocity changed significantly during curing. The frequency dependency matches well with the SAFE calculations for a variation of the Coulomb’s modulus of the adhesive layer. The potential of the shear guided wave mode for bond line inspection and monitoring will be discussed.

Multiple Frequency Amplitude and Phase C-Scan Bond Testing for Composite Structures

---Jason Habermehl, Olympus NDT, 505, boul. du Parc-Technologique, Quebec G1P4S9, Canada

---Adhesive bonded components and structures have become an important part of manufacturing in the aerospace industry. These components often rely on honeycomb composite structures for strong yet lightweight design. However, the quality of the bonds is very important to the overall integrity of the composite structures. These materials pose inspection challenges due the wide range of laminate and core configurations, especially when looking for damage in the core such as disbonds and crushed core. Although bond testing technology has existed for many years, it can still be considered a black art. The underlying physics are not well known or understood by even advanced users making selecting the appropriate frequency for a given inspection all the more difficult. Furthermore, flaw detectability is significantly influenced by the choice of frequency for a given inspection as the most appropriate frequency depends on the flaw size. It is also quite difficult with current commercially available technology to readily discriminate flaws from internal geometric features within a structure. For improved probability of detection (POD) on honeycomb composite structures, a multiple frequency C-scan based approach is proposed exploiting both amplitude and phase C-scans.
A Hybrid Analytical and a Wavestructure Based Analysis for Ultrasonic Guided Wave Interaction With a Waveguide Transition

---Padmakumar Puthillath, Cliff J. Lissenden, and Joseph L. Rose, Pennsylvania State University, Engineering Science and Mechanics, University Park, PA 16802; Jose Manuel Galan, Universidad de Sevilla, Escuela Superior de Ingenieros, Sevilla, Spain

---Inspection of bonded assemblies like a step-lap joint or a skin-stringer joint using ultrasonic guided waves requires an understanding of the guided wave scattering and mode conversion at the waveguide transition. A quantitative hybrid-analytical model based on semi-analytical Finite Element (SAFE) and Normal Mode Expansion (NME) was developed to understand the interaction of guided wave with a waveguide transition. An analysis based on wavestructures was also developed to provide a qualitative way to interpret the SAFE-NME results. Such an analysis is applicable to both metal and composite bonded structures. Experimental result based on the successful application of one of the many defect sensitive mode and frequency combinations determined from the hybrid-analytical method on a bonded aluminum joint is reported.

Ultrasonic Testing of Adhesive Bonds of Thick Composites with Applications to Wind Turbine Blades

---Sunil Kishore Chakrapani1, Vinay Dayal1, Ryan Krafka1, and Aaron Eldal1; 1Department of Aerospace Engineering and Center for NDE, Iowa State University, Ames Iowa 50010

---This paper discusses the use of pulse echo based ultrasonic testing for the inspection of adhesive bonds between very thick composite plates (thickness greater than 1.5 inch). Large wind turbine blades use very thick composite plates for its main structural members, and the inspection of adhesive bond-line is very vital. A wide gamut of samples was created by changing the plate and the adhesive thickness. An index is created to detect defective zones which include both lack of adhesive and insufficient adhesive, by using inspection method with contact ultrasonic transducers. The influence of experimental parameters such as frequency is also studied and discussed. Finally a probability of detection approach is chosen to study the effects of thickness of adhesive and composite plate on the thresholds or limits of detection. The combined results are used to develop an ultrasonic inspection system which can be implemented in the production line.
Laser Generated Ultrasound in Metals and Thin Films
---Campbell McKee, Brian Culshaw, Graham Thursby, Alison Cleary, and Ian Armstrong, University of Strathclyde, Department of Electronic and Electrical Engineering, 204 George Street, Glasgow, G1 1XW Scotland, United Kingdom

---A study of thermoelastic photoacoustic generation in metals and metallic films on silicon is presented. Results are obtained in thin metal plates and thin films on a silicon substrate. The materials studied are aluminium, copper and tungsten. Silicon is also investigated, however, the photostrictive effect is responsible for the acoustic waves in this case. The metallic films studied are Al, Au, Cu, Cr and Cr/Au. The laser source is an Nd:YAG laser with second and third harmonics available. Acoustic waveforms are detected optically using a vibrometer. The generation of acoustic waves in thin plates i.e. Lamb waves can be considered to be comprised of three processes. Absorption of electromagnetic energy by the material, subsequent thermal diffusion into the material and the production of elastic stresses due to thermal expansion. The efficiency of laser generation is investigated in the materials to determine how parameters such as absorption coefficient and optical reflectivity as functions of excitation wavelength influence the generation of Lamb waves. The optical and thermal properties of the thin films are investigated in the same manner to evaluate how the presence of these films influences the production of acoustic waves in the Silicon substrate.

Simulation of Nonspecular Reflection at the Rayleigh Angle for Evaluation of Thin Coating Layers
---Hak-Joon Kim, Soo Jeong Kim, and Sung-Jin Song, Sungkyunkwan University, School of Mechanical Engineering, Suwon, Korea; Sung-Duk Kwon, Andong National University, Department of Physics, Andong, Korea

---Coating techniques are widely adopted for performance enhancement of mechanical properties such as titanium nitride (TiN), diamond-like carbon (DLC), chemical vapor deposit (CVD) diamond and etc. Especially, CVD diamond coating layer has high hardness and wear resistance. Thus, the coated components used in severe environment. But, material properties of coating layers and substrates have large discrepancies. So, it is necessary to have nondestructive methods for evaluation of bonding quality and/or status of coating layers in order to insure integrity of the thin coating layers. Generalized Rayleigh waves is one of promising techniques among the various NDE methods, since Rayleigh waves were very sensitive to variation of surface area especially within 1.5 wavelengths deep. Through previous researches, bonding quality of thin coated specimens were performed using generalized Rayleigh waves. However, parametric investigation of quantitative evaluation of thin coating layers is not performed yet. So, in this study, we will investigate characteristics of generalized Rayleigh waves with variation of thickness and bonding strength of thin coating layers using FEM based simulation. Also, we will verify the simulation results by comparison to experimental results measured CVD diamond coated specimens with different deposition which is difference in thickness of the coating layers. And then, from the simulation results, we will establish relation between incident angle corresponding to Rayleigh angle and thickness and bonding strength of coating layers. Also, we will investigate relation between energy of reflected ultrasound at Rayleigh angle and bonding quality of the thin coating layer.---This work was supported by the R&D program of the Korea Institute of Energy Technology Evaluation and Planning (KETEP) grant funded by the Korea government Ministry of Knowledge Economy (No.2010T100100756).
Laser Ultrasound Technique Application in Material Characterization of Thermally Sprayed Nickel Aluminum Alloy System Coatings
---Cheng-Hung Yeh, Che-Hua Yang, and Cherng-Yuh Su, National Taipei University of Technology, Graduate Institute of Manufacturing Technology, Taipei, Taiwan (R.O.C); Wei-Tien Hsiao, Industrial Technology Research Institute, Material and Chemical Research Laboratories, Hsinchu, Taiwan (R.O.C.)

---Thermal spraying processing usually use nickel-aluminum alloy system as major powder due to its strong adhesion to substrates. The contents of powder material and the processing parameters used in the spraying process cause material properties of coating exhibiting a wide variation. It is difficult to investigate mechanical properties of coating layer in nondestructive way. This research aims at nondestructive characterization of thermal spraying coatings. A laser-generation/laser-detection laser ultrasound technique (LUT) is used for the measurements of dispersion spectra of guided waves. A theoretical model for surface waves propagating along a multi-layered structure with coating and substrate is used to model the sprayed coatings. An inversion algorithm based on Shuffled Complex Evolution (SCE-UA) is used to extract mechanical properties from the measured dispersion spectra cooperating with theoretical model. The results, three sets of surface wave dispersion spectra are measured for three different coatings which correspond to three different sprayed powders and powder processing like mixing or balling. The difference of coatings is reacted to dispersion spectrum of guided waves. It also related to mechanical properties of coating in theoretical model. This method is potentially useful to characterize the mechanical properties of thermal spraying coating in a nondestructive way.

Lamb Wave Propagation in a Restricted Geometry Composite Pi-Joint Specimen
---James L. Blackshire, Air Force Research Laboratory, AFRL/RXLP, WPAFB, OH 45433-7817; Som Soni, Department of System & Engineering Management, AFIT, WPAFB, OH 45433-7817

---The propagation of elastic waves in a material can involve a number of complex physical phenomena, resulting in both subtle and dramatic effects on detected signal content. In recent years, the use of advanced methods for characterizing and imaging elastic wave propagation and scattering processes has increased, where for example the use of scanning laser vibrometry and advanced computational models have been used very effectively to identify propagating modes, scattering phenomena, and damage feature interactions. In the present effort, the propagation of Lamb waves within a narrow, constrained geometry composite pi-joint structure are studied using 2D/3D finite element models and scanning laser vibrometry measurements, where the effects of varying sample thickness, complex joint curvatures, restricted geometries, and heterogeneous material properties are highlighted, and a direct comparison of computational and experimental results are provided for simulated and realistic geometry composite pi-joint samples.
Sizing and Reconstruction Methods

Accurate Method for Measurement of Pipe Wall Thickness Using a Circumferential Lamb Wave Generated and Detected by a Pair of Noncontact Transducers
---H. Nishino, Y. Taniguchi, and K. Yoshida, The University of Tokushima, Tokushima, Japan; M. Takahashi and Y. Ogura, Japan Probe Co. Ltd., Yokohama Japan

Identification of the Spatial Distribution of Conductivity by Eddy Current Defectoscopy with Application of Artificial Neural Networks
---T. Chady, I. Spychalski, and R. Sikora, West Pomeranian University of Technology, Szczecin, Poland

F.A.S.T: First Acquisition as Sole Testing – Using Parallel Phased Array Acquisitions and TDTE Reconstruction
---N. Dominguez and G. Ithurralde, EADS France - Innovation Works, Structure Health Engineering Department, Toulouse, France

A Study on Algebraic Reconstruction Method of Micro Defects Based on Ultrasonic Transducer Array
---X. Li, C. Xu, L. Wang, and H. Xu, Beijing Institute of Technology, School of Mechanical Engineering, #5, Zhongguancun South Street, Beijing, 100081, China (PRC)

An Industrial CT Reconstruction Technology to Directly Reconstruct the Characteristics
---L. Wang, Y. Zhao, F. Chen, and Y. Han, North University of China, National Key Laboratory for Electronic Measurement Technology, Tai Yuan, Shanxi, China 030051; L. Wang, Michigan State University, Nondestructive Evaluation Laboratory, East Lansing, MI 48823

Signal and Image Processing

A Genetic Algorithm-Based Approach to Ultrasonic Echoes Estimation
---Z. Liu and C. Xu, Key Laboratory of Fundamental Science for Advanced Machining, 5 South Zhongguancun Street, Beijing Institute of Technology, Haidian District Beijing 100081, China (PRC)

Novel Feature Extraction and Image Processing Technique for Eddy Current NDE
---G. Yang, L. Zhang, J. Xin, and L. Udpa, Michigan State University, East Lansing, MI 48823; J. Kim, Daegu University, Gyeongsan, Gyeongbuk 712-714, Korea
3D Acoustic Impedance Reconstruction Approach of Layered Composite Material
--- C. Xu and Z. Liu, Key laboratory of Fundamental Science for Advanced Machining, Beijing Institute of Technology, Beijing, P.R China

Time Reversal Imaging with Group of Guided Wave Modes to Improve Pipeline Inspection Range and Accuracy
--- S. Liu, North Carolina State University, Mechanical and Aerospace Engineering, Raleigh, NC 27695; W. Li and L. Song, Corporate Strategic Research, ExxonMobil Research and Engineering, 1545 Rt 22 East, LC326, Annandale, NJ 08801

Sensors, Transducers, and Probes

3D Modeling and Experimental Determination on Testing the Effective of Eccentric Bus-Bar Testing Method of Current Sensors
--- J. Xing, W. Zhao, and S. Huang, Tsinghua University, State Key Lab of Power Systems, Department of Electrical Engineering, Beijing 100084, China; B. Jiang, Sichuan Electric Power Test and Research Institute, Chengdu 610015, China; K. Qu, China Electric Power Research Institute, Department of High Voltage, Beijing 100192, China

Design, Characterization and Application of Transducers with Ultrasonic Axicon Lenses

Printed Circuit Board Transducer Powered by Impulse Eddy Current Testing System
--- T. Chady, P. Frankowski, and R. Sikora, West Pomeranian University of Technology, Szczecin, ul. Sikorskiego 37, 70-313 Szczecin, Poland

Phased Array Inspection Design of Steam Turbine Blade Using CIVA Simulation Software
--- M. P. Dubois and M. S. Lonne, Extende, 86 rue de Paris, Batiment Erable, 91400 Orsay, France; M. E. Rasselkorde, Siemens Energy, 841 Old Frankstown Road, Pittsburgh, PA 15239

Simulation for IDT of SAW Sensor Using ANSYS
--- J. Liu, S. Zhou, Y. Zhang, J. Hao, and D. Xiao, Beijing Institute of Technology, School of Mechanical Engineering, Beijing, P. R. China

Nondestructive Evaluation of Residual Stresses in Case Hardened Steels by Magnetic Anisotropy and Hysteresis Measurements
--- C. C. H. Lo, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

New Techniques and Systems

Phase Measurement with a Simplified Ultrasonic Time Delay Spectrometry System
--- P. M. Gammell, Gammell Applied Technologies, LLC Exmore, VA 23350; S. Maruvida, Y. Liu, K. A. Wear, and G. R. Harris, Food and Drug Administration, Center for Devices and Radiological Health, Silver Spring, MD 20903

Assessment of Real-Time Techniques for Ultrasonic Non-Destructive Testing
--- S. Robert and O. Casula, CEA-LIST, Centre de Saclay, 91191 Gif-sur-Yvette, France; M. Njiki and O. Roy, Société M2M, 1 rue de Terre-Neuve, 91940, Les Ulis, France
Development of Subharmonic Phased Array with a Single Array Transducer for Closed Crack Imaging
---S. Horinouchi, Y. Ohara, Y. Shintaku, and K. Yamanaka, Tohoku University, Department of Materials Processing, Sendai, Miyagi, Japan

A Phased-Array Method for Tracking Scarfing Line of ERW Pipes
---F. Zottig, J. Zhang, and C. Imbert, Olympus NDT, 505, boul. du Parc-technologique, Quebec (Quebec) G1P 459, Canada

Design of the 3-D Magnetic Flux Leakage Inspection Platform Used in the Evaluation of Surface Corrosion
---H. Feng, S. Huang, and W. Zhao, Tsinghua University, State Key Laboratory of Control and Simulation of Power System and Generation Equipments, Department of Electrical Engineering, Beijing, 100084, China; R. Han, Tsinghua University, Department of Precision Instruments and Mechanology, Beijing, 100084, China

---R. El Guerjouma, M. Bentahar, J. H. Thomas, and A. El Mahi, LAUM, UMR CNRS 6613, Universite du Maine, Le Mans, France

Simulation of Magnetic Flux Leakage: Application to Tube Inspection and to the 2011 ECT Benchmark Problem
---D. Prémel, E. A. Fraiche, and S. Djaffa, CEA, LIST, F- 91191, Gif-sur-Yvette, France; A. Trillon and B. Bisiaux, VMF - CEV Centre de Recherche VALLOUREC, Aulnoye-Aymeries, France

Electromagnetic Radiation Techniques

Synchrotron X-Ray CT Characterization of Friction-Welded Joints in TiAl Turbocharger Components
---J. G. Sun, J. A. Kropf, and D. R. Vissers, Argonne National Laboratory, Argonne, IL 60439; J. Katsoudas, Illinois Institute of Technology, Chicago, IL; N. Yang and D. Fei, Caterpillar Inc., Peoria, IL 61656

3D X-ray Microtomography Inspection in Microalloyed Steels: An Offshore Application

Diffraction Enhanced Imaging and X-Ray Fluorescence Microtomography at LNLS- Brazil
---G. R. Pereira, Federal Univ. of Rio de Janeiro, Non-destructive Testing, Corrosion and Welding Laboratory, Department of Metallurgical and Materials Engineering COPPE/UFRJ, Rio de Janeiro/RJ – Brazil; H. S. Rocha, I. Lima, and R. T. Lopes, Federal Univ. of Rio de Janeiro, Nuclear Instrumentation Lab, Department of Nuclear Engineering COPPE/UFRJ, Rio de Janeiro/RJ - Brazil

Terahertz Radiation Study on FRP Composite Solid Laminates
---K. H. Im, Woosuk University, Department of Automotive Engineering, Chonbuk, 565-701, Korea; D. K. Hsu, C.-P. T. Chiou, and D. J. Barnard, Iowa State University, Center for NDE, Ames, IA 50011; I.-Y. Yang, Chosun University, Department of Mechanical Design Engineering, Gwangju 501-759, Korea; J.-W. Park, Chosun University, Department of Naval Architecture and Ocean Engineering, Gwangju 501-759, Korea
THz Imaging Based Catalog of Composite Materials Defects
---Tomasz Chady, Przemyslaw Lopato, Krzysztof Goracy, Ryszard Pilawka, and Piotr Baniukiewicz, West Pomeranian University of Technology, Szczecin, Poland

POD and Reliability

An Objective Comparison of Pulsed, Lock-In, and Frequency Modulated Thermal Wave Imaging
---K. Chatterjee and S. Tuli, Indian Institute of Technology, Centre for Applied Research in Electronics, Delhi 110016 India; S. G. Pickering and D. P. Almond, University of Bath, United Kingdom Research Centre in NDE, Dept. of Mech. Engineering, Bath BA2 7AY, United Kingdom

Reliability of Re-Usable Un-Embedded FBG Sheet and Autonomous System for GWUS Field Mapping of a Composite Structure
---I. F. Saxena, Intelligent Optical Systems, Inc. 2520 W. 237th Street, Torrance, CA 90505; A. Mal, UCLA, Mechanical and Aerospace Department, Box 951597, Los Angeles, CA 90075

Assessing the Sensibility of Ultrasonic Testing Using ROC Curves

Methodology for AUT Flaw Sizing and POD Evaluation
---E. Todorov and R. Spencer, Edison Welding Institute, Engineering Services - NDE, Columbus, OH 43221-3585; M. Lozev, BP Products North America Inc., Refining Technology, Naperville, IL 60540

Probability of Detection (POD) Analysis Study Using Diffuse Ultrasound
---D. Xiang, Z. Zhai, and F. Li, 15400 Calhoun Drive, Suite 400, Rockville, MD 20855

Structural Health Monitoring

Utilizing Advanced Visualization Tools for Improved Non-Destructive Examination and Condition Assessment
---S. E. Reome, Florida Turbine Technologies, Inc., 1701 Military Trail, Jupiter, FL 33458; P. Zombo, Siemens Energy

On-Line Ultrasonic System for Measuring Thickness of Copper Stave in the Blast Furnace
---S.-W. Choi, POSCO, System Research Group, Pohang, Gyeongbuk 790-300, Korea

Sensors

Depth Profiling in Prestressed Load Bearing Components
---L. Mierczak¹, O. Kypris¹, I. Nlebedim¹, and D. C. Jiles², ¹Cardiff University, Wolfson Magnetics Research, Newport Road, Cardiff, South Wales CF24 3AA United Kingdom; ²Iowa State University, Department of Electrical and Computer Engineering, Ames, IA 50011-3060
Ultrasonic Techniques

Pattern Analysis of Guided Wave Beam Focusing on a Pipe
---J. Lee¹, Y. Cho¹, and J. D. Achenbach², ¹Pusan National University, School of Mechanical Engineering, Jangjeon-dong, Geumjeoun-gu, Busan 609-735, South Korea; ²Northwestern University, Evanston, IL 60208

A Theoretical Approach to Scattering of Surface Waves by a Three-Dimensional Cavity
---H. Phan¹, Y. Cho¹, and J. D. Achenbach², ¹Pusan National University, School of Mechanical Engineering, Jangjeon-dong, Geumjeoun-gu, Busan 609-735, South Korea; ²Northwestern University, Evanston, IL 60208

BEM Analysis for Scattered Rayleigh Waves by a Surface Defect
---T. Ju¹, Y. Cho¹, H. Phan¹, and J. D. Achenbach², ¹Pusan National University, School of Mechanical Engineering, Jangjeon-dong, Geumjeoun-gu, Busan 609-735, South Korea; ²Northwestern University, Evanston, IL 60208

Analysis of Higher Harmonics of Various Ultrasonic Waves in Solid Media
---W. Li¹, Y. Cho¹, and J. D. Achenbach², ¹Pusan National University, School of Mechanical Engineering, Jangjeon-dong, Geumjeoun-gu, Busan 609-735, South Korea; ²Northwestern University, Evanston, IL 60208

3:10 PM Break
Accurate Method for Measurement of Pipe Wall Thickness Using A Circumferential Lamb Wave Generated and Detected by a Pair of Noncontact Transducers
---Hideo Nishino, Yuta Taniguchi, and Kenichi Yoshida, The University of Tokushima, Tokushima, Japan; Masakazu Takahashi and Yukio Ogura, Japan Probe Co. Ltd., Yokohama Japan

---A noncontact method of an accurate estimation of a pipe wall thickness using a circumferential (C-) Lamb wave is presented. The C-Lamb waves circling along the circumference of pipes are transmitted and received by the critical angle method using a pair of noncontact air-coupled ultrasonic transducers. For the accurate estimation of a pipe wall thickness, the accurate measurement of the angular wave number that changes minutely owing to the thickness must be achieved. To achieve the measurement, a large number of tone-burst cycles are used so as to superpose the C-Lamb wave on itself along its circumferential orbit. In this setting, the amplitude of the superposed region changes considerably with the angular wave number, from which the wall thickness can be estimated. This paper presents the principle of the method and experimental verifications. As results of the experimental verifications, it was confirmed that the maximum error between the estimates and the theoretical model was less than 10 micrometers.

