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

July 25-30, 2004

PROGRAM

Monday, July 26, 2004

PLENARY SESSION 1
OVERVIEW OF ARRAY TECHNOLOGY
R. B. Thompson, Chairperson
Bunker Auditorium
Green Center

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

9:15 AM **Sonar Arrays and Array Processing**
---**A. B. Baggeroer**, Massachusetts Institute of Technology, Ford Professor of Engineering, Secretary of the Navy/Chief of Naval Operations, Chair for Ocean Science, Departments of Ocean and Electrical Engineering, Room 5-204, Cambridge, MA 02139

10:10 AM ***Coffee Break***

PLENARY SESSION 2
NEW NDE TECHNOLOGIES
D. E. Chimenti, Chairperson
Bunker Auditorium
Green Center

10:30 AM **Wireless Nano- and Micro-Sensors, MEMS for Health Monitoring of Engineering Structures and Neurological Disorders in Humans: Can We Get Smarter?**
---**V. K. Varadan**, University Distinguished Professor of Engineering Science, Electrical Engineering and Neurosurgery, Penn State College of Engineering and Medicine, Director, Center for Engineering of Electronic and Acoustic Materials and Devices, Pennsylvania State University, University Park, PA 16802

11:20 AM **Imaging with Terahertz Waves**
---**D. Mittleman**, Rice University, ECE Department, MS-366, 6100 Main Street, Houston, TX 77005

12:10 PM ***Lunch***

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

Sonar Arrays and Array Processing

---**A. B. Baggeroer**, Massachusetts Institute of Technology, Ford Professor of Engineering, Secretary of the Navy/Chief of Naval Operations, Chair for Ocean Science, Departments of Ocean and Electrical Engineering, Room 5-204, Cambridge, MA 02139

---Arrays of hydrophones have been part of Navy sonar systems for over fifty years now. They are used both passively and actively and now are quite sophisticated. These arrays were used in fixed configuration such as the SOSUS system and towed arrays deployed from surface ships and submarines. One can assert that these arrays were a key factor in winning the cold war. Similarly, medical ultrasonics have used many of the techniques initially developed for sonar systems save four orders of magnitude in frequency. The major area where modern sonars differ involves the use of adaptive array processing whereby one usually needs to localize a weak signal in the presence of strong interference in a nonstationary environment. Most of the recent literature concerns advancing these techniques especially making them more robust to environmental uncertainties including calibration and properties of the ocean. This presentation will give an overview of the state of the art in sonar and some parts aspects of medical ultrasonics and hopefully establish a few points of relevance with nondestructive testing.

Wireless Nano- and Micro-Sensors, MEMS for Health Monitoring of Engineering Structures and Neurological Disorders in Humans: Can We Get Smarter?

---**Vijay K. Varadan**, University Distinguished Professor of Engineering Science, Electrical Engineering and Neurosurgery, Penn State College of Engineering and Medicine, Director, Center for Engineering of Electronic and Acoustic Materials and Devices, Pennsylvania State University, University Park, PA 16802

---The term 'health monitoring' is used commonly in both medical and engineering fields. With the recent developments in Nanotechnology, MEMS, wireless technology and suitable integration packaging, one could find a technology that is useful for both in medicine and engineering. Such an integration of MEMS, IDTs (interdigital transducers) and required microelectronics and conformal antennas to realize programmable, robust and low cost microsensors and systems suitable for monitoring and control of neurological disorders in human and health monitoring of many engineering structures and systems including aircraft, missiles and munitions will be presented in this paper. Recently, the microstereo lithography revolutionizes the MEMS industry through multifunctional polymeric materials incorporating carbon nanotubes and organic thin film transistor resulting in 3D MEMS. With the emerging wireless technology, these sensors could be read wireless by Palm Pilot, Laptop computer, cell phone, and GPS. In this talk, the development of such a class of NEMS and MEMS-IDT based devices and associated wireless communication systems and their applications in health monitoring of engineering structures and neurological disorders will be presented. A sensor-in-shoe demonstration will be performed at the talk and a movie on neurosurgical implant for monitoring and control of neurological disorder will be presented.

Imaging with Terahertz Waves

---**Daniel Mittleman**, Rice University, ECE Department, MS-366, 6100 Main Street, Houston, TX 77005

---Traditionally, the region of the electromagnetic spectrum between 100 gigahertz and 10 terahertz (corresponding to the wavelength range 30 microns – 3 mm) has been among the least explored, due in part to the difficulties associated with efficient generation and detection of the radiation. However, the recent development of a number of new experimental techniques has sparked a growing interest in the use of terahertz radiation for imaging and spectroscopy. This talk presents an overview of this rapidly developing field, and a description of a few of the unique imaging capabilities of the “T-ray” imaging system. For example, by combining interferometry with the coherent detection capability of time-domain spectroscopy, it is possible to form time-of-flight images with a depth resolution well below the limit imposed by the coherence length of the radiation. Terahertz technologies provide many exciting new opportunities for non-destructive evaluation.

SESSION 3

ELASTIC AND THERMOELASTIC WAVES – PROPAGATION AND SCATTERING

P. Zinin, Chairperson

Parker Ballroom B

1:30 PM **Application of a Modular Multi-Gaussian Beam Model to Some NDE Problems**
---**H. Jeong** and M.-C. Park, Wonkwang University, Division of Mechanical and Automobile Engineering, 344-2 Sinyong-dong, Iksan, Jeonbuk 570-749, South Korea; L. W. Schmerr, Jr., Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

1:50 PM **Semi-Analytical Analysis of the High Frequency Near-Field Radiating by an Angle Beam Rectangular Ultrasonic Transducer into Elastic Half-Space**
---**D. D. Zakharov** and L. J. Fradkin, FESBE, London South Bank University, London, United Kingdom

2:10 PM **Ultrasonic Modeling in the Near Field**
---**L. Fradkin**, Faculty of Engineering, Science and Technology, London South Bank University, London, United Kingdom

2:30 PM **Simultaneous Calculation of Bulk and Surface Transient Waves Radiated by Water-Coupled Ultrasonic Transducers**
---N. Leymarie, **A. Lhémery**, and P. Calmon, Commissariat a l'Energie Atomique, LIST, Gif-sur-Yvette, France; R. Coulette, SNECMA Moteurs, Evry, France

2:50 PM **Ultrasound Focusing by a Single Planar Fracture**
---L. J. Pyrak-Nolte and **D. D. Nolte**, Physics Department, Purdue University, West Lafayette, IN 47907-2036

3:10 PM ***Coffee Break***

3:30 PM **Looking for Multiple Scattering Effects in Backscattered Ultrasonic Grain Noise from Jet-Engine Nickel Alloys**
---**P. Haldipur**, F. J. Margetan, and R. B. Thompson, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

3:50 PM **Modelling Scatter from 2D Interfacial Cracks**
---A. Gautesen, Department of Mathematics and Ames Laboratory, Iowa State University, Ames, IA 50011; **V. Kubzin** and L. Fradkin, Faculty of Engineering, Science, and Technology, London South Bank University, London, United Kingdom

4:10 PM **Nonlinear Scattering by a Partially Closed Surface-Breaking Crack**
---**M. Poznic** and C. Pecorari, Marcus Wallenberg Laboratory, Royal Institute of Technology, Stockholm, Sweden

4:30 PM **Numerical Models of Ultrasonic Backscatter Response in Polycrystals**
---**G. Ghoshal** and J. A. Turner, Department of Engineering Mechanics, University of Nebraska-Lincoln, Lincoln, NE 68588-0526

4:50 PM **Thermoelastic Waves in an Anisotropic Infinite Plate**
---**H. M. Al-Qahtani** and S. K. Datta, Department of Mechanical Engineering, 427 UCB, University of Colorado, Boulder, CO 80309-0427

Application of a Modular Multi-Gaussian Beam Model to Some NDE Problems

---**Hyunjo Jeong** and Moon-Cheol Park, Wonkwang University, Division of Mechanical and Automobile Engineering, 344-2 Sinyong-dong, Iksan, Jeonbuk 570-749, South Korea; Lester W. Schmerr, Jr., Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50010

---A modular Gaussian beam model provides an efficient formulation for modeling the wave fields of ultrasonic transducers in complex testing configurations. By the superposition of 10 to 15 Gaussian beams, one can model the corresponding wave fields of a planar or focused piston source. In this work, we describe a highly modular multi-Gaussian beam model to simulate some NDE problems. The resulting expressions given in a modular matrix form is implemented in a personal computer using MATLAB. The considered problems include flaw scattering and propagation in both isotropic and general anisotropic media. The modular Gaussian beam model combined with measurement and scattering models allows us to predict the ultrasonic response from various defects such as circular crack, side-drilled hole and vertical crack. The modular Gaussian approach is also described for propagating a Gaussian beam in a multilayered medium where layers are either isotropic or anisotropic. Simulation results are presented for these problems and compared with available experimental results.