Identification of the Spatial Distribution of Conductivity by Eddy Current Defectoscopy with Application of Artificial Neural Networks
---Tomasz Chady, Ireneusz Spychalski, and Ryszard Sikora, West Pomeranian University of Technology, Szczecin, Poland

---In many kinds of NDT systems an eddy current method is used to detect and evaluate defects in high conductivity materials (metals). The proposed eddy current system can be also used to test low conductivity materials, like biological structures. The whole system is controlled by the PC class computer connected to data acquisition devices. The system is driven by a specialized program written in LabView. Construction of the transducer enables us to achieve high sensitivity and elimination of a background signal. On the other hand, this kind of transducer has some limitations. It is prone to noises and external influences. The system was modeled using the finite element method and the measurements were carried out. The results of numerical simulations are in a good agreement with the measured signals. The database of the signals achieved for various configurations of the test objects were created and used to resolve the identification problem. Artificial neural networks were utilized as the inverse models in order to reconstruct two-dimensional distribution of conductivity. The windowed signals measured from pick-up coils constitute an input of the network. Output of the network is proportional to the conductivity at a specific point of measuring area. A detailed description of the neural model and results of identification will be given in the full paper.
### Sizing and Reconstruction Methods

**F.A.S.T: First Acquisition as Sole Testing – Using Parallel Phased Array Acquisitions and TDTE Reconstruction**
---Nicolas Dominguez and Guillaume Ithurralde, EADS France - Innovation Works, Structure Health Engineering Department, Toulouse, France

---Very large surfaces to be inspected in aeronautics and the use of complex parts and materials such as composites lead to a considerable increase of NDT costs in production. This paper presents an inspection scenario which combines optimal use of parallel ultrasonic devices for acquisition speed (paintbrush mode) and data processing to compensate for spatial resolution loss. Such solution is expected to avoid complementary inspections, which is a major slow down factor in NDT throughputs. The Time Domain Topological Energy (TDTE) reconstruction process is applied and shows good performances in defect reconstruction from “paintbrush” data. High performance computing on GPU is implemented, leading to realistic solutions for diagnosis in industrial contexts.

### A Study on Algebraic Reconstruction Method of Micro Defects Based on Ultrasonic Transducer Array
---Xipeng Li, Chunguang Xu, Lijiu Wang, and Hanhui Xu, Beijing Institute of Technology, School of Mechanical Engineering, #5, Zhongguancun South Street, Beijing, 100081, China (PRC)

---The reconstruction of cross-hole tomography and the linear interpolation method are introduced for detection of metal defects in NDE technology using ultrasonic transducer array. The ultrasonic guided wave tomography method is developed to detect the internal micro defects in the test block, on the basis of algebraic reconstruction technology (ART). Experiments conducted verify that the use of technology can increase signal to noise ratio (SNR) and improve the precision of testing, and the ART algorithm is practical for reconstructing the image of micro defects.
**Sizing and Reconstruction Methods**

An Industrial CT Reconstruction Technology to Directly Reconstruct the Characteristics

---Liming Wang, Yingliang Zhao, Fanglin Chen, and Yan Han, North University of China, National Key Laboratory for Electronic Measurement Technology, Tai Yuan, Shanxi, China 030051; Liming Wang, Michigan State University, Nondestructive Evaluation Laboratory, East Lansing, MI 48823

---In the traditional industrial CT, the reconstruction methods are difficult to obtain high-frequency characteristics and remove the noise, so generally not suitable to detect the smaller flaws. In addition to the filter is more complicated to design. An industrial CT reconstruction technology to directly reconstruct the characteristics was brought forward for the purpose of not the overall image quality but the best requirements. Based on the FDK method and the trait of RADON transform, the feasibility of the novel two-dimensional and three-dimensional CT algorithms was theoretically deduced. Combined with the signal processing algorithms such as the wavelet and EMD, it is deduced to extract the characteristics using 1-D or 2-D algorithm, and to directly reconstruct the characteristics in the 2-D or 3-D CT. Experimental results and parameters were further calculated to compare and prove its advantages in keeping better high-frequency feature, better noise immunity, and short time-consuming and easier design.

**Signal and Image Processing**

A Genetic Algorithm-Based Approach to Ultrasonic Echoes Estimation

---Zhongzhu Liu and Chunguang Xu, Key Laboratory of Fundamental Science for Advanced Machining, 5 South Zhongguancun Street, Beijing Institute of Technology, Haidian District Beijing 100081, China (PRC)

---In ultrasonic nondestructive evaluation (NDE) using pulse-echo configuration, the received ultrasonic echoes are used to evaluate the property of the material inspected. The ultrasonic echoes’ parameters, such as time of arrival (TOA), amplitude, etc. all have corresponding physical meanings, which can be used to evaluate the location of defect, the acoustic impedance of medium, sound velocity, layer thickness, etc. Therefore, it’s important to attain the parameters of ultrasonic echoes. Model-based estimation approach of ultrasonic echoes is processed with Gaussian-Newton algorithm, which works well in many cases. But this method requires good initial guess for echoes parameters, and bad initial guesses often lead to huge computation load and incorrect estimation. Here, we suggest a genetic algorithm-based approach to estimate the reflected echoes. The method can not only attain good initial guesses for normal model-based estimation application, but also achieve good estimation result directly. Some simulations have been carried out with the genetic algorithm-based approach, and the simulation result proves that the genetic algorithm-based estimation approach works well.
Signal and Image Processing

Novel Feature Extraction and Image Processing Technique for Eddy Current NDE

---Guang Yang, Lu Zhang, Junjun Xin, and Lalita Udpa, Michigan State University, East Lansing, MI 48823; Jaejoon Kim, Daegu University, Gyeongsan, Gyeongbuk 712-714, Korea

---The automatic analysis of eddy current (EC) data has facilitated the analysis of the large volume of data generated in the inspection of steam generator. The typical procedure for analysis of EC data generated during inspection of steam generator (SG) tubes in nuclear power plants includes data calibration, pre-processing, region of interest (ROI) detection, feature extraction and classification. The accurate ROI detection has been enhanced by pre-processing, which involves reducing noise, increase SNR of the raw image and other undesirable components as well as enhancing defect indications in the raw measurement. In this paper, developed algorithms to improve EC image based feature extraction and classification are discussed. The HHT (Hilbert-Huang Transform) method is used to extract image features in the detected ROIs. The Wavelet Transform (WT) and filter based methods are introduced to combine HHT for unsupervised classification, which have promoted the present rule based classification approach.

---Layered composite material is used in some important area widely, and its inner structure's integrity infects the product's integrity seriously. To evaluate the composite material's integrity, the real inner structure should be inspected first. In ultrasonic pulse-echo testing, the layered material structure is often difficult to identify because the reflected echoes from each layer's top and bottom surface may overlapped and multi reflections increase the difficulty. Acoustic impedance is a property of material in acoustic wave field, which will be used to represent the layered composite material's inner structure. Improved model-based method are adopted here to attain the accurate ultrasonic echoes' information of every layer, such as amplitude, time of arrival, etc. With these information, each layer's acoustic impedance can be reconstructed, which can be stored in an impedance matrix. Then a 3D image of the layered composite material’ inner structure can be viewed. In the end, simulation experiment is carried out to validate the method.
Signal and Image Processing

Time Reversal Imaging with Group of Guided Wave Modes to Improve Pipeline Inspection Range and Accuracy
---Shuntao Liu, North Carolina State University, Mechanical and Aerospace Engineering, Raleigh, NC 27695; Weichang Li and Limin Song, Corporate Strategic Research, ExxonMobil Research and Engineering, 1545 Rt 22 East, Annandale, NJ 08801

---Guided wave inspection has been increasingly applied for inspection in energy production and transport pipelines. However, the technology's performance, including the inspectable range, the defect detection probability and sizing resolution, is still limited compared with practical field needs. This paper presents a time reversal imaging technique utilizing a group of guided wave modes over a broad frequency band. This increases both the bandwidth integrated power and the mode diversity of the propagating wave. Rather than selecting a single mode to minimize dispersion as typically being done, we develop algorithms to coherently combine the group of modes to obtain increased signal to noise ratio and sensitivity. This approach compensates for dispersion using time reversal to improve imaging quality and extend inspectable range. Imaging is computed via an efficient angular spectrum propagation algorithm without numerically computing the Greens functions. The performance improvement is demonstrated via signal processing results based on numerically simulated data.

Sensors, Transducers, and Probes

3D Modeling and Experimental Determination on Testing the Effective of Eccentric Bus-bar Testing Method of Current Sensors
---Jin Xing, Wei Zhao, and Songling Huang, Tsinghua University, State Key Lab of Power Systems, Department of Electrical Engineering, Beijing 100084, China; Bo Jiang, Sichuan Electric Power Test and Research Institute, Chengdu 610015, China; Kaifeng Qu, Department of High Voltage, China Electric Power Research Institute, Beijing 100192, China

---To test the effective of the shielding on current sensors, a method called Eccentric Bus-bar Testing Method has been invented. Results of detailed experimental measurements of the working magnetic field and the leaked magnetic field of the current sensor are compared against the numerical results by finite element method (FEM) using ANSYS. The accuracy of the experimental and numerical results is discussed respectively in detail. Some significant conclusions derived from the comparison are also presented in the paper such as the applicability of the testing method, etc.
Sensors, Transducers, and Probes

Design, Characterization and Application of Transducers With Ultrasonic Axicon Lenses

---In this paper the applications, detailed in previous works, of ultrasonic transducers with the addition of axicon lenses are extended. In order to generalize the calculation formulas, an approach that takes into account the lens materials and the material which transmits the ultrasonic wave, has been developed. Axicon lenses were manufactured to generate an angular refracted beam in order to study defectology in welds and other components. To achieve greater depth of focus while maintaining a relationship between depth of focus and near field (F/N) less than 0.4, larger diameter transducers were used. Furthermore, its effect on the focus diameter (dF) was also analyzed. For different combinations of lens-transducer, diagrams of axial and transverse sound pressure distribution were obtained. At last, several practical applications are shown where it is possible to exploit the advantages that these transducers offer; for example: sizing of shallow cracks, discrimination between a weld root and a defect very close to it, high resolution corrosion mapping, etc.

Sensors, Transducers, and Probes

Printed Circuit Board Transducer Powered by Impulse Eddy Current Testing System
---Tomasz Chady, Pawel Frankowski, and Ryszard Sikora, West Pomeranian University of Technology, Szczecin, ul. Sikorskiego 37, 70-313 Szczecin, Poland

---This paper presents eddy current PCB transducer, which is powered by an impulse eddy current system. The transducer consists of two detection coils fabricated on the top of the thin film and one excitation coil on the bottom side. The detection coils are connected in a differential manner. Such construction of the probe is aimed at its miniaturization and improved spatial resolution. The transducer has been designed for detection of flaws located in the test specimen made of titanium, which is widely used in the aerospace industry. Experiments have been carried out using 7mm thick plate, with flaws in the form of EDM (Electric Discharge Method) notches (width 0.2mm and length 5mm). The flaws have relative depth from 20 to 80%. Numerical analysis of the transducer was done in order to investigate the transducer properties. The numerical simulations were carried out using FEM method with the software COMSOL Multiphysics 3.5a. Results of numerical analysis of the transducer model and results of experiments will be presented in full version of the paper.
Sensors, Transducers, and Probes

**Phased Array Inspection Design of Steam Turbine Blade Using CIVA Simulation Software**

---M. Philippe Dubois and M. Sébastien Lonne, Extende, 86 rue de Paris, Batiment Erable, 91400 Orsay, France; **M. El Mahjoub Rasselkorde**, Siemens Energy, 841 Old Frankstown Road, Pittsburgh, PA 15239

---Advanced NDE techniques have become an important tool for the reliability of the inspection of highly stressed turbine blade attachment and blade root. Stress on these components can affect the life of the turbine and may lead catastrophic failure. Phased array inspection has been able to reduce the inspection time and increase the reliability of the inspection. Simulations tools are very essential to design and optimize the inspection capability, especially for applications with complex geometry. Turbine component have different curvatures and surface changes, which affect the sound beam and hence the inspection reliability. The simulation allows overcoming the complex shape of the component by directing the beam at the right area and visualizing the beam profile as well as measuring defect responses. The CIVA software platform, developed by CEA LIST in FRANCE, gathers simulation tools for UT, ET and RT inspections. UT simulation codes include beam propagation and flaw scattering models. CIVA is now extensively used in different industrial sectors. In particular SIEMENS ENERGY, throughout his experimental work and achievement of simulations with CIVA, greatly contributes to validating the CIVA software in typical industrial applications such as turbine blade inspection. This poster illustrates the inspection of Steam Turbine blade and shows comparison between simulated and experimental data.

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**Simulation for IDT of SAW Sensor Using ANSYS**

---Jing Liu, Shiyuan Zhou, Yuntao Zhang, Juan Hao, and Dingguo Xiao, Beijing Institute of Technology, School of Mechanical Engineering, Beijing, P. R. China

---In this paper, we apply ANSYS software for the simulation for interdigital transducer (IDT) of surface acoustic wave (SAW) sensor. In order to study the electrode second order effects (ESOE) in the high frequency environment, IDT model of high frequency SAW sensor was set up by choosing the YX-128Â cut LiNbO3 as the substrate and aluminum as the metallic electrodes. Considering the computation time, a section of IDT is modeled and the results are validated for the full device. In modal analysis of ANSYS, the dissemination state of the SAW was described and the resonance and anti-resonance frequency were extracted. The simulation diagram shows that the dissemination depth of SAW is only 1-2 wavelength in the piezoelectric structure and the resonance and anti-resonance frequency are the edges of stopband of SAW sensor. In harmonic analysis, the relationship between the IDT admittance and the center frequency are plotted. The analysis indicated the relationship between the ESOE, the metallization ratio, the electrode height and the aperture. In this way, we would like to show IDT as a typical model for simulating SAW sensor using ANSYS.
Sensors, Transducers, and Probes

Nondestructive Evaluation of Residual Stresses in Case Hardened Steels by Magnetic Anisotropy and Hysteresis Measurements

--- C.C.H. Lo, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

--- This paper reports on a recent study aimed at developing magnetic measurement techniques for evaluation of residual stresses in case hardened steel components. In addition to improving hardness and wear resistance, case hardening introduces compressive surface residual stresses which help retard fatigue crack growth. NDE methods capable of characterizing residual stresses are desirable to fully exploit residual stress protection. Recent studies have shown the promise of stress-induced magnetic anisotropy (SMA) and magnetic hysteresis techniques for detecting residual stress distributions in ferritic/pearlitic steels. Nevertheless, the potential use of the methods on case hardened components is yet to be investigated. In this work, SMA measurements were conducted on induction hardened discs with a planar geometry. The results confirm the feasibility of detecting stress magnetic anisotropy. For a given case depth, the permeability signals detected along the principal stress axes was found to correlate with the surface stresses measured by XRD. The complex dependence of magnetic properties on both stress and case depth was studied by performing in situ hysteresis measurements on induction hardened steel rods under uniaxial applied stresses. Samples with larger case depths show weaker stress dependence of magnetic properties. Magnetostriiction measurements revealed that a fully martensitic sample has a significantly lower magnetostriiction than a ferritic/pearlitic sample. This suggests a weaker magnetomechanical effect in the hardened martensitic case than in the ferritic/pearlitic bulk, which accounts for the weaker stress dependence of magnetic properties for samples with larger case depths.

New Techniques and Systems

Phase Measurement with a Simplified Ultrasonic Time Delay Spectrometry System

--- Paul M. Gammell, Gammell Applied Technologies, LLC Exmore, VA 23350; Subha Maruvada, Yunbo Liu, Keith A. Wear, and Gerald R. Harris, Food and Drug Administration, Center for Devices and Radiological Health, Silver Spring, MD 20903

--- Time delay spectrometry (TDS) is a swept-frequency technique that has proven useful in several ultrasonic applications. Most applications provide only the amplitude data. We previously have described a system that is easy to replicate with equipment available in most laboratories. That system is used here to produce phase as well as amplitude data. The procedure involves a change to the software processing of the digitized signal but no hardware modifications. The TDS system described previously digitizes a signal derived from heterodyning transmitted and received signals from a linear frequency sweep. The frequency of that digitized signal is proportional to the ultrasonic time delay from transmitter to receiver. In the modified system, two methods have been used to extract phase information from the digitized signal. In one, analytic signal analysis is employed. In the other, quadrature demodulation produces two components of the complex signal. In this latter method, if the demodulation frequency is chosen to equal the sweep rate times the time delay, these components will be at baseband (dc) and, to within a constant phase shift, are equal to the real and imaginary components of the measured response of the system under test.
New Techniques and Systems

Assessment of Real-Time Techniques for Ultrasonic Non-Destructive Testing
---Sébastien Robert and Oliver Casula, CEA-LIST, Centre de Saclay, 91191 Gif-sur-Yvette, France; Mickaël Njiki and Olivier Roy, Société M2M, 1 rue de Terre-Neuve, 91940, Les Ulis, France

Ultrasonic arrays probes are more and more used for non-destructive testing (NDT) of industrial components. This technology is able to master the characteristics of a focused beam in a part of known geometry by applying appropriate emission delays to each element of the probe. In practice, most of industrial components have complex and variable geometries, so the use of arrays often requires the implementation of specific algorithms in systems to achieve rapid and reliable inspections. In this context, the paper presents three real-time techniques embedded in M2M acquisition systems. The first is a real-time imaging technique based on the synthetic imaging algorithm "Total Focusing Method". The second was developed for the underwater inspection of aeronautical stiffened parts made of composite material. The technique is based on an iterative algorithm allowing the adaptation of an incident wave front to a complex surface. The real-time adaptive process is illustrated through experimental results obtained with realistic stiffeners. The third technique is an adaptive focusing algorithm that optimizes the focusing on a flaw without a priori knowledge of the geometrical and acoustical properties of a component. This auto-focusing process is demonstrated via acquisitions carried out on a realistic mock-up representing a butt weld.

New Techniques and Systems

Development of Subharmonic Phased Array With A Single Array Transducer for Closed Crack Imaging
---Satoshi Horinouchi, Yoshikazu Ohara, Yohei Shintaku, and Kazushi Yamanaka, Tohoku University, Department of Materials Processing, Sendai, Miyagi, Japan

Crack closure leads to a serious problem of underestimation or overlook in the ultrasonic inspection. To solve this problem, among the nonlinear ultrasound, subharmonic waves are specifically useful because of their excellent selectivity for closed cracks. Thus far, we have developed a novel imaging method, subharmonic phased array for crack evaluation (SPACE). The SPACE used a LiNbO3 (LN) transmitter for generating intense ultrasound and an array receiver for focusing on reception. However, the measurement on a small-surface object was difficult because of the large area occupied by the two transducers. In addition, the selectivity of closed cracks was insufficient in welds with coarse grains. Here, we propose SPACE with a single array transducer (single array SPACE) to remove the above mentioned difficulty. As a transducer, we selected a commercially available PZT array, since we found that it can generate intense ultrasound by focusing even in exciting not so high voltage. The waves received by the array are then phase-matched following the delay laws. Fundamental array (FA) and subharmonic array (SA) images can indicate the open and closed parts of cracks, respectively. To verify the proposed method, a closed-crack specimen is needed. Thus, we used the closed SCC in a heat affected zone (HAZ) of type 304 stainless steel formed in high temperature pressurized water similar to atomic power plants. We imaged it by the single array SPACE with a PZT array of 32 elements positioned to avoid the weld metal with strong anisotropy and high attenuation. As a result, the SCC was not visualized in FA image because of strong scattering at the coarse grains. In contrast, in SA image, the closed tip was successfully visualized with high selectivity. In conclusion, we demonstrated that single array SPACE is useful in evaluating closed SCCs. This will significantly contribute the safety of atomic power plants.
New Techniques and Systems

A Phased-Array Method for Tracking Scarfing Line of ERW Pipes
---Federico Zottig, Jinchi Zhang, and Christophe Imbert, Olympus NDT, 505, boul. du Parc-technologique, Quebec (Quebec) G1P 459, Canada

---This paper presents a phased-array method for tracking the scarfing area on ERW pipes. The time of flight C-Scan image generated by the phased-array system is processed by an algorithm that identifies the center of the scarfing area. The weld centerline, of interest for the inspection, is detected and tracked. The information of the position of the weld line is used to control the position of the PA probes that automatically follows the weld seam for the flaw inspection. The algorithm is capable of identifying the loss of the detection and disengaging the tracking requiring for an operators intervention.

New Techniques and Systems

Design of the 3-D Magnetic Flux Leakage Inspection Platform Used in the Evaluation of Surface Corrosion
---Huacheng Feng, Songling Huang, and Wei Zhao, Tsinghua University, State Key Laboratory of Control and Simulation of Power System and Generation Equipments, Department of Electrical Engineering, Beijing, 100084, China; Runqi Han, Tsinghua University, Department of Precision Instruments and Mechanology, Beijing, 100084, China

---Magnetic flux leakage (MFL) inspection is a powerful technology used to detect surface and subsurface corrosions of ferromagnetic material. It is widely used in nondestructive testing (NDT) of oil and gas pipelines. The one dimension (1-D) MFL system is usually employed in practice for its convenience. However, the 1-D MFL technology has its inherent limitations since the magnetic sensor is primarily sensitive to the magnetic flux perpendicular to it. For the arbitrary defects, the three dimension (3-D) MFL technology is required. In this paper, we proposed a 3-D MFL inspection platform used to characterize the arbitrary flaws in the wall of oil and gas pipelines. In the platform, the data acquisition system is composed of two main parts, the sensor modules and the control board. The sensor modules are used to sample the MFL signal. The control board is employed to collect all the data acquired by the sensor modules, store them in the NAND FLASH chip, and transmit the data to PC via USB bus when the data acquisition process is finished. In each sensor module, there are 12 hall sensors. They are divided into 4 groups, and in each group 3 hall sensors are perpendicularly mounted and used to sample the MFL signal in the 3-axis, namely, the radial, axial and circumferential directions at the present position. All sensor modules communicate with the control board individually via high-speed RS-485 bus, and the baud rate of the bus is up to 6.125Mbps. In the experiments, a pipeline with artificial corrosion defects was inspected, and the acquired data were analyzed by the specially developed software on the PC. The experimental results show that the 3-D MFL technology is more effective than the 1-D counterpart for the detection of arbitrary defects in the ferromagnetic pipelines.
New Techniques and Systems

---R. El Guerjouma, M. Bentahar, J. H. Thomas and A. El Mahi, LAUM, UMR CNRS 6613, Université du Maine, Le Mans, France

---Structural heterogeneous materials damage characterization as concrete, rocks, or composites by classical linear acoustical methods does not generally give the expected sensitivity to early damage detection. As such, acoustical nonlinear methods appear like an interesting alternative. In this contribution we present a NonLinear Resonance Spectroscopy (NLRS) approach and use some NLRS features as Resonance frequency shift and Q-factor change as a function of the peak amplitude to characterize damage in concrete and polymer-based composite. Materials are characterized at intact and gradually damaged states. Besides, damage was monitored using the Acoustic Emission (AE) generated by the material during the damage process. A classification of the AE signals is proposed to identify the different damage mechanisms and to understand their contribution to the evolution of the NonLinear behaviour of the materials under investigation. Furthermore, another NonLinear phenomenon we investigated in relation with damage is Acoustical Slow Dynamics (ASD) which correspond to the response of the material when an external high drive harmonic acoustic stressing applied to the material is removed. In the case of hysteretic materials the initial properties are not recovered instantaneously but take a given time, which depends on the perturbation level as well as the materials integrity. In this contribution we report observations of ASD behaviour corresponding to a polymer-based composite sample taken at the intact as well as progressively damaged states. ASD measurements are correlated to Acoustic Emission data recorded during the different damage steps. With the help of the classification procedure of AE hits, damage mechanisms are identified and then correlated to the global material ASD relaxation. Original relaxation features are then identified for every damage mechanism. More particularly, relaxation time and frequency shift have been found to be very sensitive to damage creation and development for polymer-based composite and concrete. This work shows the relevance of this approach in developing new highly sensitive methods for Non Destructive Testing and Structural Health Monitoring purpose.

New Techniques and Systems

Simulation of Magnetic Flux Leakage: Application to Tube Inspection and to the 2011 ECT Benchmark Problem
---Denis Prémel, Emna Amira Fnaiech, and Steve Djaffa, CEA, LIST, F- 91191, Gif-sur-Yvette, France; Adrien Trillon and Bernard Bisiaux, VMF - CEV Centre de Recherche VALLOUREC, Aulnoye-Aymeries, France

---This communication presents the results obtained at CEA-LIST, using newly developed models for simulating Magnetic Flux Leakage (MFL) technique. Those developments were supported by Vallourec. In the first part of this communication, the MFL model, based on an integral formulation, which allows dealing with both linear and nonlinear materials, is presented. Then, results obtained for tube inspections (with a MFL system surrounding the tube) are presented and discussed in the second part. All simulations are performed in 2D. Works, currently in progress at CEA-LIST, aim at extending the MFL simulation code to 3D problems.
Electromagnetic Radiation Techniques

**Synchrotron X-Ray CT Characterization of Friction-Welded Joints in TiAl Turbocharger Components**
--- J. G. Sun, J. A. Kropf, and D. R. Vissers, Argonne National Laboratory, Argonne, IL 60439; J. Katsoudas, Illinois Institute of Technology, Chicago, IL; N. Yang and D. Fei, Caterpillar Inc., Peoria, IL 61656

--- Titanium aluminide (TiAl) is an advanced intermetallic material and is being investigated for application in turbocharger components for diesel engines. A TiAl turbocharger rotor consists of a cast TiAl turbine wheel and a Ti-alloy shaft that are joined by friction welding. Although friction welding is an established industrial process, it is still challenging to join dissimilar materials especially for brittle intermetallics. These joints are therefore required to be inspected using a nondestructive evaluation (NDE) method. Industrial weld inspection is usually performed by ultrasonic method, which may have lower sensitivity and provide limited information on flaw distribution within the material. In this study, synchrotron x-ray CT developed at the advanced photon source at Argonne National Laboratory was used for NDE characterization of friction-welded joints in TiAl turbocharger rotors. The synchrotron x-ray source has high peak energies (>150keV) to penetrate thick metallic materials, and the detector (imager) has high spatial resolutions (<40µm) to resolve small flaws. The CT inspections revealed detailed 3D crack distributions within poorly welded joints. The crack detection sensitivity and resolution was calibrated and found to be correlated well with destructive examination. These results will be presented and discussed.

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**3D X-Ray Microtomography Inspection in Microalloyed steels: An Offshore Application**

--- The reliable of inspection and measurements in a nondestructive way is quite important in industrial area, mainly when it is related to quality control of soldier joints. Ultrasound and Radiography can be used in order to check weld integrity. However they just can often be identified by visual inspection. 3D x-ray microtomography permits a real time quantitative investigation all over the micro architectural of the sample with a very good spatial resolution (micro order). The porosity parameter can be very important because it is related to the properties of alloy interconnects, such as degradation of mechanical performance. The goal of this work is to investigate critical welding flaws such as longitudinal, sagittal and transversal cracks, lack of penetration and porosity by 3D x-ray microtomography. For this study it was used pipes manufactured with laminated carbon steel plate and a microfocus x-ray source combined with a flat panel detector. The results show that it is possible to visualize the size and distribution of the defects presented in the solder in a nondestructive way.
**Electromagnetic Radiation Techniques**

**Diffraction Enhanced Imaging and X-Ray Fluorescence Microtomography at LNLS-Brazil**

---Gabriela R. Pereira, Federal Univ. of Rio de Janeiro, Non-destructive Testing, Corrosion and Welding Laboratory, Department of Metallurgical and Materials Engineering COPPE/UFRJ, Rio de Janeiro, Brazil; Henrique S. Rocha, Inaya Lima, and Ricardo T. Lopes, Federal University of Rio de Janeiro, Nuclear Instrumentation Laboratory, Dept. of Nuclear Engineering COPPE/UFRJ, Rio de Janeiro, Brazil

---A Diffraction Enhance Imaging (DEI) system and an X-ray Fluorescence Microtomography (XRFμCT) system was implemented in the Brazilian Synchrotron Light Laboratory (LNLS), Campinas, Brazil. DEI and XRFμCT are non-destructive techniques used to complement other techniques used for samples characterization. The DEI system is based on the contrast imaging obtained by extinction, diffraction and refraction characteristics. It can show details in low attenuation samples while X-ray fluorescence tomography allows mapping all elements within the sample, since even a minute fluorescence signal can be detected. The DEI system was set up in a high-resolution diffraction beam line with a setup using a Si(111) monochromator and two channel cut Si(333) crystals. A direct conversion water-cooled CCD camera was positioned in front of the incident beam after the analyzer crystal. The sample and the detector were positioned in a high-precision linear translator. Images were taken in scan mode. The XRFμCT experiments were performed at the X-Ray Fluorescence beamline. A quasi-monochromatic beam produced by a multilayer monochromator was used as an incident beam. The fluorescence photons were acquired with an HPGe detector placed at 90° to the incident beam, while transmitted photons were detected with a fast Na(Tl) scintillation counter placed behind the sample in the beam direction. All the tomographic images were reconstructed using a filtered-back projection algorithm. In this work, breast tissue samples were investigated in order to verify the distribution of certain elements by x-ray fluorescence microtomography correlated with the characteristics and pathology of each tissue observed by diffraction enhanced imaging. DEI imaging techniques revealed the complex structure of the disease, confirmed by the histological section, and showed microstructures in all planes of the sample. The XRFμCT showed the distribution of Zn, Cu and Fe at higher concentration.

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**Electromagnetic Radiation Techniques**

**Terahertz Radiation Study on FRP Composite Solid Laminates**

---K.-H. Im, Woosuk University, Department of Automotive Engineering, Chonbuk, 565-701, Korea; D. K. Hsu, C.-P. Chiou, and D. J. Barnard, Iowa State University, Center for NDE, Ames, IA 50011; I.-Y. Yang, Chosun University, Department of Mechanical Design Engineering, Gwangju 501-759, Korea; J.-W. Park, Chosun University, Department of Naval Architecture and Ocean Engineering, Gwangju 501-759, Korea

---Investigation of terahertz time domain spectroscopy (THz TDS) was made and reflection and transmission configurations were studied as a nondestructive evaluation technique for the nondestructive evaluation of composite materials and structures. Here carbon fiber-reinforced plastics (CFRP) derived their excellent mechanical strength, stiffness and electrical conductivity from carbon fibers. Especially, the electrical conductivity of CFRP composites depends on the direction of unidirectional fibers since carbon fibers are electrically conducting while the epoxy matrix is not. The THz TDS can be considered as a useful tool using general non-conducting materials; however it is quite limited to conducting materials. In order to solve various material properties, the index of refraction(n) and the absorption coefficient (±) are derived in reflective and transmission configuration using the terahertz time domain spectroscopy. Also, for a 48-ply thermoplastic PPS(poly-phenylene sulfide)-based CFRP solid laminate, the terahertz scanning images were made at the angles ranged from 0° to 180° with respect to the nominal fiber axis. So, the images were mapped out based on the electrical field (E-field) direction in the CFRP solid laminates. It is found that the conductivity (f) depends on the angles of the nominal axis in the unidirectional fiber.
Electromagnetic Radiation Techniques

THz Imaging Based Catalog of Composite Materials Defects
--- Tomasz Chady, Przemyslaw Lopato, Krzysztof Goracy, Ryszard Pilawka, and Piotr Baniukiewicz, West Pomeranian University of Technology, Szczecin, Poland

---Because of high strength to weight ratio, stiffness and corrosion resistance, fiber reinforced composite materials are intensively used in industrial applications. Although there are many well-established methods for nondestructive testing of composites (e.g. ultrasonics, x-rays or thermography), the time domain terahertz imaging method due to its unique properties is increasingly used. In this paper a catalog consisting of raw and processed B- and C-scan data acquired in the vicinity of defective areas will be shown. Defects occurring in glass and basalt fiber reinforced composites as well as in polymeric anticorrosion coatings will be considered. Utilized signal processing algorithms in order to enable better defects detection and classification will be also shown. Finally, a discussion about detectability of various types of defects using terahertz radiation will be presented.

POD and Reliability

An Objective Comparison of Pulsed, Lock-In, and Frequency Modulated Thermal Wave Imaging
--- Krishnendu Chatterjee and Suneet Tuli, Indian Institute of Technology, Centre for Applied Research in Electronics, Delhi 110016 India; Simon G. Pickering and Darryl P. Almond, University of Bath, UK Research Centre in NDE, Department of Mechanical Engineering, Bath BA2 7AY, United Kingdom

---Pulsed thermography (PT), lock-in (LI) thermography, and frequency modulated thermal wave imaging (FMTWI) are three different thermal non-destructive evaluation (NDE) techniques. An objective comparison of the three techniques has been carried using matched effective excitation energies. A test sample of carbon fiber reinforced plastic (CFRP), containing twelve 6mm diameter back-drilled flat-bottomed holes, at depths starting from 0.25mm, and increasing in step of 0.25mm, is used for the study. In PT, the effective flash energy is estimated from the rise in the sample surface temperature. The effective energy in the AC excitations for LI, and FMTWI are then matched using the surface temperature oscillation amplitude. While calculating the signal to noise ratio (SNR), the sound regions of a thermal image is fitted with a 3D surface to remove background heating non-uniformity. The defective regions are automatically excluded by comparing their local temperature deviation to the root mean square (RMS) deviation of the fit. After subtracting this background, the maximum deviation of the thermogram over a defective region is considered as the signal due to the defect, and the RMS of the temperature deviations over the sound regions is the noise. Based on SNR, PT is found to be superior for shallow defects (< 1mm). For deeper defects, LI and FMTWI become comparable with, if not better than PT. Using time series reconstruction (TSR) algorithm, only PT can detect the 2.5mm deep defect. LI is found to suffer from the blind frequency effect wherein combination of defect diameter/depth and excitation frequency generate no phase difference between the defective and non-defective regions. The application of FMTWI is shown to overcome this drawback.
POD and Reliability

Reliability of Re-Usable Un-Embedded FBG Sheet and Autonomous System for GWUS Field Mapping of a Composite Structure
---Indu Fiesler Saxena, Intelligent Optical Systems, Inc. 2520 W. 237th Street, Torrance, CA 90505; Ajit Mal, UCLA, Mechanical and Aerospace Department, Box 951597, Los Angeles, CA 90075

---Nondestructive techniques (NDT) based on ultrasound scanning of aircraft structures and components have a widely used for defects and damage detection. Guided wave ultrasound (GWUS) in composite structures, in particular, can have very large range NDT capability. Piezoelectric based GWUS have already demonstrated this capability, whereas fiber optic ultrasound receivers furthermore offer the advantage of being passive, or free of electromagnetic-induced noise. We have demonstrated a larger area, automated GWUS field mapping capability with a re-usable sheet of FBG sensors, that offers great flexibility, and requires no acoustic couplant. We report results upon multiple measures to demonstrate its reliability and re-usability of the Bragg grating ultrasound transducer sheet.

POD and Reliability

Assessing the Sensibility of Ultrasonic Testing using ROC Curves
---Pablo U. Bartholo, Joao M. A. Rebello, Fabio C. da Silva, Luis M. M. Tavares, Federal University of Rio de Janeiro - Department of Metallurgical and Materials Engineering - COPPE/UFRJ - P.O. Box 68505 CEP 21941-972, Rio de Janeiro RJ, Brazil; Sergio D. Soares, PETROBRAS R&D Center - Rio de Janeiro/RJ, Brazil

---One way to estimate the reliability of a technique is through a sensitivity analysis. When working with a high sensitivity, the lower amplitude signals are picked up, increasing the risk of noisy signals being interpreted as signals from a flaw. On the other hand, when the inspector is working with low sensitivity, the system is only capable of distinguishing signals of high amplitude. ROC (receiver operating characteristic) curve is a technique for evaluating, organizing and selecting classifiers based on their performance. The ROC curves may show four signs of return, among them, rates of hits and false alarms of the classifiers, which serve to evaluate the sensitivity of the technique. They have a system ranging from 0 to 1 where they describe the relationship between probability of detection and the probability of false alarm. The paper investigates the sensitivity of the manual ultrasonic technique in API X70 pipes containing defects of different types and at different ranges of length and height. The results showed that the ROC curve is an excellent tool to assess the sensitivity of ultrasonic testing, being capable to demonstrate the significance of the flaw height on the probabilities of detection and false alarm.
Methodology for AUT Flaw Sizing and POD Evaluation
---Evgueni Todorov and Roger Spencer, Edison Welding Institute, Engineering Services - NDE, Columbus, OH 43221-3585; Mark Lozev, BP Products North America Inc., Refining Technology, Naperville, IL 60540

---The performance for flaw detection and sizing of automated ultrasonic testing (AUT) systems needs to be validated or quantified so that reliable inspection results are used in fitness-for-service programs. Estimation of sizing capabilities is needed for several flaw parameters or measurands – flaw height, length, depth and start – stop positions. Simple additive model is used to describe the relationship between the measurement and AUT estimate, “true” value, and measurement error. Destructive testing was a primary reference although results were investigated where fingerprinting was used as reference. A procedure with well established statistical routines and techniques (normality test, normal probability plot, parametric and nonparametric tests for means and standard deviations, boxplot and others) was suggested and demonstrated for evaluation of sizing capabilities. Evaluation of flaw fabrication process and conformance to specifications was conducted. Actual flaws were fabricated with larger height than requested. Flaw type or category effect on sizing performance was also investigated and flaw categories with significant effect were not considered for the AUT sizing capability estimates. For POD estimates, the effect of different link functions was demonstrated with the same data sample. If possible, a single POD link function or software package should be used when comparing POD performance of various systems. Removal from the AUT quantification data sample of flaw categories such as small pores, inter-bead lack of fusion and interacting flaws was recommended due to the significant and difficult to control effect on sizing performance.

Probability of Detection (POD) Analysis Study Using Diffuse Ultrasound
---Dan Xiang, Zhiwei Zhai, and Fang Li, 15400 Calhoun Drive, Suite 400, Rockville, MD 20855

---The effectiveness of the SHM technology can be characterized by a probability of detection (POD) and receiver operating characteristic (ROC) curve. The POD of a crack depends upon the uncertainty of its detection and is a function of the crack length, crack location and testing environment. NASA is developing a theoretical model, which diagnoses the severity of a growing crack in a structure. This theoretical model needs experimental data (e.g., POD and ROC) for refinement and experimental verification of its probabilistic fatigue crack growth model. The objective of this work is to produce experimental POD and ROC curves of growing cracks in aluminum specimens by using diffuse ultrasonic technique. With the match pursuing decomposition algorithms, the diffuse ultrasonic technique has proven to be very efficient and sensitive for detecting growing cracks on 2 feet by 2 feet aluminum specimens in lab conditions. Preliminary experiment results suggest that it is very possible to compensate and minimize the temperature and surface wetness effects on the POD of cracks. It is also possible for diffuse ultrasonic technique to differentiate the defect signals from two growing cracks located certain distance away.
Structural Health Monitoring

Utilizing Advanced Visualization Tools for Improved Non-Destructive Examination and Condition Assessment
---Scott E. Reome, Florida Turbine Technologies, Inc., 1701 Military Trail, Jupiter, FL 33458; Paul Zombo, Siemens Energy

---Future requirements for turbine engine propulsion are pushing the limits of existing sensor capabilities for real-time monitoring and detection of defects in hardware. The Siemens High Speed Infrared (IR) On Line monitor as well as the off line SIEMAT® acoustic thermography and Global Inspection System®, 3D color component scanning technologies have been in development as non-destructive evaluation (NDE) techniques and have proved to be successful in inspecting components for cracks and other defects. However, early prototype On Liner Monitor systems have required extensive engine modifications for real-time monitoring. Further, defect detection techniques for components out of the engine are in need of improvements and consolidation in both hardware as well as fused 3D Data reporting. Recent developments by Siemens Energy Inc. have led to improved systems for on line monitoring and component NDE by adapting optics for using existing borescope ports. This will enable the use of real-time monitoring of component behavior and detection of thermal conditions in engine components in-situ at significantly reduced cost and on virtually any turbine outfitted with typical bore scope ports. This new capability will eliminate the need for engine modifications previously required for the on line monitoring technique. Secondly, the advanced off line NDE methods have been significantly improved. The new Smart SIEMAT® Acoustic Thermography development incorporates a unique combination of resonant frequency detection and isolation in order to reduce setup and inspection condition optimization for defect detection sizing and characterization. Both the SIEMAT® and GIS Global Inspection Technologies® have now been combined into the same hardware and software system to allow seamless multiple inspections as well as 3D data fusion.