Semi-Analytical Analysis of the High Frequency Near-Field Radiating by an Angle Beam Rectangular Ultrasonic Transducer Into Elastic Half-Space

---**D. D. Zakharov** and L. Ju. Fradkin, FESBE, London South Bank University, London, United Kingdom

---The two-tier asymptotic approach is used for simulating the transient wave field of a rectangular angled-beam ultrasonic transducer directly coupled to a homogeneous and isotropic elastic solid. The near field asymptotics of the time-harmonic displacements are found using the uniform stationary phase method. All the geometrical effects (main beam, edge and corner waves) and the penumbral boundary layers are described. The closed form solution is derived and simplified to present the results via elementary and well-known special functions. The transient field - the pulse train - is found by harmonic synthesis. It is shown that the angled beam leads to a ray geometry dramatically different to that of the normal beam. Results elucidate the physics of the problem by allowing to identify various pulse arrivals and give explicit dependence of the radiated waves on model parameters. The approach allows to produce a code for simulating action of the angled-beam transducer, which is thousands of times faster than any direct numerical code, but is practically just as accurate.

Ultrasonic Modelling in The Near Field
---**Larissa Fradkin,** Faculty of Engineering, Science and Technology, London South Bank University, London, United Kingdom

---In nuclear industry many inspection arrangements involve the near field of both the probe and defect. For several years now our group has been advocating the high-frequency asymptotic approach to modelling the near field radiation, scatter and reception. This involves using various versions of the GTD (The Geometrical Theory of Diffraction), which can be justified by applying the Uniform Stationary Phase Method to the asymptotic evaluation of the Rayleigh integrals over the face of the probe and defect. The resulting semi-analytical codes are thousands of times faster than the direct numerical codes - when the latter exist - and within their limits of applicability are just as accurate. In this talk we will present further validation of our approach by comparing outputs of ours and various direct numerical codes.

Simultaneous Calculation of Bulk and Surface Transient Waves Radiated By Water-Coupled Ultrasonic Transducers
---Nicolas Leymarie, **Alain Lhémery**, and Pierre Calmon, Commissariat à l'Energie Atomique, LIST, Gif-sur-Yvette, France; Richard Coulette, SNECMA Moteurs, Evry, France

---The model developed at the French Atomic Energy Commission in the CIVA software for computing wavefields radiated into parts by an arbitrary ultrasonic transducer has been presented in this series over the past years, each year new capabilities being developed to handle more complex configurations. The model is based on the so-called pencil method, a high frequency theory that has been proved to accurately predict ultrasonic fields radiated in both canonical configurations and complicated ones (complex material and geometry). Until now, the model was limited to configurations of bulk wave generation into the part. Here, model capabilities are extended to deal with configurations in which surface wave generation is involved, typically to configurations designed to mainly generate surface waves. For this, the pencil method is adapted theoretically to deal with pencils of surface waves propagating along the part surface and possibly leaking energy by radiating bulk waves, under a description compatible with the formulation developed for bulk waves. The theoretical model is then validated by comparing results of Rayleigh wave generation it can predict to available exact solutions. Finally, computations of wavefields involving both bulk and surface waves are shown to illustrate capabilities of the model and its associated software.

Ultrasound Focusing by a Single Planar Fracture

---Laura J. Pyrak-Nolte and **David D. Nolte,** Physics Department, Purdue University, West Lafayette, IN 47907-2036

---We demonstrate that a single plane fracture under an axially symmetric stress distribution, in an otherwise isotropic homogeneous medium, behaves as an acoustic lens that focuses ultrasound energy to a beam waist at a focal plane. This lensing behavior occurs from both phase and amplitude effects. Radial gradients in the fracture specific stiffness produce a radially varying group time delay which causes the wave to refract. One interesting outcome of this effect is an apparent violation of Snell's Law (but not Fermat's Principle) in which a wave incident normally on the fracture refracts into a finite angle after transmission. The radial gradient in fracture specific stiffness also results in a fracture transmission amplitude that approximates a Fresnel zone plate. Acoustic imaging experiments were performed to confirm this focussing effect of an axially symmetric stress distribution on wave propagation across a single planar fracture in aluminum. This work demonstrates that a two-dimensional planar fracture can focus ultrasound waves, possibly affecting the interpretation of QNDE data from fractured media with heterogeneous stress.

Looking for Multiple Scattering Effects in Backscattered Ultrasonic Grain Noise from Jet-Engine Nickel Alloys

---**Pranaam Haldipur**, F. J. Margetan, and R. B. Thompson, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---For pulse/echo inspections of metals, models which predict backscattered noise characteristics often make a “single-scattering” assumption, i.e., multiple-scattering events in which sound is scattered from one grain to another before returning to the transducer are ignored. Models based on the single-scattering assumption have proven to be very useful in simulating inspections of aircraft engine-alloy billets and forgings. However, this assumption may not be accurate if grain scattering is too “strong” (e.g., if the mean grain diameter or inspection frequency is too large). If multiple scattering effects are significant, they are expected to alter the shapes of the grain-noise-versus-depth curves. The shapes of the curves are influenced by the average grain diameter and their elastic anisotropy, the inspection frequency, and the degree of beam focusing. To gain a better understanding of these influences, a series of single-scattering noise model calculations were carried out to simulate inspections of pure-Ni microstructures having various average grain diameters. The model simulations treat both focused and planar transducer inspections, and assume broadband sound pulses with various center frequencies. Backscattered noise data from specimens cut from Ni-alloy billets are then examined. The specimens have approximately equiaxed microstructures and span a range of mean grain diameters. Measured and predicted grain-noise-versus-depth curves for these specimens are then compared to search for differences that may signal multiple scattering.---This material is based upon work supported by the Federal Aviation Administration under Contract #DTFA03-98-D-00008, Delivery Order #IA029 and performed at Iowa State University's Center for NDE as part of the Engine Titanium Consortium program, through the Airworthiness Assurance Center of Excellence.

Modelling Scatter From 2D Interfacial Cracks
---Arthur Gautesen, Department of Mathematics and Ames Laboratory, Iowa State University, Ames, IA 50011; **Victoria Kubzin** and Larissa Fradkin, Faculty of Engineering, Science and Build Inviroment, London South Bank University, London, United Kingdom

---Interfacial cracks are ubiquitous in industrial components and modelling their interaction with ultrasonic fields is an outstanding problem in NDE. In this report we address one of the relevant canonical problems, that of diffraction by a 2D semi-infinite crack sandwiched in-between two different isotropic half-planes. We assume that the crack is interrogated by a plane ultrasonic wave. Over the years purely numerical approaches to this kind of problem based on finite differences, finite elements or boundary integral technique proved unreliable, probably because they do not easily allow the practitioners to take into account the tip condition that renders solution unique. In this report we use several mathematical ideas that have been developed by the first author over the past thirty years in his quest to find a reliable semi-analytical approach to the wedge diffraction problems. We show that similarly to others, the problem at hand can be reduced to a system of regular integral equations, easily solvable with standard collocation techniques.

Nonlinear Scattering By A Partially Closed Surface-Breaking Crack
---**Milan Poznic** and Claudio Pecorari, Marcus Wallenberg Laboratory, Royal Institute of Technology, Stockholm, Sweden

---A theoretical model describing the nonlinear scattering of acoustic waves by surface-breaking cracks with faces in partial contact is presented. The nonlinear properties of the crack are accounted for by suitable boundary conditions which are derived from micromechanical models of the dynamics of elastic rough surfaces in contact. Both linear and nonlinear response of the crack are shown to be largest for a shear vertical (SV) wave incident on the surface containing the crack at an angle just above the critical angle for longitudinal waves. These findings question the fitness-for-purpose of a conventional inspection method, which utilizes SV waves at 45 degrees of incidence to search for surface-breaking cracks in many engineering components. For angles of incidence proximal to the critical angle of longitudinal waves the efficiency of the second harmonic's generation appears to be the highest. Thanks to the increased sensitivity to surface-breaking cracks, this configuration seems to offer a solution to the localization problem, a task that has eluded nonlinear techniques operating under other circumstances. Finally, this model suggests a simple interpretation of the highly localized nonlinear response of delaminations in composite materials.

Numerical Models of Ultrasonic Backscatter Response in Polycrystals

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

---The scattering of elastic waves in polycrystalline materials is relevant for ultrasonic materials characterization and nondestructive evaluation (NDE). Ultrasonic backscatter is used widely to extract the microstructural parameters such as grain size and also to detect flaws in materials. Accurate interpretation of experimental data requires robust scattering models. Such models typically assume constant density, uniform grain size and ergodicity hypotheses. The accuracy and limits of applicability of these models cannot be fully tested with experiments due to practical limits of real material processing. Here, this problem is examined in terms of numerical simulations using Voronoi polycrystals that are discretized using finite elements. Wave propagation is studied by integrating the system directly in time using a plane-strain formulation. Voronoi crystals with cubic symmetry and random orientations are used, making the bulk material statistically isotropic. Example numerical results for materials with various degrees of scattering and grain distribution that are of common interest are presented. The numerical results are presented and compared with backscatter theories, in terms of the Figure of Merit (FOM), which characterizes the scattering from the microstructure. These results are anticipated to impact ultrasonic NDE of polycrystalline media.---Work supported by DOE.

Thermoelastic Waves in an Anisotropic Infinite Plate

---**Hussain M. Al-Qahtani** and Subhendu K. Datta, Department of Mechanical Engineering, 427 UCB, University of Colorado, Boulder, CO 80309-0427

---The study of the influence of the temperature of an elastic solid upon the distribution of stress and strain, and of the inverse effect of the deformation upon the temperature distribution is the subject of the theory of thermoelasticity. An analysis of the propagation of thermoelastic waves in a homogenous, anisotropic, thermally conducting plate has been presented in the context of the generalized (L-S) theory of thermoelasticity. Three different methods are used in this analysis: two of them are exact and the third is a semi-analytic finite element method (SAFE). In our exact analysis, two different approaches are used. The first one, which is applicable to transversely isotropic plate, is based on introducing displacement potential functions, whereas in the second approach, which is applicable to any triclinic material, we rewrite the governing equations and boundary conditions in a matrix form. Finally, in the SAFE method, the plate is discretized along its thickness using N parallel, homogeneous layers, which are perfectly bonded together. Frequency spectrum and dispersion curves are obtained using the three methods and are shown to agree well with each other. The effects of thermal relaxation time and coupling term are also investigated. Finally, transient response to laser pulse is investigated. Numerical calculations have been presented for a silicon nitride (Si_3N_4) plate. However, the methods can be used for other materials as well.

SESSION 4
COMPOSITES AND FABRICATED MATERIALS
C.-H. Yang, Chairperson
Parker Ballroom A

1:30 PM **Ultrasonic Field Computation into Multilayered Composite Materials Using a Homogenization Method Based on Ray Theory**
---**S. Deydier**, N. Gengembre, and P. Calmon, CEA/LIST, CEA-Saclay, Bat. 611, 91191 Gif-sur-Yvette, France; V. Mengeling and O. Petillon, EADS/CCR, BP 76, 12 Rue Pasteur, 92152 Suresnes, Cedex, France

1:50 PM **Ultrasonic Ply-by-Ply Detection of Matrix Cracks in Composite Laminates**
---**V. K. Kinra** and A. S. Ganpatye, Dept. Aero. Eng., Texas A&M University, MS-3141, College Station, TX 77843-3141

2:10 PM **Experimental Assessment of Induced Damage for a Graphite-Epoxy Composite Using Ultrasonic Techniques**
---**B. R. Nadler**, J. R. Wait, and C. R. Farrar, Weapon Response Group, Engineering Sciences and Applications, Los Alamos National Laboratory, MS T006, Los Alamos, NM 87545; T. N. Claytor, Applied Eng. Technologies Group, Los Alamos National Laboratory, Los Alamos, NM 87545

2:30 PM **Measurement of Angle-Dependent Ultrasonic Backscatter from Textile Composites**
---**P. H. Johnston**, NASA Langley Research Center, 3 East Taylor Street, MS 231, Hampton, VA 23681

2:50 PM **Nondestructive Evaluation of Composites Using Micro-Focused X-Ray CT Scanner**
---**S. Sugimoto**, T. Aoki, Y. Iwahori, and T. Ishikawa, Advanced Composite Evaluation Technology Center, Institute of Space Technology and Aeronautics, Japan Aerospace Exploration Agency, Mitaka, Tokyo, Japan

3:10 PM ***Coffee Break***

3:30 PM **Experimental Approach on the Behavior of Composite Laminated Shell Under Transverse Impact Loading**
---Y. N. Kim[1], **K. H. Im**[2], K. S. Lee[3], Y. J. Cho[3], S. H. Kim[3], and I. Y. Yang[4], [1]Chosun University, Department of Mechanical Design Engineering, 375 Seosuk-dong, Dong-gu, Kwangju, 501-759, Korea; [2]Woosuk University, Department of Automotive Engineering, Wanju-gun, Chonbuk, 565-701, Korea; [3]Chosun University, Dept. Mech. Design Eng., Graduate School, 375 Seosuk-dong, Dong-gu, Kwangju, 501-759, Korea; [4]Chosun University, Department of Mechanical Design Engineering, 375 Seosuk-dong, Dong-gu, Kwangju, 501-759, Korea

3:50 PM **Detection of Impact Damage on Space Shuttle Structures Using Acoustic Emission**
---**E. I. Madaras** and W. H. Prosser, NDE Sciences Branch, NASA Langley Research Center, Hampton, VA 23681; M. R. Gorman, Digital Wave Corporation, 11234A Caley Avenue, Englewood, CA 80111

4:10 PM **Evaluation of Degradation of Ceramic Fiber Mat by Acoustic Emission**
---**K. Ito** and M. Enoki, Department of Materials Engineering, Graduate School of Engineering, The University of Tokyo, Tokyo, Japan; H. Takahashi, Ibiden Co., Ltd., Ogaki, Gifu, Japan

4:30 PM **Iterative Simulation of Elastic Wave Scattering in Particle-Filled Materials**
---**T. E. Doyle**, Department of Physics, Utah State University, SER Building 250, 4415 Old Main Hill, Logan, UT 84322-4415

4:50 PM **An Experimental Study of Lamb and Horizontal Shear Mode Sensitivity to Flaws in Multilayered Structures**
---**M. J. Quarry**, Manufacturing and Materials Department, Lawrence Livermore National Laboratory, Livermore, CA 94550

Ultrasonic Field Computation Into Multilayered Composite Materials Using A Homogenization Method Based on Ray Theory

---**Sébastien Deydier**, Nicolas Gengembre, and Pierre Calmon, CEA / LIST, CEA-Saclay, Bât 611, 91191 Gif-sur-Yvette, France; Vanessa Mengeling and Odile Petillon, EADS / CCR, BP76, 12 rue Pasteur, 92152 Suresnes cedex, France

---The simulation of ultrasonic NDT of carbon-fiber-reinforced epoxy composites (CFRP) is an important challenge for the aircraft industry. In a previous communication, we proposed to evaluate the field radiated into such components by means of a homogenization method coupled to the pencil model implemented in CIVA software. Following the same goals, an improvement is proposed here, through the development of an original homogenization procedure based on ray theory. The components studied present a periodical stacking sequence (for instance a [(0/90/+45/-45)] pattern) with arbitrary ply ratios. The homogenization is based on the follow-up of the energy ray path inside each ply of the pattern, which gives access to an average energy direction. The relationship between phase and energy directions leads to the geometrical construction of the overall slowness surfaces. These surfaces describe an anisotropic homogeneous medium, characterizing the whole composite. An inverse method can then be applied to obtain the associated effective stiffness tensor. The benefits of this procedure are then shown through comparisons between fields computed into different media, either homogenized or not. Different homogenization methods are employed and compared to the present one. The results are also confronted with experiments.