Structural Health Monitoring

On-Line Ultrasonic System for Measuring Thickness of Copper Stave in the Blast Furnace
---Sang-Woo Choi, POSCO, System Research Group, Pohang, Gyeongbuk 790-300, Korea

---The blast furnace is used to make molten iron from sintered ore and cokes in the steel industry and the recently, the copper stave cooling system placed inside the blast furnace was employed to protect the steel shell from heat damage. In the high temperature environment, the wear between the stave and the materials makes the cooling stave thinning by the downward movement of the materials in the blast furnace. The thickness of the cooling stave should be aware in order to prevent leakage of coolant into the furnace chamber and to make actions before the failure. It was impossible to access copper stave with the ultrasonic sensor for measuring thickness because the copper stave is cover steel shell and there backing refractory between the stave and the steel shell. The unique ultrasonic sensor which can approach the cooling stave through the cooling line was developed to measure thickness of the worn cooling stave. In addition, another ultrasonic sensor was developed to be installed at the copper stave permanently, and to provide on-line thickness measurement system for the copper stave. Sixteen ultrasonic sensors were mounted in the copper stave during rebuilding one of blast furnaces in POSCO and the on-line stave thickness measuring system were constructed.
Sensors

Depth Profiling in Prestressed Load Bearing Components
---L. Mierczak¹, O. Kypris¹, I. Nlebedim¹, and D. C. Jiles², ¹Cardiff University, Wolfson Magnetics Research, Newport Road, Cardiff, South Wales CF24 3AA United Kingdom; ²Iowa State University, Department of Electrical and Computer Engineering, Ames, IA 50011-3060

---Detection of unwanted residual stress in load bearing components has become vital in aerospace applications where the failure of parts can have catastrophic consequences. Methods such as eddy current and ultrasonic testing are able to pinpoint defects, but unable to provide information about the stress state of the specimens under examination. Load bearing parts are usually made of high strength materials such as steels and this allows the use of magnetic methods for evaluation of the mechanical condition. In ferromagnetic materials, applied stress as well as changes in the microstructure have a direct effect on bulk magnetic properties. In some of the most recent results the amplitudes of the envelopes of Magnetic Barkhausen Noise pulses have been calculated and the reciprocal of their peak amplitude was found to be proportional to the applied stress. This is an important result in the search for a reliable method for profiling the depth dependence of stress. Extracting the depth dependent information, however, still remains a challenge. This study shows how to extract stress information from measured Magnetic Barkhausen Noise signals. More specifically, a newly developed Barkhausen spectrometer measurement system is used to acquire the peak amplitude of MBN pulses at different magnetization frequencies, for specimens with a controlled stress depth profile. A suitable signal processing routine produces a plot of stress versus depth into the specimen.

Ultrasonic Techniques

Pattern Analysis of Guided Waves Beam Focusing on a Pipe
---Jaesun Lee¹, Younho Cho¹, Jan D. Achenbach², ¹School of Mechanical Engineering, Pusan National University, Jangjeon-dong, Geumjeoun-gu, Busan 609-735, South Korea; ²Northwestern University, Evanston, IL 60208

---The guided waves inspection technique is widely used in pipe line evaluation, because of the advantages of long distance inspection. Guided waves propagating patterns have been calculated with respect to specific excitation modes. Guided wave focusing techniques have been employed in this paper to analyze focusing patterns in a pipe. A longitudinal dominant mode and a torsional dominant mode are used for various frequencies to determine the sensitivity of the focusing techniques. Furthermore, a laser generation condition has been considered. It is shown that laser based guided waves technique can be also used for long range inspection.
Ultrasonic Techniques

A Theoretical Approach to Scattering of Surface Waves by a Three-Dimensional Cavity

---Haidang Phan¹, Younho Cho¹,*, Jan D. Achenbach², ¹ School of Mechanical Engineering, Pusan National University, Jangjeon-dong, Geumjeong-gu, Busan 609-735, South Korea; ² Northwestern University, Evanston, IL 60208

---This paper theoretically investigates the scattering of surface waves by a three-dimensional (3D) cavity which is at the free surface of a homogeneous, isotropic, linearly elastic half-space. The 3D wave field scattered by the cavity is obtained in an elegant manner by using a superposition technique and the reciprocity theorem for three-dimensional elastodynamics. For the scattered field, two elastodynamic states, one of which is the actual wave field due to time-harmonic point loads, and the other is a virtual surface wave, are connected by the reciprocity theorem. The amplitudes of the scattered waves can then easily be obtained with a much simpler calculation than by the conventional theoretical approach, namely the integral transform technique. The results can be applied to solve the inverse problem of identifying characteristic features of corrosion pits.

Ultrasonic Techniques

BEM Analysis for Scattered Rayleigh Waves by a Surface Defect

---Taeho Ju¹, Younho Cho¹,*, Haidang Phan¹, Jan D. Achenbach², ¹ School of Mechanical Engineering, Pusan National University, Jangjeon-dong, Geumjeong-gu, Busan 609-735, South Korea; ² Northwestern University, Evanston, IL 60208

---This study employs the boundary element method (BEM) to model two-dimensional Rayleigh wave scattering by a cylindrical cavity on the surface of an elastic half-space. The BEM considered in this paper uses a special condition which eliminates Rayleigh wave reflection from the truncation points. To account for the contribution of the omitted part of the boundary an additional matrix, called the correction matrix, is added into the standard BEM displacement system matrix. Computational results for the displacements and stresses caused by the scattering of Rayleigh waves are compared with curves obtained by a theoretical approach to prove the validity of the theoretical results.
Ultrasonic Techniques

Analysis of Higher Harmonics of Various Ultrasonic Waves in Solid Media
---Weibin Li¹, Younho Cho¹,*, Jan D. Achenbach², ¹ School of Mechanical Engineering, Pusan National University, Jangjeon-dong, Geumjeong-gu, Busan 609-735, South Korea; ² Northwestern University, Evanston, IL 60208

---Higher harmonics of ultrasonic waves are investigated as a potential technique to characterize material microstructure in isotropic solids. Analytical expressions for longitudinal and transverse plane wave harmonic generation, have been derived in a second order approximation. Nonlinear parameters describing various elastic waves have been developed. For Rayleigh surface waves and Lamb waves, the nonlinear parameter has been expressed in terms of the ratios of the amplitudes of the higher harmonics and fundamental waves. The nonlinear parameters of guided waves are related to the corresponding quantities for the longitudinal wave. The nonlinear parameters of second harmonic Lamb waves depend on the type of wave mode and the frequency. Measurements of the amplitudes of the fundamental waves and second harmonics of Lamb modes on an elastic plate surface by using wedge transducers are presented. The results of this work could be applied to detect material nonlinearity due to damage mechanism, by using various ultrasonic waves.
Session 28
SESSION 28
GUIDED WAVE APPLICATIONS AND SYSTEMS
A. Lhemery, Chairperson
Sugar Maple Ballroom

3:30 PM  Analysis of Guided Wave Scattering by Defects in Composite Plates with a Hybrid Method
---X. (Kevin) Qi and X. (George) Zhao, Intelligent Automation, Inc. 15400 Calhoun Drive, Suite 400, Rockville, MD 20855

3:50 PM  Full Dynamic Homogenization of Fiber-Reinforced Unidirectional Viscoelastic Composite
---M. Hollette and A. Lhémery, CEA, LIST, Gif-sur-Yvette, France; C. Aristégui, Université de Bordeaux, CNRS UMR 5295, I2M, Talence, France

4:10 PM  Inspecting Disbands of Laminated Composite Plate by Lamb Wave
---C. Xu, H. Xu, S. Zhou, and D. Xiao, School of Mechanical Engineering, Beijing Institute of Technology, Beijing, China

4:30 PM  An EMAT-Based Ultrasonic Guided Wave Scanning System for Defect Detection in Plates and Multi-Layered Structures

4:50 PM  Hand-Held Nonlinear Guided Wave Imaging System for Composite Cylinder Inspection
---X. (George) Zhao and X. (Kevin) Qi, Intelligent Automation, Inc. 15400 Calhoun Drive, Suite 400, Rockville, MD 20855; A. Sutin, Stevens Institute of Technology, 711 Hudson St., Hoboken, NJ 07030

5:10 PM  A Method to Estimate the Size of Corrosion Patches with Guided Waves in Pipes
---R. Carandente and P. Cawley, Imperial College, UK Research Centre in NDE, London SW72AZ, United Kingdom
Analysis of Guided Wave Scattering by Defects in Composite Plates with a Hybrid Method
---Xue (Kevin) Qi and Xiaoliang (George) Zhao, Intelligent Automation, Inc. 15400 Calhoun Drive, Suite 400, Rockville, MD 20855

---A hybrid method is presented to quantitatively study guided wave scattering at defects in composite plates. The composite plate is divided into global and local regions. The local region encloses the defects and is simulated with the Finite Element Analysis (FEA). The region outside the local region is the global region, and it is modeled with linear combination of plate waves calculated from the Semi-Analytical Finite Element (SAFE) method. Transmission and reflection coefficients are calculated for guided waves scattered by defects in a Graphic/Epoxy composite. The influence of defect size, location, wave propagation direction and frequency are discussed. The numerical results are verified with the commercial FEA software ABAQUS and data from literature.

Full Dynamic Homogenization of Fiber-Reinforced Unidirectional Viscoelastic Composite
---Matthieu Hollette and Alain Lhémery, CEA, LIST, Gif-sur-Yvette, France; Christophe Aristégui, Université de Bordeaux, CNRS UMR 5295, I2M, Talence, France

---Unidirectional fiber composites enter in the manufacturing of many materials. Optimizing ultrasonic testing of parts made of these materials requires accurate knowledge of wave behavior (wavespeed and attenuation variations with polarization, propagation direction and frequency). Homogeneous media being easier to handle, an effective medium can be defined whose viscoelastic properties (five complex-valued constants) lead to the same wave behaviors as those in the composite material. In a previous work, a model predicting bulk waves (P, SV, SH) propagating perpendicularly to fibers has been developed, combining viscosity and multiple scattering by fibers. Three of the five constants were obtained with excellent accuracy. Here, a method is developed to complement the effective medium description. The two remaining constants are predicted by considering guided wave propagation in the fiber direction. Guided waves in a rod made of a bundle of fibers in a viscous matrix are first predicted by the semi-analytic finite element method which numerically accounts for viscosity and multiple scattering in the rod section. A genetic algorithm is developed comparing wavemodes in the heterogeneous medium to those in a homogeneous one defined by the three already known constants, the two others being varied genetically until a cost function is minimized.
Inspecting Disbonds of Laminated Composite Plate by Lamb Wave
---Chunguang Xu, Hanhui Xu, Shiyuan Zhou, and Dingguo Xiao, School of Mechanical Engineering, Beijing Institute of Technology, Beijing, China

---Laminated composite materials have been widely used in industries such as aerospace due to their unique and superior performance characteristics. The defect of disbonds is the main influencing factor for the safe working load of laminated composite plate, such as Carbon-Epoxy laminates. Ultrasonic guided wave is used for testing laminated composite plate for its sensitivity to the disbonds in this paper. The multi-mode Lamb wave signal was analyzed by time-frequency method for extracting featured parameter to represent the size of the defect. The single S0 mode signal was separated from multi-mode signal to construct the featured parameter. Carbon-Epoxy laminates with [45/-45]2S layup was tested in the experiment. Dispersion curves of laminated composite plate were obtained by global matrix method for finding the effect of defect on the propagation character of Lamb wave. In comparison with the results from the theory and experiment, it is confirmed that the method proposed in this paper is efficient for inspecting laminated carbon-epoxy composite plate with defect of disbonds.

An EMAT-Based Ultrasonic Guided Wave Scanning System for Defect Detection in Plates and Multi-Layered Structures
---Owen M. Malinowski and Joseph L. Rose, The Pennsylvania State University, Department of Engineering Science & Mechanics, University Park, PA 16802; Michael J. Avioli and Steven E. Owens, Feature Based Systems, Inc., State College, PA 16801

---Detecting defects in plates and in thin multi-layered structures is a difficult task; especially when the defects are interior to the structure or exist on a non-visible or inaccessible surface of the structure. Although methods exist for defect detection in such structures, those methods can be time-consuming, cumbersome, and often, altogether impossible. A guided wave scanning system based on an Electromagnetic Acoustic Transducer (EMAT) probe has been developed for detecting defects throughout the thickness of plate-like structures. The probe utilizes two EMAT transducers in a through-transmission configuration and a low-profile encoder for probe position tracking. The absence of couplant facilitates clean and timely inspection of large areas of plate-like structures. The characteristic wavelength associated with the EMAT coil spacing translates to a sloped excitation line on the guided wave dispersion curves, providing superior guided wave mode and frequency control. Using signal processing, raw data is conditioned for extraction of physically-based features and application of pattern recognition algorithms for defect characterization and classification. After guiding the user through the scanning process, system software presents the results via easy-to-read graphs that provide information about the size, type, and location of defects.
Hand-Held Nonlinear Guided Wave Imaging System for Composite Cylinder Inspection
---Xiaoliang (George) Zhao and Xue (Kevin) Qi, Intelligent Automation, Inc. 15400 Calhoun Drive, Suite 400, Rockville, MD 20855; Alexander Sutin, Stevens Institute of Technology, 711 Hudson St., Hoboken, NJ 07030
---This paper introduces a novel nonlinear guided wave imaging (NGWI) system that can detect small incipient damage in curved composite structures. It makes use of two linear arrays of piezoelectric probes separated by a distance, a low-frequency vibrator, a data acquisition and processing module, and a user-friendly interface to process data and display the results. The NGWI system can scan over large scale structures with complex geometries and is more sensitive to micro-damages than the commonly used linear ultrasound testing techniques. As an example, the NGWI system was applied to inspect artificial delaminations in a carbon fiber composite cylinder. Tests were performed on a 6" inner diameter quasi-isotropic carbon/epoxy cylinder with [±30/90]3 layup and total thickness about 4.17 mm. Guided wave transducer array was designed and fabricated to generate circumferential guided waves in the cylinder. A low frequency magnetostrictive emitter was used to insonify the cylinder. Controlled impact was introduced to the cylinder to produce small damage/delamination. Experiments showed that guided wave signal which passed through the impacted region recorded higher level of modulation than the signals propagated out of damage area. The severity of the modulation correlated very well with the damage size.

A Method to Estimate the Size of Corrosion Patches with Guided Waves in Pipes
---Rosalba Carandente and Peter Cawley, Imperial College, UK Research Centre in NDE, London SW72AZ, 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. Recently a study of the reflection of the fundamental torsional mode T(0, 1) from three dimensional defects with different shapes in pipes has been carried out. The results from these analyses have been used to propose a practical approach to determine the maximum depth of real corrosion patches from the knowledge of the reflection behavior and circumferential extent of the defect. The main limitation of the method is on defects with a gradual corrosion section profile, but with a sudden change of the depth over a small circumferential region. The objective of this work is therefore to adapt this methodology to deal with the problematic corrosion patches; the idea is to be able to detect when the circumferential profile changes sharply by inspecting the discontinuity at higher frequencies. It has been found that the use of information about the presence of sharp changes in the defect profile in the circumferential direction given by the high frequency inspection, coupled with information on the extent of the gradual corrosion given by the low frequency inspection, may give a good estimation of the maximum depth of most of the complex corrosion patches.
Thursday, July 21, 2011

SESSION 29
NEW TECHNIQUES AND APPLICATIONS
D. Barnard, Chairperson
Mildred Livak Ballroom

3:30 PM  
Prospects and Limitations of Digital Shearography and Active Thermography in Finding and Rating Flaws in CFRP Sandwich Parts with Honeycomb Core  
---J. Gruber and G. Mayr, Research and Development, Wels, Austria; G. Hendorfer, Upper Austrian University of Applied Sciences, Wels, Austria

3:50 PM  
A Performance Measure Based on Principal Component Analysis for Ceramic Armor Integrity  
---D. K. Rollins, Sr., C. Stiehl, and K. Kotz, Iowa State University, Department of Chemical and Biological Engineering, 2114 Sweeney Hall, Ames, IA 50011; D. K. Rollins, Sr. and L. Beverlin, Iowa State University, Department of Statistics, Ames, IA 50011; L. Brasche, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

4:10 PM  
Application of Frequency Compounding to Ultrasonic Signals for the NDE of Concrete  
---K. S. Ho, M. H. Li, R. O'Leary, and A. Gachagan, University of Strathclyde, Centre for Ultrasonic Engineering, Department of Electronic & Electrical Engineering, 204 George Street, Glasgow, Scotland, G1 1XW, United Kingdom

4:30 PM  
Crack Detection in High-Pressure Turbine Blades with Flying Spot Active Thermography in the SWIR Range  
---T. Maffren, F. Lepoutre, and G. Deban, Onera, The French Aerospace Lab, Département Matériaux et Structures Composites, 92322 Châtillon, France; P. Juncar, Laboratoire national de métoologie et d'essais, 78197 Trappes, France

4:50 PM  
Ultrasonic Rayleigh Wave Inspection of Waviness in Wind Turbine Blades: Experimental and Finite Element Method  
---S. K. Chakrapani1, V. Dayal1, D. Barnard1, A. Eldal1, and R. Krafa1, 1Department of Aerospace Engineering, & Center for NDE, Iowa State University, Ames Iowa 50010

5:10 PM  
Inspection of Tubular Joint Welds of Offshore Platform Structures Using a Portable Ultrasonic Phased Array Device  
---B. Shan, L. Jingan, and O. Japing, School of Civil Engineering, Harbin Institute of Technology, Harbin, 150090, China; D. Zhongdong, Department of Civil and Environmental Engineering, Shenzhen Graduate School of Harbin Institute of Technology, Shenzhen, 518055, China; S. Wei, Shanghai Angtai-LanJer Telecommunication Integration Corp., Shanghai, 200060, China; O. Japing, Dalian University of Technology, Dalian, 116024, China

5:30 PM  
Development of Ultrasonic Phased Array Systems for Applications in Tube and Pipe Inspection  
---Y. Guo, Q. Yuan, Z. Sun, K. Logan, and C. Lam, Technical Center of Tuboscope, National Oilwell Varco, 2835 Holmes Rd., Houston, TX 77051
Prospects and Limitations of Digital Shearography and Active Thermography in Finding and Rating Flaws in CFRP Sandwich Parts with Honeycomb Core
---Juergen Gruber and Guenther Mayr, Research and Development, Wels, Austria; Guenther Hendorfer, Upper Austrian University of Applied Sciences, Wels, Austria

---In this paper we show the prospects and limitations of digital shearography and active thermography for finding and rating defects. In former studies we showed the possibility of both methods to characterize artificial flaws such as drill holes and brass/Teflon inclusions in flat panels. Based on these results we expanded our investigations on more complex structures, as used in aviation. Shearography- and thermography-measurements are carried out on CFRP-sandwich parts with aluminum and nomex-paper cores including typical types of defects. Delaminations in different layers of the CFRP-skin are simulated by inserted Teflon-foils. Furthermore artificial disbonds with different lateral sizes and shapes between skin and core are achieved by milling out a thin layer of the core. The experiments are carried out in transmission as well as reflection mode with thermal excitation. To verify the results we also applied ultrasonic, a well-established method in the aviation industry, as well as the reference method computed tomography. The latter provides 3D information about the inner structure. Shearography and thermography even allow distinguishing delaminations from bondings, which show similar damping coefficients in ultrasonic measurements. With help of CT-measurements we obtain a good basis for rating the prospects and limitations of these methods.