Ultrasonic Ply-by-Ply Detection of Matrix Cracks in Composite Laminates

---**Vikram K. Kinra** and Atul S. Ganpatye, Department of Aerospace Engineering, Texas A&M University, MS-3141, College Station, TX 77843-3141

---Extensive use of laminated composites at cryogenic temperatures is envisaged in the next generation Reusable Launch Vehicles (RLVs). The RLVs will include light fuel tanks made up of graphite/epoxy laminates and will contain liquid hydrogen (LH2) propellant. These tanks undergo extensive thermo-mechanical loading leading to the formation of matrix cracks and delaminations. A build up of matrix cracks in the composite-wall may lead to the formation of a network of interconnected cracks through the thickness of the tank-wall and provide a path for hydrogen to leak to the outside, and ignite. Therefore the detection of matrix cracks with emphasis on their interconnectivity takes on an unprecedented significance. In this work, an ultrasonic technique for the ply-by-ply detection of matrix cracks in laminated composites is developed. Results are reported for eight-ply, quasi-isotropic, graphite/epoxy laminates having [90/45/0/-45]s lay-up. Matrix cracks in each of the plies of the laminated composites were detected even when there was a rather high density of cracks in all of the plies. The ultrasonic data were corroborated by comparing them with the corresponding results obtained by using the traditional methods of optical microscopy and X-radiography, and an excellent quantitative correlation was observed between the two.

Experimental Assessment of Induced Damage for a Graphite-Epoxy Composite Using Ultrasonic Techniques
---**Brett R. Nadler**, Jeannette R. Wait, and Charles R. Farrar, Weapon Response Group, Engineering Sciences and Applications, Los Alamos National Laboratory, MS T006, Los Alamos, NM 87545; Thomas N. Claytor, Applied Engineering Technologies Group, Los Alamos National Laboratory, Los Alamos, NM 87545

---Understanding the material interaction in fatigue-induced damage has become paramount because of the widespread use of composite materials in structural systems. In this experimental study, a pulse-echo ultrasonic system is employed to detect invisible flaws in a composite plate. Two damage scenarios, high-speed projectiles and quasi-static loading, are used to seed damage in the form of delamination and fiber breakage. Baseline C-scan methods are utilized in time of flight and amplitude based imaging prior to damage initiation. Instrumented graphite epoxy plates are then impacted with steel projectiles accelerated through a gas gun to fractional ballistic velocities. Post event scans permit the identification of specific inter-ply failures and the boundaries of delamination. The composite plate is loaded under a displacement regulated three-point bending to grow the region of delamination. Results from waveform analyses and amplitude flaw detections are compared in order to observe damage growth for future monitoring and predictive models.

Measurement of Angle-Dependent Ultrasonic Backscatter from Textile Composites
---**Patrick H. Johnston**, NASA Langley Research Center, 3 East Taylor Street, Mail Stop 231, Hampton, VA, 23681

---Fiber reinforced composite materials are widely used in aerospace and other areas of applications. Recently, progress has been made in fabrication methods using resin infiltration of dry fiber textile-based preforms. Ranging from stacks of simple two-dimensional weaving to complex three-dimensional braided and knitted fabrics, the textile fiber architectures in these composite materials lead to new measurement challenges for ultrasonic NDE. The large degree of spatial variability of the highly anisotropic fiber breaks the usual assumptions allowing a one-dimensional interpretation of ultrasonic interrogations. The sound is scattered and refracted in complex ways which are difficult or impossible to interpret using standard ultrasonic probes. In this work, a long linear array is used to measure the spatial variation of scattered ultrasound arising from the fiber architecture in unidirectional and three-dimensional braided composite panels. It is speculated that the angular scattering signature can potentially be used as the basis for improved and more complete ultrasonics characterization of these types of composite materials.---This work was performed in part in the laboratories of R/D Tech, Quebec, QC, CA.

Nondestructive Evaluation of Composites Using Micro-Focused X-Ray CT Scanner

---**Sunao Sugimoto**, Takuya Aoki, Yutaka Iwahori, and Takashi Ishikawa, Advanced Composite Evaluation Technology Center, Institute of Space Technology and Aeronautics, Japan Aerospace Exploration Agency, Mitaka, Tokyo, Japan

---Micro-Focused X-Ray CT (Micro CT) Scanner has been used for nondestructive evaluation (NDE) of composite materials at Institute of Space Technology and Aeronautics, Japan Aerospace Exploration Agency. Some successful examples of NDE of composites using Micro CT will be presented in this presentation. One example is debonding of fiber/matrix interface, splitting of fiber bundle and matrix crack in carbon/carbon composite. Another example is NDE of stitched CFRP. It was easy to evaluate state of stitch fiber. It has been demonstrated that Micro CT is a powerful device for detecting small damage/flaw in composites, such as delamination, matrix crack and void.

Experimental Approach on the Behavior of Composite Laminated Shell Under Transverse Impact Loading

---Y. N. Kim[1], **K. H. Im**[2], K. S. Lee[3], Y. J. Cho[3], S. H. Kim[3], and I. Y. Yang[4], [1]Chosun University, Department of Mechanical Design Engineering, 375 Seosuk-dong, Dong-gu, Kwangju, 501-759, Korea; [2]Woosuk University, Department of Automotive Engineering, Wanju-gun, Chonbuk, 565-701, Korea; [3]Chosun University, Department of Mechanical Design Engineering, Graduate School, 375 Seosuk-dong, Dong-gu, Kwangju, 501-759, Korea; [4]Chosun University, Department of Mechanical Design Engineering, 375 Seosuk-dong, Dong-gu, Kwangju, 501-759, Korea

---Composites are considered for many structural applications structural weight. These materials have high strength-to-weight and stiffness-to-weight ratios. However, they are susceptible to impact loading because they are laminar systems with weak interfaces. Matrix cracking and delamination are the most common damage mechanisms of low velocity impact and are dependent on each other. This paper is to study the behavior of composite shell under transverse impact loading. In this study, carbon-epoxy composite laminates with various curvatures was used. Low velocity impact tests were performed using a drop weight testing machine. The 100mmx100mm shells were clamped in order to produce a central circular area (ϕ=80mm). An hemispherical impactor (m=0.1kg and ϕ=10mm) was used and the tests were done with velocities ranging from 2.8 to 4.8 m/s. The real curve force/time was registered in order to obtain the maximum contact force and contact time. And then, we know that contact force and delamination area of flat-plate is higher than cylindrical shell panel in the same kinetic energy level, and flat-plate is easily penetrated than cylindrical shell panel. And contact force, deflection and delamination area decrease as the curvature increase.

Detection of Impact Damage on Space Shuttle Structures Using Acoustic Emission

---**Eric I. Madaras** and William H. Prosser, Nondestructive Evaluation Sciences Branch, NASA Langley Research Center, Hampton, VA 23681; Michael R. Gorman, Digital Wave Corporation, 11234A Caley Ave, Englewood, CO 80111

---As a result of the loss of the Space Shuttle Columbia, which was caused by impact damage from foam debris shedding off the Shuttle's external tank during ascent, NASA started a comprehensive program to investigate the effect of various debris striking the Shuttle's thermal protection systems. One facet of this research was to study the feasibility of on-board impact detection technologies. AE sensing has been used to monitor a wide variety of impact conditions on Space Shuttle components. The impactors range from foam, ice and ablator materials at ascent velocities to simulated hypervelocity micrometeoroid and orbital debris impacts. Impact targets include reinforced carbon composite (RCC) leading edge materials, fiberglass mockups of the RCC, as well as Shuttle thermal tile materials on representative aluminum wing structures. Results from these impact tests will be presented with a focus on the acoustic emission sensor responses to these impact conditions. These tests have demonstrated the potential of employing an on-board Shuttle impact detection system.

Evaluation of Degradation of Ceramic Fiber Mat by Acoustic Emission

---**Kaita Ito** and Manabu Enoki, Department of Materials Engineering, Graduate School of Engineering, The University of Tokyo, Tokyo, Japan; Hidetomo Takahashi, Ibiden Co., Ltd., Ogaki, Gifu, Japan

---Alumina-silica fiber is widely used as insulator because its good performance of chemical and thermal stability under high temperature environment. Sealing mat of catalytic converter nearby car engine is one of these applications. However, this sealing mat degrades gradually during long-term use under pressure and high temperature, and it was reported that gripping force of mat was lost and converter was failed. In this study, compression stress and acoustic emission (AE) signals were monitored concurrently during cyclic compression tests at both room temperature and elevated temperature. Consequently, some of AE parameters gave useful information to evaluate compression and degradation behavior of fiber mat. RMS voltage of AE signals demonstrated a similar behavior to compression stress and large AE signals corresponding to fiber breakage diminish soon. This analysis enables to evaluate compression stress and degradation level of fiber mat. Furthermore, predict a residual lifetime and optimal compression condition.

Iterative Simulation of Elastic Wave Scattering in Particle-Filled Materials

---**Timothy E. Doyle**, Department of Physics, Utah State University, SER Building 250, 4415 Old Main Hill, Logan, UT 84322-4415

---Predicting the propagation behavior of elastic waves in random particulate media is difficult due to multiple scattering between particles, mode conversion from scattering at particle surfaces, and the lack of periodicity in the microstructure. A numerical modeling approach was therefore developed to simulate the propagation of shear and longitudinal sound waves in arbitrary, dense dispersions of spherical particles. The scattering interactions were modeled with vector spherical wave functions and boundary condition solutions for each particle. Multiple scattering was simulated by translating the scattered wave fields from one particle to another with the use of translational addition theorems, summing the multiple-scattering contributions, and recalculating the scattering using an iterative method. The models can simulate 3D material microstructures with a variety of particle size distributions, compositions, and volume fractions. To test the models, spectra and wave field patterns were generated from both ordered and disordered microstructures containing up to several hundred particles. The models correctly predict wave propagation phenomena such as refractive focusing, mode conversion, and band gap phenomena. The convergence of the iterations ranges from excellent to fair, and is dependent on the field (longitudinal or shear), particle configuration, and elastic wave frequency.

An Experimental Study of Lamb and Horizontal Shear Mode Sensitivity to Flaws in Multilayered Structures

---**Michael J. Quarry**, Manufacturing and Materials Department, Lawrence Livermore National Laboratory, Livermore, CA 94550

---An experimental study was performed on multilayered structures consisting of metallic plates bonded with adhesives. The purpose of the study was to investigate the reflection of Lamb and horizontal shear plate modes to optimize sensitivity using a technique based on guided waves. Notches of various depths and cross-sections were used to simulate cracks in multilayered structures. Cross-sections were reduced for notches of lesser depth to simulate a possible crack at various stages. Flaws were placed in the bottom layer of a three-layer structure to quantify guided wave capabilities for inspecting the bottom layer of a multilayer structure. A piezoelectric array was used to generate Lamb modes, while an electromagnetic acoustic array (EMAT) was utilized to generate horizontal shear. Experimental reflection coefficients were normalized with end of plate echoes to provide a basis for comparing amplitudes between two different sources.

SESSION 5

NDE FOR INFRASTRUCTURE AND ENVIRONMENT

S.-J. Song, Chairperson
Parker Ballroom C

1:30 PM **Experimental Study of Elastic Waves in Concrete for NDE in Civil Engineering**
---**B. Koehler** and F. Schubert, Branch Lab Dresden, Fraunhofer IZFP, Dresden, Germany; D. Algernon, A. Gardai, F. Milenz and M. Krause, Federal Institute for Materials Research and Testing, Berlin, Germany

1:50 PM **Towards Large-Scale, Nondestructive Inspection of Concrete Bridges**
---A.-R. Mahmoud, A. H. Shah, and **N. Popplewell**, University of Manitoba, Mechanical and Industrial Engineering Department, Winnipeg, R3T 5V6, Canada

2:10 PM **The Use of Magnetoresistors for Imaging Steel Bars in Concrete**
---**V. Torres**, P. Gaydecki, G. Miller, B. Fernandes, and M. Zaid, Department of Instrumentation and Analytical Science, UMIST, P. O. Box 88, Manchester M60 1QD, United Kingdom

2:30 PM **Elastic Wave Propagation in Concrete and Continuous Wavelet Transform**
---**C.-H. Chiang,** Chaoyang University of Technology, Department of Construction Engineering, Gifeng E. Road, No. 168, Wufeng, Taichung 413, Taiwan, China

2:50 PM **Automatic Detection of Subsurface Defects in FRP Bridge Decks Using Infrared Thermography**
---**G. M. Lonkar** and P. Klinkhachorn, Lane Dept. of Computer Science and Electrical Engineering, West Virginia University, Morgantown, WV 26506-6109; U. B. Halabe and H. V. GangaRao, Dept. of Civil and Environmental Engineering, West Virginia University, Morgantown, WV 26506-6103

3:10 PM ***Coffee Break***

3:30 PM **Detecting Juvenile Wood in Southern Pine Lumber by Measuring Phase Shift**
---**P. Steele**, J. Cooper, and B. Mitchell, Department of Forest Products, Forest and Wildlife Research Center, Mississippi State University, Box 9820, Mississippi State, MS 39762

3:50 PM **Detection of Wetwood in Lumber by Ultrasonic Measurement**
---**M. F. Kabir**, Virginia Tech, Dept. of Wood Science and Forest Products, Blacksburg, VA 24060; T. D. Leininger, USDA Forest Service, Southern Research Station, Stonville, MS 38776; P. A. Araman, USDA Forest Service, Southern Research Station, Brooks Forest Products Center, 1650 Ramble Road, Blacksburg, VA 24061

4:10 PM **A Study on Ultrasonic Evaluation of Material Homogeneity in Wood**
---**K.-H. Im**[1], D. K. Hsu[2], S.-K. Kim[3], S.-J. Song[4], H. Cho[4], J.-W. Park[5], J.-K. Sim[5], and I.-Y. Yang[5], [1]Woosuk University, Dept. of Automotive Engineering, Wanju-kun, Chonbuk, 565-701, Korea; [2]Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011; [3]Iksan National College, Dept. of Automobile Engineering, 194-5 Ma-dong, Iksan, Chonbuk, 570-752, Korea; [4]Sungkyunkwan University, School of Mechanical Engineering, Kyonggi-do, 440-746, Korea; [5]Chosun University, College of Engineering, 375 Seosuk-dong, Dong-gu, Kwangju 501-759, Korea

4:30 PM **Characterization of Unburned Carbon Content in Coal Fly Ash with Dielectric Constant Measurement**
---**K. Chan**[1]**,** R. J. Weber[1], and R. C. Brown[2], [1]Department of Electrical and Computer Engineering, [2]Center for Sustainable Environmental Technologies, Iowa State University, Ames, IA 50011

4:50 PM **Acoustic Emission for Diagnosing the Incipient Generation of Flaws Within Solid Materials, The Natural Environment, and Manmade Structures**
---S. Guarniere, A. Bottari, A. Marino, and A. Teramo, Osservatorio Sismologico, Di.C.T.A. Universita di Messina, via Osservatorio 4, 98121 Messinga, Italy; G. P. Gregori and **G. Paparo**, Istituto di Acustica O. M. Corbino (CNR), via Fosso del Cavvaliere 100, 00133, Roma, Italy