A Performance Measure Based on Principal Component Analysis for Ceramic Armor Integrity
---Derrick K. Rollins, Sr., Cory Stiehl, and Kaylee Kotz, Iowa State University, Department of Chemical and Biological Engineering, 2114 Sweeney Hall, Ames, IA 50011; Derrick K. Rollins, Sr. and Lucas Beverlin, Iowa State University, Department of Statistics, Ames, IA 50011; Lisa Brasche, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

---Principal Component Analysis (PCA) has being applied to thru-transmission ultrasound data taken on ceramic armor. PCA will help find and accentuate differences within the tile, making it easier to find defects. First, the thru-transmission ultrasound data was analyzed. As the ultrasound transducer moves along the surface of the tile, the signal from the sound wave is measured as it reaches the receiver, giving a time signal at each tile location. The information from this time signal is dissected into ten equal segments, and the maximum peak is measured within each segment, or gate. This gives ten measurements at each tile location. An image can be made for each of the ten gate measurements. PCA was applied to this data for all of the tile samples, and a performance measure was developed from the loading information. A performance measure was developed and tested for on six samples from each of the panels. When these performance measures are compared to the results of the ballistics tests, it can be seen that the performance measure correlates well to the penetration velocities found from the ballistics tests.
Application of Frequency Compounding to Ultrasonic Signals for the NDE of Concrete
---Kwok Shun Ho, Ming Hui Li, Richard O'Leary, and Anthony Gachagan, University of Strathclyde, Centre for Ultrasonic Engineering, Department of Electronic & Electrical Engineering, 204 George Street, Glasgow, Scotland, G1 1XW, United Kingdom

---In ultrasonic NDT, the internal grain microstructure of the material produces backscattered noise that can make the detection of true defects difficult. The noise is caused by the stationary scatterers that cause constructive and destructive interference to the transmitted signal. Even if the defects inside the test sample are significantly larger than these random scatterers, these defects maybe difficult to detect due to the present of the additive noise caused by the interfering scatterers. This interference causes the presence of speckle noise in ultrasound imaging, thereby limiting the detectability, and making images generally difficult to interpret. Speckle also limits automated computer-aided analysis, such as edge detection, and 3D volume display. In this study, frequency compounding (FC) method has been applied to the ultrasonic signals in concrete. The transmitted and received wave modes may suffer from the structural noise and attenuate greatly due to the heterogeneous nature of the material. It was shown in simulations that the signal-to-noise ratio (SNR) of the A-scan signals can be improved by splitting the spectrum into narrower subbands and sum. Experiments were performed to validate the simulated results. The possibility of using this type of processing in such material and merits are discussed.

Crack Detection in High-Pressure Turbine Blades With Flying Spot Active Thermography in the SWIR Range
---Thierry Maffren, François Lepoutre, and Geoffrey Deban Onera, The French Aerospace Lab, Département Matériaux et Structures Composites, 92322 Châtillon, France; Patrick Juncar, Laboratoire national de métrologie et d'essais, 78197 Trappes, France

---High pressure turbine blades located behind the turbojet combustion chambers undergo heavy thermomechanical constraints which drive initiation and propagation of cracks. The inspection of blades is currently conducted with endoscopes or videoscopes in the visible range. The cracks, which have very small dimensions can be difficult to detect in the images given by the control equipment. The suspicious blades must be removed for a careful analysis under microscope. The aim of this study is to propose an in situ alternative to the observation in the visible range to reduce or eliminate the necessity of disassembling the blades. The proposed solution is to use an active thermography process called flying spot (scanning laser heating) in the 1-2 µm range. This wavelength range offers two advantages: it gives different and complementary informations to the visible range and it is compatible with optical systems used in endoscopes.---This work is funded by the French Ministry of Defense, DGA through the Ph.D scholarship program and the contract 2010.60.018.
Ultrasonic Rayleigh Wave Inspection of Waviness in Wind Turbine Blades: Experimental and Finite Element Method
---Sunil Kishore Chakrapani¹, Vinay Dayal¹, D. Barnard¹, Aaron Eldal¹, and Ryan Kraft¹
¹Department of Aerospace Engineering, & Center for NDE, Iowa State University, Ames Iowa 50010

---This paper presents the investigation of discrete, out-of-plane waviness (marcel) in thick composite plates with applications to wind turbine blades. The investigation was carried out with the help of air coupled ultrasonics and a two-step procedure was developed to assist production line implementation. The first step involved detection of marcels, and the second step involved the characterization of these marcels with the help of an index called aspect ratio. A set of standardized samples with known aspect ratios were manufactured and used for this study. Finite element models were created to understand the wave propagation in wavy composite plates. All the experimental data was correlated with numerical B scans and conclusions concerning the method were made.

Inspection of Tubular Joint Welds of Offshore Platform Structures Using a Portable Ultrasonic Phased Array Device
---Baohua Shan, Li Jigan, and Ou Jinping, School of Civil Engineering, Harbin Institute of Technology, Harbin, 150090, China; Duan Zhongdong, Department of Civil and Environmental Engineering, Shenzhen Graduate School of Harbin Institute of Technology, Shenzhen, 518055, China; Shen Wei, Shanghai Angtai-Lanjer Telecommunication Integration Corp., Shanghai, 200060, China; Ou Jinping, Dalian University of Technology, Dalian, 116024, China

---Aiming at the practical inspection requirement of complex tubular joints weld of offshore platform structures, a portable ultrasonic phased array inspection device is developed in paper. The device is small, integrated and portable, which can perform the shear wave and longitudinal wave detection, automatically transmit and receive sound wave, accomplish data acquisition in real time, provide many imaging modes. As designed, the device can implement different algorithm of the ultrasonic phased array inspection technology. With proposed inspection scheme, the experiment of T tubular joint model was performed in lab. Experiment results indicate that the portable ultrasonic phased array inspection device developed in paper is feasible, the portable ultrasonic phase array device can factually imaging the size and shape of flaws on T tubular joint weld, which are nearly consistent with the practical condition. Compared to the conventional ultrasonic testing device, the current device works more efficiently and reliably in the flaw detection and evaluation. Furthermore the portable phased array inspection device can detect the dead zone existing in the conventional manual ultrasonic testing, and the testing speed can be improved greatly.
Development of Ultrasonic Phased Array Systems for Applications in Tube and Pipe Inspection

---Yanming Guo, Qingshan Yuan, Zhigang Sun, Kevin Logan, and Clive Lam, Technical Center of Tuboscope, National Oilwell Varco, 2835 Holmes Rd., Houston, TX 77051

---Ultrasonic nondestructive testing methods are commonly used in the inspection of oil country tubular goods for structural and material defects, e.g., cracks, corrosions, delaminations, inclusions, and so on. Conventionally, one or more single element ultrasonic probes or multi-element array probes have been used in tests, and they must be physically oriented in different directions to detect defects with different orientations, such as longitudinally, transversely, and obliquely oriented defects with respect to the axis of the pipe under testing. An inspection system performing defect detection in multiple orientations could become very complex. More recently, ultrasonic phased array technology was introduced into the field allowing simpler design of inspection systems and leading to improved inspection efficiency. This work reports the development of ultrasonic phased array systems used for tubular inspection. First the design of a linear phased array is discussed with considerations of both theoretically and practically important factors. Then systems utilizing the linear phased array will be introduced for different applications. To evaluate the system performance, tests were performed on flat bottom holes and artificial notches, including notches in longitudinal, transverse, and oblique orientations made according to API specifications. Test results will be presented.
Session 30
SESSION 30
LASER ULTRASONICS
J.-P. Monchalin, Chairperson
Silver Maple Ballroom

3:30 PM Continuous Laser Generation of Ultrasound for Nondestructive Evaluation
--- J. N. Caron, G. P. DiCom, and S. Nikitin, Research Support Instruments, 4325-B Forbes Boulevard, Lanham, MD 20706; J. N. Caron, Quartzet, 205 Indian Spring Drive, Silver Spring, MD 20901

3:50 PM Recent Progress in Multi-Channel Random-Quadrature Laser-Ultrasonic Receivers
--- B. Pouet, A. Wartelle, and S. Breugnot, Bossa Nova Technologies, 606 B Venice Blvd., Venice, CA 90291

4:10 PM A Laser-Ultrasonic System for the Inspection of Large Structures Fabricated by Automatic Fiber Placement
--- A. Blouin, C. Padioleau, C. Néron, and J.-P. Monchalin, Industrial Materials Institute, National Research Council Canada; M. Hojjati, Institute for Aerospace Research, National Research Council; M. Choquet, Tecnar Automation

4:30 PM Scanning Laser Source and Scanning Laser Detection Techniques for Different Surface Crack Geometries
--- R. S. Edwards, B. Dutton, A. R. Clough, and M. H. Rosli, University of Warwick, Department of Physics, Coventry, United Kingdom

4:50 PM Elastic Stiffness of FePt Thin Film Studied by Picosecond Ultrasonics
--- N. Nakamura, A. Uranishi, M. Wakita, H. Ogi, and M. Hirao, Osaka University, Graduate School of Engineering Science, Toyonaka, Osaka, Japan; M. Nishiyama, Osaka University, Renovation Center of Instruments for Science Education and Technology, Toyonaka, Osaka, Japan

5:10 PM Laser-Ultrasonic Attenuation and Absorption Measurements in Metals
--- M. Perton, D. Lévesque, A. Moreau, G. Lamouche, and J.-P. Monchalin, National Research Council Canada, Industrial Materials Institute, Boucherville, Quebec, Canada
Continuous Laser Generation of Ultrasound for Nondestructive Evaluation
---James N. Caron, Gregory P. DiComo, and Sergei Nikitin, Research Support Instruments, 4325-B Forbes Boulevard, Lanham, MD 20706; James N. Caron, Quarktet, 205 Indian Spring Drive, Silver Spring, MD 20901

---Non-contact generation of ultrasound in materials is often accomplished using pulsed lasers. The rapid heating from the laser pulse produces a thermoelastic expansion in the material that produces the ultrasound. Here we present an alternative method, designated Continuous Laser Generation of Ultrasound (CLGU), that follows from the development of cost-efficient high-power cw fiber lasers. With enough power, a cw laser can be scanned across the surface of the test material creating an ultrasonic wavefront. The leading edge of the scanning beam coupled with the speed of the scan creates the preferred rise time for ultrasound generation through thermoelastic expansion. The waveform combines with previous ones to form a wavefront that propagates through the material. Discontinuities in the wavefront indicate defects in the material. The main advantage is the scanning rate. The scanning rate of pulsed lasers is limited by the repetition rate of the lasers, commonly ranging between 10 and 100 Hz. Scanning a meter line with millimeter resolution would take between 10 and 100 seconds. In contrast, the scanning time with CLGU for an equal distance may take as little as 10 milliseconds. We will discuss the operation of a CLGU system as well as potential detection techniques.

Recent Progress in Multi-Channel Random-Quadrature Laser-Ultrasonic Receivers
---Bruno Pouet, Alexis Wartelle, and Sebastien Breugnot, Bossa Nova Technologies, 606 B Venice Blvd., Venice, CA 90291

---In order to address the specific needs associated with applying Laser-based ultrasonic (LBU) inspection to industrial environments, we proposed and demonstrated in 2004 a new type of LBU receiver based on multi-channel random-quadrature (MCRQ) detection. We showed that we can transform a high-sensitivity but delicate laboratory interferometer into a rugged system capable of enduring tough industrial environment. This MCRQ architecture combines a classic interferometric design (Michelson interferometer) with an innovative multi-speckle processing technique that takes advantage of the random distribution of speckles for quadrature detection. The ultrasonic information is extracted from the interference signal with simple signal processing based on high-pass filtering followed by signal rectification. The MCRQ interferometer is very robust because no path stabilization is required and background vibrations and perturbations are filtered out electronically. We will review the recent developments which were introduced in order to increase the MCRQ interferometer performances. (1) We will discuss two intensity noise rejection schemes based on differential detection and signal compression. (2) Comparison between free-space and fiber designs will be carried out. (3) Finally, we will demonstrate a new demodulation scheme which allows for linear detection and we will discuss limitations and advantages of both linear and rectified demodulation schemes.
A Laser-Ultrasonic System for the Inspection of Large Structures Fabricated by Automatic Fiber Placement
---Alain Blouin, Christian Padialeau, Christian Néron, and Jean-Pierre Monchalin, Industrial Materials Institute, National Research Council Canada; Mehdi Hojjati, Institute for Aerospace Research, National Research Council; Marc Choquet, Tecnar Automation

---Automatic fiber placement (AFP) is an innovative method for fabricating monolithic large scale composite structures, such as big and long barrels that can be assembled to make the fuselage of an airplane. Laser-ultrasonics and laser tapping are well known noncontact techniques appropriate for detecting defects in composite structures such as delaminations and disbonds. A laser-ultrasonic system with a configuration well adapted to the inspection of these big barrel structures was designed, built and installed in a production facility near Montreal. The laser-ultrasonic system is mounted on a long cantilever that is inserted into the fuselage. The probing head includes a rotating mirror assembly allowing 360° and one meter wide or more scanning of the whole internal wall of the barrel. The system can also inspect the external wall when the barrel is mounted on carriage allowing rotation around its axis as well as various smaller complex shape parts. This inspection system can be operated in both laser-ultrasonic and laser tapping modes, the latter being particularly useful for honeycombs. A detailed description of the system and of its performances as well as results on test parts will be presented.

Scanning Laser Source and Scanning Laser Detection Techniques for Different Surface Crack Geometries
---Rachel S. Edwards, Ben Dutton, Andrew R. Clough, and Mohd H. Rosli, University of Warwick, Department of Physics, Coventry, United Kingdom

---Standard test samples typically contain simulated defects such as slots machined normal to the surface. However, real defects will not always propagate in this manner; for example, rolling contact fatigue in rails propagates at around 25° to the surface, and corrosion cracking can grow in a branched manner. Therefore, there is a need to understand how ultrasonic surface waves interact with different crack geometries. Here, we present measurements of machined slots inclined at an angle to the surface normal, and/or with simple branched geometries, using laser ultrasound. Recently, Rayleigh wave enhancements observed when using the scanning laser source (SLS) technique, where a generation laser is scanned along a sample, have been highlighted for their potential in detecting surface cracks. We show that the enhancement measured with laser detector scanning can give a more significant enhancement than SLS when different crack geometries are considered. We discuss the behavior of an incident Rayleigh wave in the region of an angled defect, and consider mode-conversions which lead to a very large enhancement when the detector is close to the opening of a shallow defect. This process could be used in characterizing defects, as well as being an excellent fingerprint of their presence.
Elastic Stiffness of FePt Thin Film Studied by Picosecond Ultrasonics
---Nobutomo Nakamura, Atsuyoshi Uranishi, Mamoru Wakita, Hirotugu Ogi, and Masahiko Hirao, Osaka University, Graduate School of Engineering Science, Toyonaka, Osaka, Japan; Masayoshi Nishiyama, Osaka University, Renovation Center of Instruments for Science Education and Technology, Toyonaka, Osaka, Japan

---L10 FePt shows a chemically ordered face-centered tetragonal structure, which consists of stacks of alternating monatomic layers of Fe and Pt in the [001] direction. It shows high uniaxial magnetic anisotropy in the [001] direction, making it a candidate for high-density magnetic recording media. Considerable attention has been focused on L10 FePt, and the relationship among crystallographic structure, morphology, and magnetic properties has been investigated intensively. However, the elastic constant has not yet been measured experimentally. In the literature, elastic constants have been deduced using several calculation methods. However, the calculated values vary widely depending on the method, and the elastic property remains unknown. In this study we determine the perpendicular elastic stiffness of FePt thin films using laser-induced picosecond ultrasonics coupled with x-ray reflectivity measurement. In FePt films, a remarkable change in the morphology occurs; with increasing film thickness, isolated particles grow, and coalesce, forming a continuous film. We investigate the relationship between the elastic stiffness and morphology while varying the total film thickness, and determine the elastic constant of single crystal L10 FePt. Finally, we compare the experimentally determined elastic constants with the reported calculated values.

Laser-Ultrasonic Attenuation and Absorption Measurements in Metals
---Mathieu Perton, Daniel Lévesque, André Moreau, Guy Lamouche, and Jean-Pierre Monchalin, National Research Council Canada, Industrial Materials Institute, Boucherville, Quebec, Canada

---The attenuation of acoustic waves in metals comes from scattering caused by grain anisotropy and random grain orientation and from absorption caused by mechanisms such as dislocations and magnetic domains motion. Non-contact laser ultrasonics has been used to measure absorption by monitoring the temporal decay of acoustic energy in a small isolated sample. When absorption is negligible, the scattering contribution to attenuation, which is related to grain size, is measured by analyzing the amplitude decrease of ultrasonic echoes. Another method providing information on grain size and an estimate of absorption uses the diffusion of the acoustic energy in the strongly scattering regime. More recently, another method has been reported to measure absorption by using Lamb waves with zero group velocity (ZGV) i.e., that the acoustic energy around the generation does not propagate. Their temporal decay was attributed to absorption and also to energy leaks related to velocity dispersion, without considering the possibility of a scattering contribution. In this paper, a comparative study is made between these various methods for measuring absorption, grain scattering and characterizing metal microstructure.
Session 31
SESSION 31
BENCHMARK VALIDATION NDE
L. Schmerr, Chairperson
Frank Livak Ballroom

3:30 PM  Benchmark Problems for Predictive FEM Simulation of 1-D and 2-D Guided Wave for Structural Health Monitoring with Piezoelectric Wafer Active Sensors
---M. Gresil, S. Yanfeng, and V. Giurgiutiu, University of South Carolina, Laboratory for Active Materials and Smart Structures (LAMSS), Department of Mechanical Engineering, 300 Main Street, Columbia SC 29208

3:50 PM  Ultrasonics Guided Wave Benchmark: CEA Simulations for the Scattering of Guided Waves in a Stiffened Isotropic Plate
---K. Jezzine, A. Lhémery, D. Ségur, and L. Taupin, CEA, LIST, Gif-sur-Yvette, France

4:10 PM  Benchmark Guided Wave Transmission at an Adhered Stringer
---R. A. Roberts, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames IA 50011

4:30 PM  Ultrasonic Guided Wave Benchmark: Further Developments of Semi-Analytical Finite Element Method
---P. D. Wilcox, A. Velichko, M. D. Todd, B. W. Drinkwater, and A. J. Croxford, University of Bristol, Department of Mechanical Engineering, Queens Building, University Walk, Bristol, BS8 1TR, United Kingdom
Benchmark Problems for Predictive FEM Simulation of 1-D and 2-D Guided Wave for Structural Health Monitoring with Piezoelectric Wafer Active Sensors

---M. Gresil, S. Yanfeng, and V. Giurgiu, University of South Carolina, Laboratory for Active Materials and Smart Structures (LAMSS), Department of Mechanical Engineering, 300 Main Street, Columbia SC 29208

---Predictive simulation of ultrasonic nondestructive evaluation (NDE) and structural health monitoring (SHM) in realistic structures is challenging. Analytical methods can perform efficiently modeling of wave propagation by are limited to simple geometries. Realistic structures with complicated geometries are usually modeled with the finite element method (FEM). However, to obtain accurate wave propagation solution at ultrasonic frequencies is computationally intensive and may become prohibitive for realistic structures. Several investigators have previously addressed the convergence of FEM solutions for NDE-type ultrasonic inspection (bulk waves) and have developed useful guidelines. This paper addresses this issue in the context of guided-waves for SHM with piezoelectric wafer active sensors (PWAS). In our preliminary studies, we have discovered that frequency-domain artifacts appear in the FEM simulation of even simple 1-D guided waves propagation. The unexpected frequency domain artifact is that the central frequencies of the two wave packets (A0 and S0) are not the same and deviate significantly from the excitation frequency. Therefore, we are proposing two benchmark problems, one 1-D and the other 2-D, which we would like to share with the community in a round-robin fashion for developing guidelines to achieve reliable and trustworthy predictive simulation of ultrasonic guided wave SHM with FEM codes.

Ultrasonics Guided Wave Benchmark: CEA Simulations for the Scattering of Guided Waves in a Stiffened Isotropic Plate

---Karim Jezzine, Alain Lhémery, Damien Ségur, and Laura Taupin, CEA, LIST, Gif-sur-Yvette, France

---A problem of guided wave propagation and scattering has been submitted to QNDE 2011 benchmark session by P. D. Wilcox (Bristol University, United Kingdom). It is concerned with the scattering of guided waves emitted and received by two EMAT transducers positioned on either side of a stiffener over a plate made of Aluminum alloy. The problem in hands requires the computation of cases of oblique incidence onto the stiffener. It is solved using a hybrid method recently developed at CEA which will also be presented in the conference (“Hybrid SAFE/FE model for the scattering of guided waves in a stiffened multilayered anisotropic plate” by L. Taupin et al.). The method used for computing the benchmark case was originally developed to deal with multilayered anisotropic plates and stiffeners; it can of course deal with the elastically simpler case of an isotropic homogeneous stiffened plate. Numerically simulated results and available experimental measurements will be compared and the accuracy of the global simulation approach (including the model of EMAT behavior in transmission and reception) will be discussed.
Benchmark Guided Wave Transmission at an Adhered Stringer

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

---Computational results are presented for the UT guided wave benchmark problem of plate wave transmission at an adhered rectangular hollow stringer. The computation uses a boundary integral model developed for application to arbitrarily shaped bodies joining multiple semi-infinite plate sections (see accompanying poster this conference). The formulation computes wave motions on the surface of the joining body using pre-calculated impedance conditions over surfaces to which the semi-infinite plates attach, thereby restricting computational effort to the motion of the joining body alone, without explicit computation of motions in the adjoining plate sections. Transmission and reflection coefficients are obtained by integration of the motions on the plate attachments with the far field expressions for the associated infinite plate Green function. In this problem, the joining body consists of the stringer, adhesive layer, and a section of plate to which the stringer is adhered. The canonical calculation considers plane wave incidence at arbitrary angle of incidence. Responses for other incident field geometries (e.g. point source) are obtained through a Fourier integral in spatial frequency. Results will be compared to the posted benchmark experimental results for S0 transmission at varying angles of incidence.