Experimental Study of Elastic Waves in Concrete for NDE in Civil Engineering
---**Bernd Koehler** and Frank Schubert, Branch Lab Dresden, Fraunhofer IZFP, Dresden, Germany; D. Algernon, Andre Gardai, Frank Milenz, and Martin Krause, Federal Institute for Materials Research and Testing, Berlin, Germany

---The propagation of elastic waves in solids and their interaction with inhomogeneities like flaws can be studied by numerical modelling. For that, precise material parameters (elastic constants, density), parameters of the component geometry and of the flaw geometry are necessary. There are a lot of situations where these parameters are not known and cannot be gained easily. Especially challenging is the situation when interfaces are not known precisely concerning to their elastic behavior but play a significant role with respect to wave propagation. That is the case for concrete. Here, detailed experimental study of the wave propagation can be very helpful, to clarify the situation. A technique to visualize the propagation of elastic waves using a scanning Laser vibrometer was developed. It is now applied to the strong heterogeneous material concrete. After a short introduction to the method various examples of visualizations are given which include: the vibration of the exciting transducer displayed over the transducer interface, the sound fields of a single transducer visualized along a sidewall of concrete and the wave fields generated by impact excitation. High resolved measurements of ultrasonic waves travelling along a cross section of a sample allow visualizing the scattering process explicitly. This reveals the influence of interfaces between aggregates and cement matrix, which are not perfect in each case.

Towards Large-Scale, Nondestructive Inspection of Concrete Bridges
---Abdel-Rahman Mahmoud, Arvind H. Shah, and **Neil Popplewell**, University of Manitoba, Mechanical and Industrial Engineering Department, Winnipeg MB R3T 5V6, Canada

---It is estimated that the rehabilitation of deteriorating engineering infrastructure in the harsh North American environment could cost billions of dollars. Bridges are key infrastructure components for surface transportation. Steel-free and fiber-reinforced concrete is used increasingly nowadays to circumvent the vulnerability of steel rebar to corrosion. Existing steel-free and fiber-reinforced bridges may experience extensive surface-breaking cracks that need to be characterized without incurring further damage. In the current study, a non-destructive testing procedure is assessed that characterizes, on a large scale, damage in bridges having such concrete. The procedure is based on the idea of fixing a receiving transducer, then using a hammer to transiently excite the bridge in the vicinity of the transducer. The procedure is practical since it requires access to only the top surface of the bridge. It also minimizes the time the bridge would be closed to traffic as the hammer can be relocated faster than the transducer. Moreover, the procedure is made even more effective by reducing the number of receiving locations through maximizing the transducer-hammer separation. A specially designed spring-loaded hammer overcomes the inherent attenuation of concrete and allows a maximum separation of at least two meters. A portion of a one-third model of a bridge was used to conduct a feasibility assessment after the model was loaded and damaged. The good correlation between the power spectra of the signals received from several points and cut-outs from the model shows that defects can indeed be revealed. Automation of the technique will further enhance its applicability to real-life rather than laboratory situations.

The Use of Magnetoresistors For Imaging Steel Bars in Concrete

---**Vladimir Torres**, Patrick Gaydecki, Graham Miller, Bosco Fernandes, and Muhammad Zaid, Department of Instrumentation and Analytical Science, UMIST, P.O. Box 88, Manchester M60 1QD, United Kingdom

---This paper reports on the design of a new system for the detection and imaging of steel bars in concrete. It is based on the magnetoresistive effect, whereby the resistance of a material changes due to the presence of a magnetic field. An important advantage of using such sensors is related to the well defined axis of sensitivity which improves the detection of small changes on the magnetic field in a particular direction. Furthermore, its resolution, high sensitivity and excellent repeatability make the entire design a robust detection system. The complete system is divided into three stages. The first stage comprises the design of a stable and temperature compensated coil working in the linear region of detection of the magnetoresistive sensor. The second stage takes advantage of the ability of the magnetoresistive sensor to realign the material and eliminates the effect of past magnetic history. Here, a circuit for setting and resetting the sensor using a microcontroller is implemented. This restores the sensor's sensitivity and improves the overall response of the combined system. The last stage is the collection and evaluation of data where the results are compared with an inductive Q-detection sensor highlighting its advantages and recommendations for further developments.

Elastic Wave Propagation in Concrete and Continuous Wavelet Transform

---**Chih-Hung Chiang**, Chaoyang University of Technology, Department of Construction Engineering, Gifeng E. Road, No. 168, Wufeng, Taichung 413, Taiwan, China (ROC)

---Elastic wave methods, such as the ultrasonic pulse velocity and the impact echo, are often subject to multiple reflections at the boundaries of various constituents of concrete. Current study aims to improve the feature identification of elastic wave propagation due to buried objects in concrete slabs and cylinders. Embedded steel reinforcement, steel and PVC tubes, wooden disks, and rubber spheres are tested. Numerical simulations are carried out based on models constructed using the finite element method. The received signals, both experimental and simulated, are analyzed using both fast Fourier transform and continuous wavelet transform. The amplitude spectra can only provide global information and lose some important local effects of frequency components. Continuous wavelet transform, on other hand, preserves the transient effects in the frequency domain. As a result, signals are decomposed into distinctive frequency bands. The interpretation of multiple reflections at different boundary conditions then becomes more straightforward. Features related to reflections from steel bar, PVC tube and steel tube are readily identified in the magnitude plot of wavelet coefficients. Vibration modes of the concrete slab corresponding to different buried objects can also be separated based on corresponding time duration.

Automatic Detection of Subsurface Defects in FRP Bridge Decks Using Infrared Thermography

---**Gajanan M. Lonkar** and Powsiri Klinkhachorn, Lane Department of Computer Science and Electrical Engineering, West Virginia University, Morgantown, WV 26506-6109; Udaya B. Halabe and Hota V. GangaRao, Department of Civil and Environmental Engineering, West Virginia University, Morgantown, WV 26506-6103

---In this paper we substantiate an automatic defect detection technique to detect subsurface anomalies in fiber reinforced polymer (FRP) bridge decks. Defects can be of two types viz. delaminations or debonds. Conventional bridge deck inspection techniques involve analysis of the infrared image of the bridge deck by inspectors, which makes the process less reliable. Instead, software algorithms can be used to detect these defects automatically, thus eliminating human intervention. Also automated algorithms provide a cost efficient way to process large values of data. In the tests conducted, simulated subsurface defects of varying size, thickness and wearing surfaces were fabricated in the laboratory. Thermal images for these defects were captured using an infrared camera. These image sequences were then converted to a standard image format. A software algorithm was developed using image processing techniques, to analyze the images for detecting the defects automatically. This paper outlines the algorithm that is based on morphological transformations, and discusses its performance under various test conditions. A parallel algorithm using fuzzy clustering principle was also developed. The tests include a performance analysis of detecting delaminations and debonds, and the effect of distance on the detecting ability of the algorithm. The algorithm was also tested under solar radiation, to test the response under a passive heat source. The study showed that IRT can be effectively used to detect subsurface defects and the process can be automated with substantial accuracy. The study showed that debonds can be detected with ease in comparison to delaminations. It also characterized the effect of parameters such as depth from the surface, area of the defect, distance of the infrared camera, environmental conditions etc. on the accuracy of the defects detected.

Detecting Juvenile Wood in Southern Pine Lumber by Measuring Phase Shift

---**Philip Steele**, Jerome Cooper, and Brian Mitchell, Department of Forest Products, Forest and Wildlife Research Center, Mississippi State University, Box 9820, Mississippi State, MS 39762

---Fast-grown southern pine plantations are rapidly increasing their relative percentage of total southern forest acreage by replacing slower-grown natural stands. Young pine stems produce a wood type termed juvenile wood that exhibits extreme longitudinal shrinkage, resulting in a high degree of warp in lumber. Faster-grown plantation pine stems produce a much higher volume of juvenile wood than do slower-grown naturally regenerated stems. Identification of juvenile wood in green lumber following sawing would allow for segregation of juvenile wood from mature wood and application of special drying procedures to reduce warp. A non-contact dielectric means to detect juvenile wood by analysis of the real and imaginary components of an applied sinusoidal signal has been tested. A sinusoidal signal is applied via adjacent electrodes. Frequency of the applied signal as well as the moisture content and density of juvenile wood as compared to mature wood appear to be factors allowing for identification.

Detection of Wetwood in Lumber by Ultrasonic Measurement

---**Mohammed Firoz Kabir**, Virginia Tech, Department of Wood Science and Forest Products, Blacksburg, VA 24060; Theodor D. Leininger, USDA Forest Service, Southern Research Station, Stonville, MS 38776; Philip A. Araman, USDA Forest Service, Southern Research Station, Brooks Forest Products Center, 1650 Ramble Road, Blacksburg, VA 24061

---Wetwood or bacterially infected wood is a severe processing problem for the lumber industry. It causes serious drying defects such as excessive and deep surface checking, honeycomb, collapse and ring separation. The detection of wetwood is therefore, important for proper processing and quality wood products. An investigation has been carried out to detect wetwood in wood of cherry (*Prunus serotina*), oak (*Quercus rubra, L.*), hickory (*Carya cordiformis*), and cottonwood (*Populus deltoids*) using ultrasound signal. Samples were collected from several sawmills/landowners from Stonville, Mississippi. The ultrasound measurements were carried out at different moisture content in three different grain directions-longitudinal, radial, and tangential. Each ultrasonic waveform was characterized using eight ultrasonic variables-three involving time of flight, two involving ultrasound pulse energy, one using ultrasound pulse duration, and peak frequency. Linear positive correlations were found for most of the time of flight (TOF) with moisture content (MC). A significant strong correlation was found for TOF-energy. Wetwood exhibited higher MC than healthy wood for all species and higher specific gravity for hickory species. Results also showed that wetwood has higher TOF and greater loss of energy compare to healthy wood. This study suggested that wetwood in living trees as well as in lumber can be identified using ultrasound based system.

A Study on Ultrasonic Evaluation of Material Homogeneity in Wood

---**Kwang-Hee Im**[1], David K. Hsu[2], Sun-Kyu Kim[3], Sung-Jin Song[4], Hyeon Cho[4], Je-Woung Park[5], Jae-Ki Sim[5], and In-Young Yang[5], [1]Woosuk University, Department of Automotive Engineering, Wanju-kun, Chonbuk, 565-701, Korea; [2]Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011; [3]Iksan National College, Department of Automobile Engineering, 194-5 Ma-dong, Iksan, Chonbuk, 570-752, Korea; [4]Sungkyunkwan University, School of Mechanical Engineering, Kyonggi-do, 440-746, Korea; [5]Chosun University, College of Engineering, 375 Seosuk-dong, Dong-gu, Kwangju 501-759, Korea

---In this work, a wood has nondestructively been characterized and a technique has been developed to measure ultrasonic velocity using automated data acquisition software. It is desirable to perform nondestructive evaluation (NDE) to assess material properties and absorption content for wood because the wood is consisting of various contents. Several ultrasonic techniques were applied to wood for the evaluation of variations in material properties. The variations of ultrasonic velocity was measured and found to be consistent with the nonuniform content area in the course of nature absorption. Low frequency (1MHz) through-transmission scans based on both amplitude and time-of-flight of the ultrasonic pulse were used for mapping out the material property inhomogeneity. A technique has been developed to measure ultrasonic velocity using automated data acquisition software. These results were compared with those obtained by dry-coupling ultrasonics. A good correlation was found between ultrasonic velocity (a pulse overlap and gap method) and C-scan image signal based on peak-to-peak amplitude.

Characterization of Unburned Carbon Content in Coal Fly Ash with Dielectric Constant Measurement

---**Kingsang Chan**[1]**,** Robert J. Weber[1], and Robert C. Brown[2], [1]Department of Electrical and Computer Engineering, [2]Center for Sustainable Environmental Technologies, Iowa State University, Ames, IA 50011

---The research was to investigate the relationship between dielectric constant of fly ash and unburned carbon content in fly ash. Dielectric constant is a factor measures the ratio of the permittivity of dielectric material to the permittivity of free space (8.85 x 10-12 F/m). It describes the extent to which dielectric material interacts with electric flux. The dielectric constant of fly ash can be extracted from phase measurement with using a network analyzer and a fixture based on coaxial transmission line design. Unburned carbon in fly ash is a major index to determine the efficiency of coal combustion in a power plant. Loss-on-ignition (LOI) technique and thermogravimetric analysis (TGA) are among techniques being used in the industrial to determine unburned carbon content in fly ash. Measuring dielectric constant of fly ash approach is promising as an alternative non-destructive way to determine the amount of unburned carbon in fly ash. The Clausius-Mossotti relation is used to determine fly ash properties with available of dielectric constant and therefore determine the unburned carbon content. Initial experiment shows the unburned carbon content estimated from dielectric constant measurement correlates closely to the unburned carbon content measured with the LOI technique.

Acoustic Emission for Diagnosing the Incipient Generation of Flaws Within Solid Materials, The Natural Environment, and Manmade Structures

---Salvatore Guarniere, Antonio Bottari, Antonio Marino, and Anotnio Teramo, Osservatorio Sismologico, Di.C.T.A. Università di Messina, via Osservatorio 4, 98121 Messinga, Italy; Giovanni P. Gregori and **Gabriele Paparo**, Istituto di Acustica O. M. Corbino (CNR) – via Fosso del Cavvaliere 100, 00133 Roma, Italy

---Acoustic emission (AE) is an effective diagnostic tool for monitoring the initial stages of the strain of solid materials, within natural environment and manmade structures. Independent of AE intensity and damping, the AE pace characterizes the space distribution of AE sources. It is possible to test the hypotheses dealing with the prime mechanisms that lead to micro-flaws. This can be detected by a non-destructive method, in terms of passive observation. The detected time scale is much shorter than every other micro-deformation monitoring. The frequency sequence of the observed AE bursts denotes a process of coalescence of esser flaws into progressively larger ones. Applications deal with crustal stress propagation, seismic phenomena, and volcanoes, correlation with soil exhalation, metal fatigue, concrete ageing, conservation of the cultural heritage, laboratory investigations on concrete specimens of different composition, evaluation of the seismic vulnerability of reinforced concrete, etc.

SESSION 6
SIGNAL PROCESSING
R. Marklein, Chairperson
Parker Ballroom D/E

1:30 PM **A Wavelet Characterization of Levy Noise for NDE**
---A. Flenner and B. DeFacio, Physics and Astronomy, University of Missouri, Columbia, MO 65211

1:50 PM **Detection of Multiple Damages in Free-Free Beams Using Genetic Algorithms**
---S. Huo[1] and X. Xue[2], [1]Department of General Engineering, [2]Department of Mechanical & Industrial Engineering, University of Illinois at Urbana-Champaign, Urbana, IL 61801

2:10 PM **Maximum A Posteriori Defect Estimation and Detection Using Hidden Markov Models**
---A. Dogandzic and N. Eua-anant, Iowa State University, Center for NDE, Ames, IA 50011

2:30 PM **A Data Fusion Approach to Blind Deconvolution of Multi-Frequency Eddy Current Data**
---**M. Kumar** and P. Ramuhalli, Michigan State University, Nondestructive Evaluation Laboratory, Department of Electrical and Computer Engineering, 2120 Engineering Building, East Lansing, MI 48824

2:50 PM **Multiresolution Data Fusion Algorithms for Aerospace Applications**
---**M. Kumar** and P. Ramuhalli, Michigan State University, Department of Electrical and Computer Engineering, 2120 Engineering Building, East Lansing, MI 48824; Z. Liu, Institute for Aerospace Research, National Research Council Canada, Ottawa, Ontario, K1A 0R6, Canada

3:10 PM ***Coffee Break***

3:30 PM **Automated Algorithms for Eddy Current Array Probes for Steam Generator Inspection**
---N. Zavaljevski, **S. Bakhtiari**, A. Miron, D. S. Kupperman, T. Y. Wei, and P. V. Marchertas, Argonne National Laboratory, 9700 South Cass Avenue, Argonne, IL 60439