Ultrasonic Guided Wave Benchmark: Further Developments of Semi-Analytical Finite Element Method

---Paul D. Wilcox, Alexander Velichko, Michael D. Todd, Bruce W. Drinkwater, Anthony J. Croxford, University of Bristol, Department of Mechanical Engineering, Queens Building, University Walk, Bristol BS8 1TR, United Kingdom

---At last year’s QNDE meeting, we presented a frequency-domain Semi-Analytical Finite Element (SAFE) method 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. Experimental results for the case of S0 guided wave transmission at an adhesively-bonded stiffener were compared with our SAFE model results and were disseminated for this year’s benchmark problem. In this paper, we review the benchmark experimental results and the previously developed SAFE procedure before presenting some further developments and applications of the latter. Specifically, we present a new technique to eliminate absorbing regions in the SAFE model that does not depend on a decomposition of the scattered wave into guided wave modes. We also use the SAFE model to investigate the variation of transmission and reflection coefficients from structural features with temperature. This is of interest in understanding the conditions under which existing temperature compensation schemes for guided wave structural health monitoring achieve satisfactory performance in the presence of structural features such as stiffeners.
Session 32 – New Reactor Designs .................................. 210
Session 33 – Composites and Resins .............................. 216
Session 34 – Sensors (All Techniques) and Sensor Materials ..................................................................... 222
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**FRIDAY, JULY 22, 2011**

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Session 32
SESSION 32  
NEW REACTOR DESIGNS  
P. Ramuhalli, Chairperson  
Mildred Livak Ballroom

8:30 AM  
Diagnostics and Prognostics Requirements for Advanced Reactors  
---P. Ramuhalli, L. Bond, R. Meyer, and J. Coble, Pacific Northwest National Laboratory, 902 Battelle Blvd., Richland, WA 99342

8:50 AM  
Monitoring and NDE to Support Long Term Operations of the Nuclear Fleet  
---J. T. Lindberg, M. Guimaraes, and J. Wall, Electric Power Research Institute, Nuclear Sector NDE Department, 1300 West WT Harris Blvd., Charlotte, NC 28262

9:10 AM  
Nondestructive Evaluation of Nuclear Grade Graphite  
---D. C. Kunerth and T. R. McJunkin, Idaho National Laboratory, P. O. Box 1625, MS 2209, Idaho Falls, ID 83415-2209

9:30 AM  
Materials Issues in High Temperature Ultrasonic Transducers for Under-Sodium Viewing  
---L. J. Bond, Pacific Northwest National Laboratory, Applied Physics Group, Richland, WA 99352

9:50 AM  
Stochastic Simulation for the Propagation of High-Frequency Acoustic Waves Through a Random Velocity Field  
---B. Lu, M. Darmon, N. Leymarie, and S. Chatillon, CEA, LIST, F-91191 Gif-Sur-Yvette Cedex, France; C. Potel, Laboratoire d’Acoustique de l’Université du Maine (LAUM), UMR CNRS 6613, 72085 Le Mans Cedex 9, France

10:10 AM  
Break

10:30 AM  
Ultrasonic NDE in a Reactor Core  
---D. A. Parks and B. R. Tittmann, Penn State University, Engineering Science and Mechanics Department, 212 ees Bldg., University Park, PA 16802

10:50 AM  
Nonlinear Rayleigh Waves to Detect Initial Damage Leading to Stress Corrosion Cracking in Carbon Steel  
---K. H. Matlack and L. Jacobs, Georgia Institute of Technology, G. W. Woodruff School of Mechanical Engineering, Atlanta, GA 30332; J.-Y. Kim and L. Jacobs, Georgia Institute of Technology, School of Civil and Environmental Engineering, Atlanta, GA 30332; J. Qu, Northwestern University, Department of Civil and Environmental Engineering, Evanston, IL 60208; P. M. Singh, Georgia Institute of Technology, School of Materials Science and Engineering, Atlanta, GA 30332

11:10 AM  
An Optical-Fiber Guided Ultrasonic Excitation and Measurement System for Online Monitoring Under High Temperature  
---J. Yang, H. Lee, and H. Sohn, Department of Civil and Environmental Engineering, Korea Advanced Institute of Science & Technology, 291 Daehak-ro, Yuseong-gu, Daejeon, 305-701 Korea

11:30 AM  
Measurement of Irradiation Effects in Precipitate Hardened Aluminum Using Nonlinear Ultrasonic Principles  

11:50 AM  
Flexible Eddy Current Probes for Inspection of Complex Parts  
---M. Marchand, M. Decitre, and M. Casula, CEA, LIST, F-91191 Gif-sur-Yvette, France; M. Ruaud, Static Etude et Developpement, 25038 Besancon, France

12:10 PM  
Adjourn
Diagnostics and Prognostics Requirements for Advanced Reactors
---P. Ramuhalli, L. Bond, R. Meyer, and J. Coble, Pacific Northwest National Laboratory, 902 Battelle Blvd., Richland, WA 99342

---Sustainable nuclear power to promote energy security is a key national energy priority. Several advanced designs are being considered for the next generation of nuclear power reactors, to provide economically viable energy options. Many of these advanced reactor designs have electrical output less than about 300 MWe, and are considered small modular reactors (SMR). In addition to economies of scale, such reactor designs are expected to primarily rely on passive safety systems resulting in inherently safe reactor designs. It is anticipated that these nuclear power reactors will have longer operation times between refueling and enable remote operation with minimal staffing while not compromising safety. However, these characteristics will result in a need for reliable instrumentation to monitor operations and safety-critical components, to better detect, manage and mitigate degradation in safety-critical components. In particular, tools for the detection of incipient failure through advanced online diagnostics tools, and determination of remaining useful life (RUL) through prognostics, will be necessary to help establish the basis for integrated system health management. These tools will enable optimal maintenance scheduling, minimize staff demands and unit downtime, and ensure effective lifetime and risk management of high-cost, safety significant components. This paper discusses key aspects of NDE, diagnostics and prognostics that are likely to be important in near-term advanced reactor design, development and deployment.

Monitoring and NDE to Support Long Term Operations of the Nuclear Fleet
---John T. Lindberg, Maria Guimaraes, and James Wall, Electric Power Research Institute, Nuclear Sector NDE Department, 1300 West WT Harris Blvd., Charlotte, NC 28262

---Most US nuclear plants have received license renewal to operate beyond 40 years; and many plants are assessing operation beyond 60 years. Long term operation (LTO) of the existing global nuclear fleet requires continuous high performance operation to 2050 and beyond. High performance is measured by safety, availability, reliability and cost. While there is strong, broad support for long term operations; there are significant challenges to success. Among the challenges to LTO are identifying potential life limiting and aging degradation issues that are not already being monitored or assessed in accordance with regulatory requirements or plant licensing commitments. Performing assessments of these new degradations mechanism may require development and implementation of inspection and monitoring technologies that are not in use today. A critical area that has been identified as potential life-limiting are plant concrete structures. Recent industry issues with leakage from spent fuel pools and the unintentional delamination of the concrete containment structure highlight the importance of the plants concrete structures. Although, the plant’s primary containment structure is periodically tested to assure structural integrity; other concrete structures may not be inspected or monitored for aging degradation. This paper will discuss the systematic approach being developed by the Electric Power Research Institute (EPRI), Electricité De France (EDF) and the Materials Aging Institute (MAI) to address monitoring and inspection of concrete for aging degradation. This integrated approach combines material science and generic issues knowledge, with computational mechanics and property modeling capabilities to develop an issues matrix and an engineering and NDE toolbox to address concrete degradation issues. While this strategy is focused on nuclear power plants; it could be used to address similar types of degradation to other concrete structures.
Nondestructive Evaluation of Nuclear Grade Graphite

---Dennis C. Kunerth and Timothy R. McJunkin, Idaho National Laboratory, P. O. Box 1625, MS 2209, Idaho Falls, ID 83415-2209

---This paper discusses the nondestructive evaluation of nuclear grade graphite performed at the Idaho National Laboratory. Graphite is a composite material highly dependent on the base material and manufacturing methods. As a result, material variations are expected within individual billets as well billet to billet and lot to lot. Several methods of evaluating the material have been explored. Particular technologies each provide a subset of information about the material. This paper focuses on techniques that are applicable to in-service inspection of nuclear energy plant components. Eddy current examination of the available surfaces provides information on potential near surface structural defects and although limited, ultrasonics can be utilized in conventional volumetric inspection. Material condition (e.g. micro-cracking and porosity induced by radiation and stress) can be derived from backscatter or acousto-ultrasound (AU) methods. Novel approaches utilizing phased array ultrasonics have been attempted to expand the abilities of AU techniques. By combining variable placement of apertures, angle and depth of focus, the techniques provide the potential to obtain parameters at various depths in the material. Initial results of the study and possible procedures for application of the techniques are discussed.

Materials Issues in High Temperature Ultrasonic Transducers for Under-Sodium Viewing

---Leonard J. Bond, Pacific Northwest National Laboratory, Applied Physics Group, Richland, WA 99352

---Maintenance of liquid metal fast reactors requires the use of high temperature ultrasonic transducers for inspection, loose parts detection, and imaging, supporting operations activities. Staff at the Pacific Northwest National Laboratory in conjunction with collaborators at the Argonne National Laboratory and the Oari Research and Development Center in Japan are pursuing the next generation of robust sensing systems for under-sodium service. This paper will discuss issues associated with the design and operation of single-element and linear phased-array ultrasonic transducers in the high temperature (250C), high radiation and in sodium environment of liquid metal fast reactors. Discussion topics will include: 1) selection of high Curie temperature, radiation-resistant piezoceramics; 2) high temperature interface-bonding options and; 3) alloy selection for rapid sodium wetting and re-wetting of the transducer face (to provide acoustic coupling). Analytical modeling results will be compared with laboratory data acquired during sodium wetting studies and under-sodium imaging experiments.
Stochastic Simulation for the Propagation of High-Frequency Acoustic Waves Through a Random Velocity Field  
---Bo Lu, Michel Darmon, Nicolas Leymarie, and Sylvain Chatillon, CEA, LIST, F-91191 Gif-Sur-Yvette Cedex, France; Catherine Potel, Laboratoire d'Acoustique de l'Université du Maine (LAUM), UMR CNRS 6613, 72085 Le Mans Cedex 9, France

---In-service inspection of Sodium-Cooled Fast Reactors (SFR) requires the development of non-destructive techniques adapted to the harsh environment conditions and the examination complexity. From past experiences, ultrasonic techniques are considered as suitable candidates. The ultrasonic telemetry is a technique used to constantly insure the safe functioning of reactor inner components by determining their exact position: it consists in measuring the time of flight of the ultrasonic response obtained after propagation of a pulse emitted by a transducer and its interaction with the targets. While in-service the sodium flow creates turbulences that lead to temperature inhomogeneities, which translates into ultrasonic velocity inhomogeneities. These velocity variations could directly impact the tolerance position by introducing time of flight variations. A stochastic simulation model has been developed to calculate the propagation of ultrasonic waves in such an inhomogeneous medium. Using this approach, the time of flight is randomly generated by a stochastic process whose inputs are the statistical moments of times of flight known analytically. The stochastic model predicts beam deviations due to velocity inhomogeneities, which are similar to those provided by a determinist method, such as the ray method.

Ultrasonic NDE in a Reactor Core  
---David A. Parks and Bernhard R. Tittmann, Penn State University, Engineering Science and Mechanics Department, 212 EES Bldg., University Park, PA 16802

---We have irradiated bulk single crystal piezoelectric aluminum nitride acting as an ultrasonic transducer to a fast neutron fluence in excess of $10^{18}$ neutrons per square centimeter. Our primary interest was in the radiation effects on the piezoelectric performance of the AlN crystal. To this end we have monitored the pulse echo operation and impedance data from our prototype transducer periodically throughout the irradiation. Additionally, the pulse echo data was utilized to measure gamma heating and second harmonic generation in an aluminum component throughout the course of irradiation. Our results provide much needed solid proof of the feasibility of in-situ non-destructive testing of components within intense radiation environments.
Nonlinear Rayleigh Waves to Detect Initial Damage Leading to Stress Corrosion Cracking in Carbon Steel
---Kathryn H. Matlack and Laurence Jacobs, Georgia Institute of Technology, G. W. Woodruff School of Mechanical Engineering, Atlanta, GA 30332; Jin-Yeon Kim and Laurence Jacobs, Georgia Institute of Technology, School of Civil and Environmental Engineering, Atlanta, GA 30332; Jianmin Qu, Northwestern University, Department of Civil and Environmental Engineering, Evanston, IL 60208; Preet M. Singh, Georgia Institute of Technology, School of Materials Science and Engineering, Atlanta, GA 30332

---This research experimentally investigates second harmonic generation of Rayleigh waves propagating through carbon steel samples damaged in a stress corrosion environment. Damage from stress corrosion cracking is of major concern in nuclear reactor tubes and in gas and fuel transport pipelines. For example, certain types of stress corrosion cracking (SCC) account for more failures in steam generator tubes than most other damage mechanisms, yet these cracks do not initiate until late in the structure’s life. Thus, there is a need to be able to measure damage state prior to crack initiation, and it has been shown that the acoustic nonlinearity parameter – the parameter associated with second harmonic generation – is sensitive to microstructural evolution. In this work, samples are immersed in a sodium carbonate-bicarbonate solution – which typically forms in the soil surrounding buried pipelines affected by SCC – and held at yield stress for 5-15 days to the onset of stress corrosion cracking. Measurements of second harmonic generation with Rayleigh waves are taken intermittently to relate cumulative damage prior to macroscopic cracking to nonlinear wave propagation. Experimental results showing changes in second harmonic generation due to stress corrosion damage are presented.

An Optical-Fiber Guided Ultrasonic Excitation and Measurement System for Online Monitoring Under High Temperature
---Jinyeol Yang, Hyeonseok Lee, and Hoon Sohn, Department of Civil and Environmental Engineering, Korea Advanced Institute of Science & Technology, 291 Daehak-ro, Yuseong-gu, Daejeon, 305-701 Korea

---This study develops an optical-fiber guided ultrasonic generation and measurement system for online monitoring of pipes within nuclear power plants, which operate under high temperature close to 350°C. Although various types of ultrasonic transducers are currently available, there are few transducers that can be permanently installed and operate under such a high temperature environment. To overcome the problem, we design optical-fibers and fixture devices so that laser beams used for ultrasonic generation and measurement can be transmitted from the laser sources to target points. For ultrasonic generation, a Nd:Yag laser beam is transmitted through an optical-fiber and illuminated at a target point. Here, an optical-fiber with a metal coating is used for improved high temperature operation, and a fixture with a beam collimator is attached to the fiber end to present beam divergence. Ultrasonic waves are measured based on the principal of laser interferometry, and the incident and reflection beams are guided by another optical fiber. The optical fiber is attached to the target surface using a specially designed fixture device with a focusing module. The feasibility of the proposed ultrasonic measurement system has been experimentally verified by measuring ultrasonic waves from a pipe specimen at high temperature environment.
Measurement of Irradiation Effects in Precipitate Hardened Aluminum Using Nonlinear Ultrasonic Principles
---Brian T. Reinhardt, David A. Parks, and Bernhard R. Tittmann, The Pennsylvania State University, The Department of Engineering Science and Mechanics, 212 EES, State College, PA 16801-6063

Currently nuclear power plants are reaching the end of their initial design life. Yet, in order to meet the energy demands, twenty year extensions have been granted to many nuclear reactor facilities. These extensions will be ending by the year 2035, leaving a large gap in the available energy supply. In order to extend the life of these facilities it will imperative to develop techniques capable detecting damage in the aging nuclear facilities. However, the high temperature and high neutron flux environment limits the materials available for use in the nuclear reactor. Because of this limitation little NDE based inspection has been implemented in high radiation environments. Yet recent developments in the understanding of Aluminum Nitride piezoelectric sensors high temperature and radiation dependent behavior have opened the door for in situ experimentation. An experiment was designed to monitor the propagation of an ultrasonic wave in a precipitate hardened aluminum specimen while being subjected to radiation at the Pennsylvania State Universities Breazeale Reactor. Measurements of harmonic generation were made up to 10^18 fluence with significant spectral difference between the pre-irradiated state and the post irradiated state. The connection between micro-structural material changes and harmonic measurements are addressed.

Flexible Eddy Current Probes for Inspection of Complex Parts
---M. Marchand, M. Decitre, and M. Casula, CEA, LIST, F-91191 Gif-sur-Yvette, France; M. Ruaud, Static Etude et Developpement, 25038 Besancon, France

---Non Destructive Testing (NDT) using Eddy Current techniques (ECT) bring a solution to many industrial needs, concerning various applications and domains as nuclear or aeronautics. Nonetheless, when size of notches decreases or inspection areas become hardly accessible or evolving, traditional probes based on classical winding coils turn out to be useless. Thanks to new tools included into CIVA 10.0 software, CEA LIST designed and optimized advanced ECT probes, based on micro-coil arrays or magnetic sensors. On the one hand, these developments concern an innovative flexible EC probe. Planar micro-coils are etched on a flexible film which is set on a head whose shape matches the geometry to be inspected. Amplifiers can be embedded into the handle of the probe, depending on the number of sensors to be driven. On the other hand, flexible probes based on magnetic sensors have been developed with the support of French Institute for Radiological Protection and Nuclear Safety. Their good sensitivity at low frequency makes magnetic sensors attractive for deep defects applications. Performances have been evaluated and experimentally compared.
Session 33
SESSION 33  
COMPOSITES AND RESINS  
P. Fromme, Chairperson  
Sugar Maple Ballroom

8:30 AM  
Analytical and Numerical Computations of Heat Transfer in Pulsed Thermography Applied to Porous CFRP  
---G. Mayr and J. Gruber, Research and Development Ltd., Wels, Austria; G. Hendorfer, Upper Austrian University of Applied Sciences, Wels, Austria

8:50 AM  
In-Plane Velocity Measurement for CFRP Modulus  
---R. Bossi, H. Tat, T. Gordon, A. Stewart, and J. Lin, Boeing Research & Technology, P. O. Box 3707, Seattle, WA 98124-2499; B. Djordjevic, Materials and Sensors Technology Inc., 798 Cromwell Park Drive, Suite C, Glen Burnie, MD 21061

9:10 AM  
Guided Wave Damage Detection in Stressed Fiber Composites  
---C. Borigo, N. DiPlacido, and J. L. Rose, Pennsylvania State University, Engineering Science and Mechanics Department, University Park, PA 16802

9:30 AM  
Non-Contact Ultrasonic Technique for Rapid and Advanced Analysis of Fibrous Materials  
---T. Periyaswamy, Central Michigan University, Human Environmental Studies, Mount Pleasant, MI 48859; T. P. Lerch, Central Michigan University, Mechanical Engineering, Mount Pleasant, MI 48859; K. Balasubramanian, Temple University, Electrical and Computer Engineering, Philadelphia, PA 19122

9:50 AM  
3D Finite Element Simulation of NCF Composites Ultrasonic Testing  
---Z. Liu, Beijing University of Technology, College of Mechanical Engineering and Applied Electronics, Beijing, China; N. Saffari and P. Fromme, University College London, Department of Mechanical Engineering, London, United Kingdom

10:10 AM  
Break

10:30 AM  
Nondestructive Assessment of Pore Size in Foam-Base Hybrid Composite Materials  
---M. Y. Chen¹ and R. T. Ko², ¹Air Force Research Laboratory, WPAFB, OH 45433; ²Univ. of Dayton Research Institute, 300 College Park, Dayton, OH 45469

10:50 AM  
A 2-D Random Void Model to Characterize Void Morphology and Its Application in Ultrasonic Determination of Void Content in Composite Materials  
---L. Lin, J. Chen, X. Zhang, S. S. Ding, and X. M. Li, Dalian University of Technology, School of Materials Science & Engineering, No. 2 Linggong Road, Ganjingzi District, Dalian City, Liaoning Province, P.R.C. 116024

11:10 AM  
Non-Destructive Evaluation of Porosity and Its effect on Mechanical Properties of Carbon Fiber Reinforced Polymer Composite Materials  
---M. R. Bhat, M. P. Binoy, and C. R. L. Murthy, Indian Institute of Science, Department of Aerospace Engineering, Bangalore, Karnataka, India; N. M. Surya, National Institute of Technology, Tiruchirapalli, Tamilnadu, India

11:30 AM  
Thermo-Elastic Nondestructive Evaluation of Fatigue Damage in PMR-15  
---J. T. Welter¹, S. Sathish², G. P. Tandon², N. D. Schehi², M. R. Cherry³, E. A. Lindgren¹, and R. Hall¹; ¹NDE Branch, Air Force Research Laboratory, WPAFB, Dayton, OH 45433; ²Composite and Hybrid Branch, Air Force Research Laboratory, WPAFB, Dayton, OH 45433; ³Univ. of Dayton Research Institute, Dayton, OH 45420

11:50 AM  
Anisotropic Elastic Waves with Dissipation  
---E. L. Roetman, Embry-Riddle Aeronautical University, Whidbey Island Center, 3615 N. Langley Boulevard, Oak Harbor, WA 98278-1000

12:10 PM  
Adjourn
Analytical and Numerical Computations of Heat Transfer in Pulsed Thermography Applied to Porous CFRP

---Guenther Mayr and Juergen Gruber, Research and Development Ltd., Wels, Austria; Guenther Hendorfer, Upper Austrian University of Applied Sciences, Wels, Austria

---Pulsed thermography, especially thermal diffusivity imaging, has proved to be an efficient non-destructive testing method to locate porosity. In former experimental studies we have shown that a model based calculation of the volume porosity from thermal diffusivity values is possible under the prerequisite that the shape of the pores is known. In this paper we show a detailed verification of this analytical thermal diffusivity model by using finite element simulations. The real pore morphology for the geometrical simulation models are obtained by computed tomography measurements. The heat transfer by conduction is simulated in steady-state and transient analyses. In the transient case the thermal diffusivity values are calculated from the temperature field at the front as well as at the back side. Our investigations show that the analytical model correlates well with the thermal diffusivity values calculated from steady-state simulations. In the transient case the back side results correspond better with the analytical model. The simulations also show a discrepancy in the front side measurements due to the stronger influence of the pore morphology. These findings are similar to those seen in pulsed thermography experiments. In conclusion, this verified model allows a precise quantification of porosity in CFRP structures.

In-Plane Velocity Measurement for CFRP Modulus

---Richard Bossi, Hong Tat, Trey Gordon, Alan Stewart, and John Lin, Boeing Research & Technology, P. O. Box 3707, Seattle, WA 98124-2499; Boro Djordjevic, Materials and Sensors Technology Inc., 798 Cromwell Park Drive, Suite C, Glen Burnie, MD 21061

---Carbon Fiber Reinforced Plastic (CFRP) laminate composites are often tailored to provide stiffness in particular directions to optimize performance. The standard ultrasonic inspection however uses a cross ply measurement of acoustic attenuation to assess the consolidation quality of the CFRP. While this is useful for porosity, delamination or inclusion detection, it does not address a primary interest in the use of CFRP. A more appropriate measure of the quality of the laminate would be the determination of the in-plane characteristics to evaluate the desired directional stiffness of the product. This paper describes an in-plane ultrasound method using insertion and receiving sensors spaced known distances apart on the surface of the CFRP structure and in a desired directional orientation for evaluation. The time and distance of the transmission of the head wave from the insertion to the sensing allows a velocity calculation. This method is demonstrated using laser generated ultrasound and a pin transducer receiver. Measurement of the in-plane acoustic head wave velocity has been found to correlate to the CFRP material modulus from mechanical tests.
Guided Wave Damage Detection in Stressed Fiber Composites  
---Cody Borigo, Nicola DiPlacido, and Joseph L. Rose, Pennsylvania State University, Engineering Science and Mechanics Department, University Park, PA 16802

---A method is being developed to detect damage in composite structures under an operational load that will allow for increased sensitivity by comparing guided wave signals at loaded and unloaded states. Acoustoelastic effects cause variations in the guided wave signal measured in a structure under various states of stress, but it has been shown in isotropic metals that additional changes in this signal can occur if closed crack-like damage is present that may be opened due to applied stresses. It is theorized that a similar effect can occur in composite structures and can be used to detect such dislocations in the fibers and/or matrix with increased sensitivity. Finite element models of composite samples with macroscopic surface cracks, as well as distributed crack damage were analyzed. Additionally, distributed damage in fiber composite materials is often detected as a deterioration of stiffness parameters. One of these stiffness-degradation models was used to simulate damage in the finite element model, in which guided wave modes most sensitive to such compliance matrix changes were utilized to detect degradation. The guided wave signals were compared at loaded and unloaded states to develop a relationship between signal change and accumulated damage in the composite. Composite coupons were tested under cyclic fatigue loading while bonded sensors were used to periodically collect guided wave data at various static load states to compare the results to the finite element data.

Non-Contact Ultrasonic Technique for Rapid and Advanced Analysis of Fibrous Materials  
---Thamizhisai Periyaswamy, Central Michigan University, Human Environmental Studies, Mount Pleasant, MI 48859; Terence P. Lerch, Central Michigan University, Mechanical Engineering, Mount Pleasant, MI 48859; Karthikeyan Balasubramanian, Temple University, Electrical and Computer Engineering, Philadelphia, PA 19122

---Fibrous ensembles are, typically, multi-scale flexible assemblies with unique physical and rheological properties, unlike continuum materials. Macroscopic behaviors of these materials are greatly the result of non-linear interactions at the micro levels. These micro-scale interactions can be assessed by capturing the material behavior under low mechanical stress conditions. While ultrasonic based non-destructive testing was suitably implemented for continuum materials, their application to fibrous structures was limited primarily due to the inherent structural arrangements of these unique assemblies. Discontinuities, non-uniform orientations and multi-phase components make these ensembles difficult to study using the existing scan-based methods. This work presents a novel rapid and advanced analysis tool for complex fibrous systems using a nondestructive and noncontact ultrasonic system. Five characteristic features of ultrasound signals transmitted through fibrous structures were studied, i.e., dampness in signal flight, signal velocity, power spectral density, signal power and rate of amplitude attenuation. Analysis of these features under two different acoustic frequencies, 500 kHz and 1 MHz, allowed us to study the componentized behavior of these materials for three of the key mechanical properties including bending rigidity, shear rigidity and low stress tensile stress. A material response index (MRI) was also derived using the signal features.
3D Finite Element Simulation of NCF Composites Ultrasonic Testing
---Zenghua Liu, Beijing University of Technology, College of Mechanical Engineering and Applied Electronics, Beijing, China; Nader Saffari and Paul Fromme, University College London, Department of Mechanical Engineering, London, United Kingdom

---Composite materials offer many advantages for aerospace applications, e.g., good strength to weight ratio. Different types of composites, such as non-crimp fabrics (NCF), are currently being investigated as they offer reduced manufacturing costs and improved damage tolerance as compared to traditional pre-impregnated composite materials. NCF composites are made from stitched fiber bundles (tows), which typically have a width and thickness in the order of millimeter. This results in strongly inhomogeneous and anisotropic material properties. Different types of manufacturing imperfections, such as porosity, resin pockets, tow crimp and misalignment can lead to reduced material strength and thus to defects following excessive loads or impact, e.g., fracture and delaminations. The ultrasonic non-destructive testing of NCF composites is difficult, as the tow size is comparable to the wavelength, leading to multiple scattering in this inherently three-dimensional structure. For typical material properties and geometry of an NCF composite, a full three-dimensional Finite Element (FE) model has been developed in ABAQUS. The propagation of longitudinal ultrasonic waves has been simulated and the effect of multiple scattering at the fiber tows investigated. The potential for the detection and quantification of typical defects is discussed based on the observed influence on the ultrasonic wave propagation and attenuation.

Nondestructive Assessment of Pore Size in Foam-Base Hybrid Composite Materials
---M. Y. Chen¹ and R. T. Ko², ¹Air Force Research Laboratory, Wright-Patterson Air Force Base, OH 45433; ²University of Dayton Research Institute, 300 College Park, Dayton, OH 45469

---Preliminary results will be presented for nondestructive assessment of pore size in foam-based hybrid composite materials using ultrasonic techniques. Pore size was monitored through the frequency content of ultrasonic signal. The effects of porosity on the attenuation of ultrasound as a function of frequency were studied. We varied the frequency to obtain different level of scattering caused by the pores, knowing high frequency ultrasound wave with wavelength less than the pore size will be scattered by the pores more significantly as compared to low frequency ultrasound wave. Feasibility of this method was demonstrated on two types of unfilled foams with various pore sizes.
A 2-D Random Void Model to Characterize Void Morphology and Its Application in Ultrasonic Determination of Void Content in Composite Materials

---Li Lin, Jun Chen, Xiang Zhang, Shan Shan Ding, and Xi Meng Li, Dalian University of Technology, School of Materials Science & Engineering, No. 2 Linggong Road, Ganjingzi District, Dalian City, Liaoning Province, P.R.C. 116024

---Utilizing statistical methods, the matrix elasticity and elastic fluctuations from voids of composite materials are characterized as large and small scale heterogeneities, respectively. A two-dimensional RVM (Random Void Model) is innovatively proposed to describe morphology of voids and quantitatively correlate ultrasonic attenuation coefficient with void content of composite materials. Calculations from RVM of CFRP (Carbon Fiber Reinforced Polymer) composite specimens with void content 0.03-4.62% at 5MHz are much closer to the experiments than Martinà’s model. Furthermore, RVM can also cover abnormal coefficient from unusual large voids. The significant enhancement quantitatively between void content and ultrasonic attenuation coefficient makes this method a good candidate for predicting void content of composite materials.

Non-Destructive Evaluation of Porosity and Its effect on Mechanical Properties of Carbon Fiber Reinforced Polymer Composite Materials

---M. R. Bhat, M. P. Binoy, and C. R. L. Murthy, Indian Institute of Science, Department of Aerospace Engineering, Bangalore, Karnataka, India; N. M. Surya, National Institute of Technology, Tiruchirappalli, Tamilnadu, India

---Porosity invariably gets introduced in polymer matrix composite materials during the fabrication process. While it is a fact that porosity cannot be totally avoided in this type of material, the presence of such defects beyond a certain limit can be highly detrimental to the mechanical properties of the final product and hence their performance as a structural component. Though there are standard destructive methods in practice to quantify the porosity, the need for a Non-destructive Evaluation (NDE) tool to evaluate polymer composite component for the porosity content cannot be over emphasized. In the present work an attempt is made to induce porosity of varied levels in carbon fiber reinforced epoxy based polymer composite laminates fabricated using prepregs by varying the fabrication parameters such as applied vacuum, autoclave pressure and curing temperature. Different NDE tools have been utilized to evaluate the porosity content and correlate with measurable parameters of different NDE techniques. Primarily acoustic wave based methods, ultrasonic imaging and real time digital X-ray imaging have been tried to obtain a measurable parameter which can represent or reflect the amount of porosity contained in the composite laminate. Destructive standard burn-off tests have been performed to obtain actual porosity contents in the fabricated composite laminates. Open hole compression tests and Inter laminar shear strength (ILSS) tests were conducted to study the effect of porosity content on the mechanical properties of the material. Thus, effect of varied porosity content on mechanical properties of the CFRP composite materials is investigated through a series of experimental investigations. The outcome of the experimental approach has yielded interesting and encouraging trend as a first step towards developing an NDE tool for quantification of effect of varied porosity in the polymer composite materials.
Thermo-Elastic Nondestructive Evaluation of Fatigue Damage in PMR-15

---J. T. Welter¹, S. Sathish³, G. P. Tandon³, N. D. Schehl³, M. R. Cherry³, E. A. Lindgren¹, and R. Hall²; ¹Nondestructive Evaluation Branch, Air Force Research Laboratory, WPAFB, Dayton, OH 45433; ²Composite and Hybrid Branch, Air Force Research Laboratory, WPAFB, Dayton, OH 45433; ³University of Dayton Research Institute, Dayton, OH 45420

---Thermoset polyimide resins are used as the polymer matrix in high temperature composites for aerospace applications such as engine shrouds. At these locations the components have to withstand high temperatures and significant vibration. A number of studies have investigated the effects of thermal exposure on mechanical properties of polyimide resins, and the effects of fatigue on thermoplastics have been discussed at length. However, the effects of fatigue on thermosets, in particular polyimides, have largely been overlooked. In this paper we present studies of nondestructive evaluation of fatigue damage in a thermoset polyimide resin, PMR-15, performed by measuring the changes in the evolution of heat in the samples during cyclic loading. The temperature changes are measured using a high sensitivity IR camera as a function of number of fatigue cycles. Interrupted fatigue tests were performed on four samples. The temperature rise during an increment of fatigue cycling shows two linear regions each with a different slope (slope I and slope II). Slope I remains constant for every increment of fatigue, while slope II increases. The onset of slope II occurs at the same increase in temperature due to hysteretic heating for all samples. Experimental observations are explained using a phenomenological two phase model based on crosslinking density variations in observed in other thermoset resins at microscopic scales. The results of these experiments are discussed in reference to utilizing this technique for detection and evaluation of fatigue in PMR-15 resin and composites.

Anisotropic Elastic Waves with Dissipation

---Ernest L. Roetman, Embry-Riddle Aeronautical University, Whidbey Island Center, 3615 N. Langley Boulevard, Oak Harbor, WA 98278-1000

---The formulation of the elastodynamics problem as a system of first-order partial differential equations has shown promise for improved analysis for anisotropic composite materials as reported previously. All materials have some dissipation to wave propagation, which can often be ignored, but which does appear in sophisticated non-destructive measurement techniques among other applications. The system development is quickly reviewed and preliminary results are presented for isotropic and anisotropic materials that illustrate the promise of the approach. There is criticism of the viscoelastic discussion in the engineering literature directed at the complicated formulation of the models and the difficulty to identify the physical parameters. An adjustment to the first order system that indicates a linear Maxwell type dissipation structure is easily included in the system. As is expected, providing for a Voigt or standard linear model is more involved. Provision for such models in a straightforward way is proposed with illustration of some first indications of the benefit of the proposed model.
Session 34
### SESSION 34
**SENSORS (ALL TECHNIQUES) AND SENSOR MATERIALS**

J. Bowler and S. Brady, Co-Chairpersons  
Frank Livak Ballroom

<table>
<thead>
<tr>
<th>Time</th>
<th>Title</th>
<th>Authors</th>
<th>Institution</th>
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<tbody>
<tr>
<td>8:30 AM</td>
<td>Micron Size GMR Magnetic Sensor with Needle Structure</td>
<td>S. Yamada, R. Haraszczuk, M. Kakikawa, and H. Ha</td>
<td>Kanazawa University, Division of Biological Measurements and Applications, Institute of Nature and Environmental Technology, Kanazawa, Ishikawa, Japan</td>
</tr>
<tr>
<td>8:50 AM</td>
<td>Handheld, Giant-Magnetoresistive-Sensor-Based Eddy Current Probes</td>
<td>S. K. Brady and D. D. Palmer Jr.</td>
<td>The Boeing Company, P. O. Box 3707, Mailcode 2T-42, Seattle, WA 98124-2207</td>
</tr>
<tr>
<td>9:10 AM</td>
<td>Local Magnetization Unit and GMR Array Design for Magnetic Flux Leakage Inspection</td>
<td>M. Pelkner, A. Neubauer, V. Reimund, and M. Kreutzbruck</td>
<td>Federal Institute for Materials Research and Testing, Non-Destructive Testing, Acoustical and Electromagnetic Methods, Berlin, Germany</td>
</tr>
<tr>
<td>9:30 AM</td>
<td>An Analytical Model of Eddy Current Ferrite-Cored Probes</td>
<td>Y. Lu and J. R. Bowler</td>
<td>Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011</td>
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<td>10:10 AM</td>
<td>Break</td>
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<tr>
<td>10:30 AM</td>
<td>Improved Designs for Field Generation for Non Invasive Transcranial Magnetic Stimulation</td>
<td>L. Crowther and D. C. Jiles</td>
<td>Iowa State University, Department of Electrical and Computer Engineering, Ames, IA 50011-3060</td>
</tr>
<tr>
<td>10:50 AM</td>
<td>Fiber Optic Sensors for Nuclear Power Plant Applications</td>
<td>M. Kasinathan, S. Sosamma, C. B. Rao, N. Murali, and T. Jayakumar</td>
<td>Indira Gandhi Centre for Atomic Research, Kalpakkam, Tamil Nadu, 603102 India</td>
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<tr>
<td>11:10 AM</td>
<td>Photonic Crystals with a Refraction Index Modulating by Ultrasonics</td>
<td>E. K. Naimi and Y. K. Vekilov</td>
<td>National University of Science and Technology “MISIS”, Leninskiy prosp.4, 119049 Moscow, Russia</td>
</tr>
<tr>
<td>11:30 AM</td>
<td>Measurement of Acoustic Field of High-Frequency Ultrasonic Transducer</td>
<td>T. Kong, C. Xu, and Q. Pan</td>
<td>Beijing Institute of Technology, Key Laboratory of Fundamental Science for Advanced Machining, Beijing, China</td>
</tr>
<tr>
<td>11:50 AM</td>
<td>Characterization of the Effect of Temperature on the Radial Vibration Modes of a Thin Disk Made of a Modified BS-PT Piezoelectric Material</td>
<td>S. Roa-Prada, H. A. Scarton, K. R. Wilt, G. J. Saulnier, J. D. Ashdown, T. J. Lawry, P. K. Das, and A. J. Gavens</td>
<td>Knolls Atomic Power Laboratory-BMPC, P. O. Box 1072, 2401 River Road, Niskayuna, NY 12309</td>
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<tr>
<td>12:10 PM</td>
<td>Adjourn</td>
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Micron Size GMR Magnetic Sensor with Needle Structure
---S. Yamada, R. Haraszczuk, M. Kakikawa, and H. Ha, Kanazawa University, Division of Biological Measurements and Applications, Institute of Nature and Environmental Technology, Kanazawa, Ishikawa, Japan

---The work presents inimitable shaped needle type probe with spin valve giant magnetoresistive (SV-GMR) elements. Sensitive elements with 40 µm width are connected in the Wheatstone bridge structure. The length of the needle is 3 cm and its cross section is only 250 µm per 250 µm. Probe elements are characterized by high micron order spatial resolution. The needle type probe works as a gradient meter which concurrently suppresses the influence of externally applied field and detects magnetic fields emanating from nano or micro order size sources. Sensing elements present high sensitivity 100 µV/µT and are capable to detect the magnetic fields in order of few nT. SV-GMR elements present flat amplitude and phase characteristic in wide frequency range (from Hz to MHz). The characteristic feature allows utilizing the probe in detection of the in phase and out of phase signal components. Additional merit of this design is extremely small liftoff between sensing element and the source of magnetic field. The SV-GMR elements are isolated only by very thin protection layer (a few µm), that gives opportunity to apply the probe in biological (in vivo) experiments, and in nondestructive evaluation of current detection. Needle shape allows placing the sensing element in the material (or very close to its surface) what arise in direct detection of magnetic flux changes.

Handheld, Giant-Magnetoresistive-Sensor-Based Eddy Current Probes
---Steven K. Brady and Donald D. Palmer Jr., The Boeing Company, P. O. Box 3707, Mailcode 2T-42, Seattle, WA 98124-2207

---The minimum crack length detectable with conventional eddy current probes increases dramatically as the thickness of metal through which the inspection is performed increases. The skin depth phenomenon is unavoidable, and demands low frequency inspection, hindering sensitivity. However, one time derivative introduced by Faraday's Law can be avoided by using giant magnetoresistive sensors to detect eddy currents instead of conventional coils, improving sensitivity. The theory will be explained, along with some probe designs and the observed benefits in sensitivity.
Local Magnetization Unit and GMR Array Design for Magnetic Flux Leakage Inspection
---Matthias Pelkner, Andreas Neubauer, Verena Reimund, and Marc Kreutzbruck, Federal Institute for Materials Research and Testing, Non-Destructive Testing, Acoustical and Electromagnetic Methods, Berlin, Germany

---GMR sensors are increasingly used for magnetic surface inspection due to their high sensitivity and high spatial resolution. In case of simple planar or cylindrical shaped components, the GMR-based inspection procedure can be automated easily. In order to reduce the inspection time we present a GMR-based NDT-system consisting of a yoke as a local magnetization unit. This way the global magnetization step and, if necessary, the corresponding demagnetization cycle can be avoided reducing the number of working steps. The probe design was carried out by means of FEM simulations. Using the local probe we measured plates, bearings, and rails, each of which containing real fatigue cracks and reference artificial cracks of different depths and orientations. Cracks with a depth of 40 µm could be resolved with a signal-to-noise ratio better than 8. A further reduction of the measuring time can be obtained using a sensor array. We present a study of the optimized size and arrangement of the sensing GMR-layers for a NDT-adapted sensor array. The geometric sensor parameters of GMR gradiometric sensors were investigated by simulations of the magnetic flux leakage of surface cracks using an analytic model.

An Analytical Model of Eddy Current Ferrite-Cored Probes
---Yi Lu and John R. Bowler, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

---An analytical model of an axisymmetric eddy current probe with a cylindrical ferrite core is developed. Initially we consider the magnetic vector potential of a circular filament coaxial with a ferrite core. The principle of superposition is then used to derive close-form expressions for both the electromagnetic field and the impedance of a coil from the filament field. Rather than locating the probe in infinite space, it is confined coaxially within a circularly cylindrical boundary on which the vector potential field zero. The radius of this artificial boundary is large in order to ensure that is does not interfere substantially with the field near the probe. By using a truncated region in this way, the vector potential in the probe region can be expanded as a series rather than an integral form. Thus the solution of the problem amounts to finding the expansion coefficients in the series. The numerical predictions of probe impedance have been compared with experimental data showing good agreement.---This work is supported by the NSF/IU Co-operative Research Consortium at Iowa State University.
Advances in Transient (Pulsed) Eddy Current for Inspection of Multi-layer Aluminum Structures in the Presence of Ferrous Fasteners
--- Thomas W. Krause, Vijay K. Babbar, Daniel R. Desjardins, Genevieve M. Vallieres, and Paul P. Whalen, Royal Military College of Canada, Department of Physics, Kingston, Ontario, Canada

--- As a result of cyclic fatigue, 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 of fasteners introduces additional down time as well as the risk of collateral damage. In this study transient (pulsed) eddy currents and associated probe development are examined as a method for inspection of these structures when ferrous fasteners are present. Specifically, abrupt magnetization of the ferrous core by the application of 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 the differences in response due to variations in the induced eddy current field arising from the presence of the notch. Results are examined in terms of electromagnetic field diffusion and are investigated by finite element analysis and through analytical treatments by application of boundary conditions for the ferrous fastener within a conducting matrix.

Improved Designs for Field Generation for Non Invasive Transcranial Magnetic Stimulation
--- L. Crowther and D. C. Jiles, Iowa State University, Dept. of Electrical and Computer Engineering, Ames, IA 50011-3060

--- Transcranial Magnetic Stimulation (TMS) is a non-invasive method utilizing a changing magnetic field to excite or inhibit neuronal activity. The technique is used to study brain function and is increasingly being implemented for diagnostic and therapeutic applications of psychiatric disorders and neurologic diseases. Existing TMS stimulator coils are typically unable to stimulate below the cortical surface and provide poor localization of stimulation. The existing coils are also unable to stimulate brain tissue at depth without stimulating overlying regions. These factors currently limit the applications for which brain stimulation can be achieved non-invasively. A challenge faced in developing improved TMS stimulator coils is the ability to accurately calculate the site of neuronal activation due to tissue heterogeneity and anisotropy. By utilizing a realistic human head model this calculation can be improved. This is due to the intricate gyral folding pattern and the inhomogeneous electrical conductivity distribution in the head being accurately modeled in the heterogeneous head model. Simplified homogeneous head models have been found to calculate electric field intensities which differ by a factor of two compared to this improved model. The realistic head model obtained for this study is derived from MRI data of an adult male, comprising of 44 separated tissues having spatial resolution of 0.5 mm. Each of these separated tissues can have electrical properties independently applied, appropriate to the structure they represent. The effect of varying the orientation and location of standard TMS stimulator coils has been studied, indicating the challenges faced in reliably stimulating a desired cortical target. Results highlight the need for improved TMS stimulator coil design to allow localized stimulation and stimulation of desired tissue at depth. Calculations of the electric field distribution in the realistic head model provide insight into how improvements in TMS stimulator coil design can be made.
Fiber Optic Sensors for Nuclear Power Plant Applications
---Murugesan Kasinathan, Samuel Sosamma, Chelamchala Babu Rao, Nagarajan Murali, and Tammana Jayakumar, Indira Gandhi Centre for Atomic Research, Kalpakkam, Tamil Nadu, 603102 India

---Studies have been carried out for use of fiber optic sensors (FOS) for monitoring temperature and leaks in coolant loops of Nuclear Power Plants (NPP). Fast Breeder Reactors (FBRs) use liquid sodium as coolant. Continuous monitoring of temperature in the coolant loops of FBRs is important for the safety of the reactors. To withstand high temperature, gold coated fibers encased in stainless steel (SS) capillary tube are deployed. The SS capillary tube provides physical protection to the fiber. Distributed and continuous temperature measurement up to 973K is demonstrated using RDTS. The temperature response of RDTS is found to be comparable to conventional thermocouples. Potential regions of leakage in FBR sodium circuits are near welds, high stress areas, and thin sections subjected to thermal shock. An optical fiber based sodium leak detection system using RDTS is employed to measure the change in temperature during the sodium leak. The most important advantage of fiber optic sensor over other types of sensor is that it provides sensing over the length of the fiber. Thus the measurand is also coded with the spatial information. The fiber laying methodology is optimized for both detection of leak and trace the path of the percolation of the sodium leak through the insulation. In order to comply with safety requirements of overhead power transmission lines in the power grid, temperature along the transmission lines has to be monitored and also inspected for any cable defect. Studies have been carried out using a RDTS for meeting this requirement. A modified Aluminum Core Steel Reinforced (ACSR) power cable is used in this study. The reinforced steel of ACSR cable is replaced with SS capillary in which optical fiber sensor is encased. Any localized defect in the cable during power transmission will lead to hot spot. The suitability of RDTS for detecting defects in ACSR overhead power cable, manifested as hot spots, is demonstrated.

Photonic Crystals with a Refraction Index Modulating by Ultrasonics
---E. K. Naimi and Yu. Kh. Vekilov, National University of Science and Technology “MISIS”, Leninskiy prosp.4, 119049 Moscow, Russia

---The forming of space ordering optical structure with modulated by ultrasonics refraction index in photonic crystals is discussed. It is shown that at the standing ultrasonic wave excitation the structure is created from the separate light paths which are superlattice «dynamic photonic crystal». It is noted that the optical properties of these structures potentially diverse properties of three-dimensional crystals. The possible fields using of these structures are discussed. In particular, photonic crystals with a refraction index modulated by ultrasonics, may find application in various fields of acousto-optics and photonics (light modulators, reflectors, deflectors), when creating a spectral dispersion devices based on a new basis, the elements of control devices of adaptive optics and other instruments and devices.
Measurement of Acoustic Field of High-Frequency Ultrasonic Transducer
---Tao Kong, Chunguang Xu, and Qinxue Pan, Beijing Institute of Technology, Key Laboratory of Fundamental Science for Advanced Machining, Beijing, China

---Two problems, aligning of hydrophone with acoustical axis of measured transducers and aperture average of hydrophone, in measurement of high-frequency ultrasonic transducer sound field by hydrophone were discussed. And two corresponding approaches, an accurate automatic aligning method based on the sensitivity of transducer’s border-wave for off-axis position and an aperture average modification method using 2-D Wiener deconvolution, were proposed for the two problems above. Finally, two high-frequency transducers (20MHz and 50MHz) were measured and the results of experiments showed the validity of these methods.

Characterization of the Effect of Temperature on the Radial Vibration Modes of a Thin Disk Made of a Modified BS-PT Piezoelectric Material
---S. Roa-Prada, H. A. Scarton, K. R. Wilt, G. J. Saulnier, J. D. Ashdown, T. J. Lawry, P. K. Das, and A. J. Gavens, Facultad de Ingenieria Mecatronica, Universidad Autonoma de Bucaramanga, Bucaramanga, Colombia; Rensselaer Polytechnic Institute, Department of Mechanical, Aerospace & Nuclear Engineering, Troy, NY 12180; Rensselaer Polytechnic Institute, Department of Electrical, Computer & Systems Engineering, Troy, NY 12180; University of California, Electrical and Computer Engineering, La Jolla, CA 92093-0407; Bechtel Marine Propulsion Corporation, Schenectady, NY 12301

---The effect of temperature up to 315.6°C (600°F) on the coupling between the radial and longitudinal vibration modes of a thin piezoelectric disk used for nondestructive testing, or in an ultrasonic through-wall communication system (UTWC), is presented. A modified BS-PT (BiScO3–PbTiO3) piezoelectric material was selected for the fabrication of the thin disk due to its strong piezoelectric activity and properties. Results from experimental measurements exhibit both a magnification and a frequency shift of multiple radial vibration harmonics in the vicinity of the fundamental longitudinal mode as the operating temperature is increased. The combined effect of magnification and frequency shift of these modes introduces dramatic changes in the frequency response of the piezoelectric disk, in the frequency range of interest, compromising the proper functioning of the piezoelectric disk and its associated devices. The results of this work provide a comprehensive assessment of the temperature stability of the modified BS-PT material used, including the characterization of the temperature dependence of the piezoelectric properties that are responsible for the distortion of the fundamental longitudinal vibration mode with increasing temperature.
Session 35
SESSION 35
NDE FOR MATERIAL MICROSTRUCTURE, PROPERTIES
P. Panetta, Chairperson
Silver Maple Ballroom

8:30 AM  Directional Ultrasonic Backscattering in Polycrystals with Elongated Grains and Application for Material Characterization
---O. I. Lobkis, L. Yang, J. Li, and S. I. Rokhlin, The Ohio State University, Department of Materials Science and Engineering, Edison Joining Technology Center, 1248 Arthur E. Adams Dr., Columbus, OH 43221

8:50 AM  Integrated Method of Ultrasonic Attenuation and Backscattering for Characterization of Microstructures in Polycrystalline Materials
---J. Li, O. I. Lobkis, L. Yang, and S. I. Rokhlin, The Ohio State University, Department of Materials Science and Engineering, Edison Joining Technology Center, 1248 Arthur E. Adams Dr., Columbus, OH 43221

9:10 AM  Ultrasonic Backscattering Measurement of Grain Size in Aircraft Engine Alloys
---P. D. Panetta and M. Tracy, Applied Research Associates, Inc., P. O. Box 1346, Gloucester Point, VA 23062

9:30 AM  Effects of Microstructure on Nondestructive Characterization of Near Surface Conductivity and Residual Stress Profiles in Nickel-Base Superalloy by Swept Frequency Eddy Current

9:50 AM  Extraction of Texture in Metal Sheet Using Non-Contact Electromagnetic Acoustic Transducers (Emats) and Wavelet Processing
---K. S. Ho, M. H. Li, J. Mackersie, and A. Gachagan, University of Strathclyde, Centre for Ultrasonic Engineering, Department of Electronic & Electrical Engineering, 204 Gorge Street, Glasgow, Scotland, G1 1XW, United Kingdom

10:10 AM  Break

10:30 AM  Measuring the Residual Stress Field Based on Ultrasonic Wave
---Q. Pan, W. Chang, C. Xu, D. Xiao, and X. Yang, Beijing Institute of Technology, Key Laboratory of Fundamental Science for Advanced Machining, School of Mechanical Engineering, 5 South Zhongguancun Street, Haidian District, Beijing, 100081, China (PRC)

10:50 AM  Third Order Elastic Constants and Rayleigh Wave Dispersion of Shot-Peened Aero-Engine Materials

11:10 AM  Characterization of ASTM F 136, Ti-Al-V Alloy to Enhance Its Biological Performance Using Nondestructive Tools
---S. M. Bholta, R. Bhola*, B. Mishra², and D. L. Olson³, ¹Department of Nuclear Engineering and Radiological Sciences; ²Department of Biologic & Material Sciences, School of Dentistry, University of Michigan, Ann Arbor, MI 48109; ³³Department of Metallurgical and Materials Engineering, Colorado School of Mines, CO 80401

11:30 AM  Adjourn
Directional Ultrasonic Backscattering in Polycrystals with Elongated Grains and Application for Material Characterization

---O. I. Lobkis, L. Yang, J. Li, and S. I. Rokhlin, The Ohio State University, Department of Materials Science and Engineering, Edison Joining Technology Center, 1248 Arthur E. Adams Dr., Columbus, OH 43221

---In this paper theoretical and experimental analysis of the directivity of ultrasonic backscattering coefficients in polycrystalline materials with elongated grains are discussed and applied to inverse characterization of material microstructure/microtexture. An analytical solution for a spectral representation of the backscattering (BS) coefficient in polycrystals with elongated (generally ellipsoidal) grains is obtained; it is a natural generalization of the known explicit result for the BS coefficient in polycrystals with spherical grains. New insights into the dependence of the BS signal on frequency and averaged ellipsoidal grain radii are obtained. In particular it is shown that the dominant effect on the backscattering is the averaged ellipsoidal radius in the direction of wave propagation, instead of the ellipsoidal cross-section. The theory was applied to a simplified model of Ti alloy duplex microstructure and was compared with experiment. It is demonstrated that the grain size and grain morphology can be determined from directional measurements (morphological information is more accurate and easily obtainable). Also a new nondimensional parameter $q$ was introduced and measured. This parameter provides the relative contribution of the second phase (crystallites) to the backscattering signal, the effect of which is measurable and important. Comparison of the model with experiment shows there is significant advantage in using the directional ratios of backscattering coefficients for data analysis.

Integrated Method of Ultrasonic Attenuation and Backscattering for Characterization of Microstructures in Polycrystalline Materials

---J. Li, O. I. Lobkis, L. Yang, and S. I. Rokhlin, The Ohio State University, Department of Materials Science and Engineering, Edison Joining Technology Center, 1248 Arthur E. Adams Dr., Columbus, OH 43221

---The scattering of ultrasonic waves in polycrystalline materials depends on the relative misorientation of the crystallites and the crystallite size and morphology. Those parameters affect both ultrasonic attenuation and backscattering. It is shown in this paper that combined measurement and evaluation of ultrasonic backscattering and attenuation may be used advantageously for inverse microstructural characterization of polycrystalline materials. First the method is described by using recently developed models for ultrasonic attenuation and backscattering in polycrystalline materials with elongated grains. The frequency range selection for the successful application of the method is described; for this range simple relations of ultrasonic data to grain parameters are derived. Finally the application of the methods to our own experimental data for forged Ti alloy and experimental data in the literature for rolled Al alloy samples are shown.
FRIDAY, SESSION 35

Ultrasonic Backscattering Measurement of Grain Size in Aircraft Engine Alloys
---Paul D. Panetta and Maureen Tracy, Applied Research Associates, Inc., P. O. Box 1346, Gloucester Point, VA 23062

---The bore and the rim of aircraft engine disks experience different operating temperatures and conditions creating a higher propensity for fatigue cracking in the bore and creep damage at the rim. Traditionally it is common to produce the nickel alloy disks with nearly uniform microstructures across the disc. Recently, several manufactures produced nickel alloy disks with fine grains at the bore (~ 5 um) and coarse grains at the rim (~ 80 um) using thermal gradients. These discs had a longer fatigue life in the bore region and higher creep resistance in the rim region. To incorporate these disks into aircraft engines and ensure reliability through the service life, NDE tools are needed to guarantee the target grain sizes have been met during processing and maintained through the life of the engine. Ultrasonic backscattering and attenuation measurements coupled with theories for equiaxed grains are well suited to characterize these microstructures. We will present ultrasonic backscattering and attenuation measurements on nickel alloys coupled with scattering theories to determine the grain size in nickel alloys used for rotating engine disks. Our results have shown the prediction of the grain size from backscattering from nickel alloy microstructures was within 2 um for grain sizes ranging from 5 um to 35 um.

Effects of Microstructure on Nondestructive Characterization of Near Surface Conductivity and Residual Stress Profiles in Nickel-base Superalloy by Swept Frequency Eddy Current

---This paper reports on a study of the effects of microstructure on EC characterization of residual stresses in shot peened nickel-base superalloy components. The technique utilizes swept frequency EC measurements to determine the near-surface conductivity deviation profiles by means of model-based inversion, with the intent to infer the residual stress profiles based on the piezoresistivity effect. The method was applied to a series of heat treated Inconel 718 samples with different secondary phase contents which were shot peened at different Almen intensities. On one hand, the samples shot peened at the same intensity show different conductivity deviation profiles depending on their microstructures. In particular, the conductivity of the shot-affected surface layer increases for the solutionized sample but decreases for the peak-aged sample. On the other hand, both the solutionized and hardened samples were found to have compressive residual stresses at the surface, and their piezoresistivity coefficients, determined by in situ DCPD and EC measurements under static loads, are of the same sign and have similar magnitudes. The seemingly inconsistent results indicate that the piezoresistivity effect alone is not sufficient to explain the relationship between the conductivity and residual stress profiles among shot-peened samples with different microstructures. Other possible mechanisms contributing to swept EC signals and their implications in EC residual stress characterization will be discussed.---This material is based upon work supported in part by the Air Force Research Laboratory under contract # FA8650-04-C-5228 at Iowa State University Center for NDE.
Extraction of Texture in Metal Sheet Using Non-Contact Electromagnetic Acoustic Transducers (Emats) and Wavelet Processing

---Kwok Shun Ho, Ming Hui Li, John Mackersie, and Anthony Gachagan, University of Strathclyde, Centre for Ultrasonic Engineering, Department of Electronic & Electrical Engineering, 204 Gorge Street, Glasgow, Scotland, G1 1XW, United Kingdom

Texture measurements of metallic materials are important in industries, and some examples of these specific materials and applications are presented. In this work, Electromagnetic acoustic transducers (EMATs) have been used to generate multiple ultrasonic Lamb wave modes for the characterization of texture in metal sheets. While this has been studied in many previous papers, a different approach to the analysis has been taken for this work. Since only three constants (W400, W420, and W440) define the elastic anisotropy in the most commonly used approximation, in previous work, these constants were evaluated using ultrasonic velocities measured typically at 0, 45 and 90 degrees with respect to the metal sheet. However, greater accuracy in calculating these ODCs values can potentially be obtained by fitting the theoretical angular dependent velocity to the experimental data. It is then possible to extract the ODCs and obtain some degree of confidence in the values from the correlation of the fit. This process will use the Stationary wavelet transform (SWT) as a convenient and accurate technique for extracting the required data from selected Lamb wave modes, so that this approach can be implemented conveniently in the presence of multiple Lamb modes.

Measuring the Residual Stress Field Based on Ultrasonic Wave

---Qinxue Pan, Wenjun Chang, Chenguang Xu, Dingguo Xiao, and Xiangchen Yang, Beijing Institute of Technology, Key Laboratory of Fundamental Science for Advanced Machining, School of Mechanical Engineering, 5 South Zhongguancun Street, Haidian District, Beijing, 100081, China (PRC)

Residual stress takes a great effect on security and service life of components occurred interior and exterior of material, such as destructive, consuming time, inaccuracy. The traditional residual stress measurement methods cannot afford the demands of safety monitor and life extendibility of the components. In this paper, we proposed a new method of measuring the residual stress field based on ultrasonic wave. It is very important for guiding components usage to measure the distribution of the residual stress nondestructively and quantitatively. The critical refracted longitudinal (LCR) wave method is studied for inspecting the residual stress and also we developed an ultrasonic residual stress measuring system based on the LCR wave. The residual stresses inspecting is according to the effect of stresses on the propagation velocity of elastic waves. The LCR wave mode was employed and accurate travel time data were measured for plate of steel. The results of experiments indicated that the active LCR wave will effectively interact with the internal stress within a defined depth range and generate a measurable change on the travel time. As an advanced technology, the technique used ultrasonic to measure the residual stress has developed quickly recently by reason of its unique advantage.
Third Order Elastic Constants and Rayleigh Wave Dispersion of Shot-Peened Aero-Engine Materials
---Marek Rjelka, Martin Barth, Sven Reinert, and **Bernd Koehler**, Fraunhofer IZFP-D, Dep. Micro and Nano Evaluation, 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 Ti6246. Additionally, they are surface treated by shot-peening. This introduces compressive residual stress to minimize the material’s sensitivity to fatigue or stress corrosion failure mechanisms, resulting in improved performance and increased lifetime of components. Besides that, 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. It was shown that the surface treatment of aero engine alloys can be characterized by broadband Rayleigh wave dispersion but the relative contributions of compressive stress and cold work remained an open point. The present paper presents measurements of the second and third order elastic constants (TOEC) of IN718 and Ti6246. From that the Acousto Elastic Constants for Rayleigh waves are calculated and compared with previous measurements. By that the stress contribution to the surface wave dispersion can be estimated.

Characterization of ASTM F 136, Ti-Al-V Alloy to Enhance Its Biological Performance Using Nondestructive Tools
---Shaily M. Bholā¹, Rahul Bholā²*, Brajendra Mishra³, and **David L. Olson**⁴, ¹Department of Nuclear Engineering and Radiological Sciences; ²Department of Biologic & Material Sciences, School of Dentistry, University of Michigan, Ann Arbor, MI 48109; ³⁴Department of Metallurgical and Materials Engineering, Colorado School of Mines, CO 80401

---Ti6Al4V titanium alloy has been characterized for its prospective applications as an implant material. The surface treatments performed have brought about enhanced surface properties of these alloys and have produced corrosion resistant oxide films with increased bioactive properties. Characterization of the alloy surface using electrochemical impedance (EIS) has revealed the presence of a duplex oxide structure over the surface treated specimens, composed of an inner barrier layer and an outer porous layer. The inner barrier layer has imparted a high corrosion resistance to the alloy while the outer porous layer which is responsible for the increased roughness of the surface treated alloy specimens, has encouraged formation and deposition of apatite into the oxide pores and further resulted in an increase in cell adhesion over the alloy surface. Anodization and heat treatment procedures have proved advantageous to titanium alloys in terms of producing oxide films that can offer these alloys an improved biological performance.
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University of Vermont, Burlington, Vermont  
July 17 – July 22, 2011

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