3:50 PM **Automatic Guided Waveform Multi-Mode Sorting**
---**M. K. Hinders**, J. Hou, and K. R. Leonard, Department of Applied Science, College of William & Mary, Williamsburg, VA 23187-8795

4:10 PM **Directional Filter Bank Technique for NDE Image Segmentation**
---G. Swamy, **K. Balasubramaniam**, and C. V. Krishnamurthy, Centre for Nondestructive Evaluation and Department of Mechanical Engineering, Indian Institute of Technology Madras, Chennai 600 036, India

4:30 PM **Air-Coupled Ultrasound Scanning Sensors for Mobile Robots**
---**M. K. Hinders** and W. Gao, College of William & Mary, Department of Applied Science, Williamsburg, VA 23187-8795

4:50 PM **Geometrical Recoveries and Positionings for Flaws of Infrastructures Using Electrical Potential Method**
---F. Kojima and **Y. Hirabayashi**, Graduate School of Technology, Kobe University, Kobe, Hyogo, Japan; H. Fujiwara, Sumitomo Metal Industries, Ltd., Amagasaki, Hyogo, Japan; T. Kitamura, Sumitomo Metal Industries, Ltd., Sakai, Osaka, Japan

A Wavelet Characterization of Levy Noise for NDE

---**Arjuna Flenner** and Brian DeFacio, Physics and Astronomy, University of Missouri, Columbia, MO 65211

---Levy processes are stationary random processes with independent increments, and they generalize the concept of Brownian motion to random processes with jumps. A Levy process has a countable number of jumps, discontinuities of the random process, and the time and the size of the jump is determined by an underlying Poisson process. Wavelet analysis is well suited to detect the location of discontinuities, and is a popular technique used to remove noise in many NDE problems including, but not limited to, ultrasound signal detection and the removal of machine sound. After locating the jumps in time using the continuous wavelet transform and determining the size of the jumps, then it is possible to understand the Poisson process that characterizes the Levy process. To investigate this idea, stable Levy processes were simulated and the exponent that identifies the process was identified using the information gained from the continuous Wavelet transform. Simple applications to ultrasound NDE are presented.

Detection of Multiple Damages in Free-Free Beams Using Genetic Algorithms

---**Shihong Huo**[1] and Xiaojie Xue[2], [1]Department of General Engineering, [2]Department of Mechanical & Industrial Engineering, University of Illinois at Urbana-Champaign, Urbana, IL 61801

---The detection and identification of a structural damage play a key role in the monitoring and servicing of a structural system. How to locate and configure the damages is a very difficult issue. This paper seeks to apply a real-coded genetic algorithm to the damage detection problem by minimizing the objective function, which directly compares the changes of vibration data before and after damage. The mass less springs were used to represent the open cracks in the analytical modal of the cracked beam. Natural frequency changes and mode shape changes were considered for updating the analytical mode. A thorough explanation on how to find the mutation rates, crossover rate, population size, and weight of the vibration data was presented.

Maximum A Posteriori Defect Estimation and Detection Using Hidden Markov Models

---**Aleksandar Dogandzic** and Nawanat Eua-anant, Center for NDE, Iowa State University, Ames, IA 50011

---We derive a maximum a posteriori (MAP) method for estimating and detecting NDE defect signals using hidden Markov models (HMMs). In the proposed HMM framework, a set of spatially distributed NDE measurements is assumed to form a noisy realization of an underlying random field that has a simple structure with Markovian dependence. (Due to the Markovian assumption, the random field at a particular measurement location is modeled in terms of the field values at neighboring spatial locations.) Here, the random field describes the defect signals to be estimated or detected. The proposed methodology incorporates the measurement locations into the statistical analysis, which is important in the scenario where the same defect affects the measurements at multiple locations. We present several data and Markov random field (MRF) models and propose estimation, detection, classification, and calibration algorithms. We apply the proposed methodology to simulated eddy-current data and experimental ultrasonic C-scan data from an inspection of a cylindrical Ti 6-4 billet. In the ultrasonic data case, the proposed method is utilized to remove false alarms in a likelihood-ratio based detection scheme.---This work was supported by the NSF Industry-University Cooperative Research Program, Center for Nondestructive Evaluation (CNDE), Iowa State University.

A Data Fusion Approach to Blind Deconvolution of Multi-Frequency Eddy Current Data

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

---Multifrequency eddy current inspection is commonly used in the nondestructive evaluation of steam generator tubing in nuclear power plants. C-scan data is typically obtained from either rotating probes or array probes, which are analyzed to determine the flaw shape and size. A major problem in eddy current inspection is a “smearing” of the flaw image due to the finite size of the probes used in the inspection. This blurring results in inaccurate estimation of the surface dimension or footprint of the flaw. Thus, there is a need for compensation algorithms that can compensate for the blurring caused by finite probe sizes. Eddy current C-scan images can be modeled as a convolution of the true surface dimensions of the flaw with a kernel that is derived from the probe footprint. Therefore, the application of deconvolution algorithms can result in accurate characterization of the flaw. Since the form of the kernel is unknown in eddy current inspection, conventional deconvolution algorithms such as the Wiener filter are impractical, and blind deconvolution techniques are required. Single frequency blind deconvolution techniques are insufficient to correctly determine the true flaw footprint since single frequency eddy current inspection does not provide sufficient information about a flaw. Therefore, this paper proposes a blind deconvolution algorithm that fuses information present in multifrequency eddy current inspection. The algorithm, based on the widely used Richardson-Lucy blind deconvolution approach, uses complementary information present in the measurements of the defects at multiple frequencies to enhance the deconvolution result. The paper will present results of applying the proposed multifrequency deconvolution algorithm on eddy current data obtained from the inspection of steam generator tubing. In addition, the robustness of the proposed algorithm in the presence of noise will be evaluated.

Multiresolution Data Fusion Algorithms for Aerospace Applications

---**Mrityunay Kumar** and Pradeep Ramuhalli, Michigan State University, Department of Electrical and Computer Engineering, 2120 Engineering Building, East Lansing, MI 48824; Zheng Liu, Institute for Aerospace Research, National Research Council Canada, Ottawa, Ontario, K1A 0R6, Canada

---Detection of corrosion in ageing aircraft lap joints is a major challenge for the aviation industry. Generally a single inspection mechanism is used to test the sample and the amount of corrosion or remaining wall thickness is determined using calibration methods. However, these techniques are inadequate for determining corrosion in 2nd or 3rd layers and data fusion techniques that combine information from multiple measurements can potentially enhance corrosion prediction. This paper proposes the use of a multi-stage multiresolution data fusion algorithm for enhancing the accuracy of wall-thickness prediction. The first stage in this algorithm uses a multiresolution approach for fusing data from multiple measurements. The use of undecimated wavelet transform is investigated in this paper for multiresolution data fusion. The undecimated discrete wavelet transform is an efficient approach to fusion, as it is shift invariant and gives better frequency resolution than the decimated discrete wavelet transform. Fusion is achieved by selecting wavelet coefficients from the different measurements according to suitable selection criteria. The second and final stage in this process is the estimation of remaining wall-thickness and the use of neural networks to map fused data to a thickness value is proposed. The proposed algorithm was applied to fusing multi-frequency eddy current and pulsed eddy current measurements of aircraft lap joints from a service-retired airplane. The data was provided by the Institute for Aerospace Research, NRC Canada. Thickness in the 1st and 2nd layer were estimated and results indicate the superior performance of the proposed approach, when compared to both calibration approaches as well as neural network-based data fusion algorithms.

Automated Algorithms for Eddy Current Array Probes for Steam Generator Inspection

---Nela Zavaljevski, **Sasan Bakhtiari**, Adrian Miron, David S. Kupperman, Thomas Y. Wei, and Paul V. Marchertas, Argonne National Laboratory, 9700 South Cass Avenue, Argonne, IL 60439

---A newly designed eddy current array probe, X-probe, has recently been introduced to the nuclear industry for inspection of steam generator tubes. This probe has the potential of significantly shortening inspection schedules and reducing inspection costs. However, the quantity of the data acquired cannot be efficiently analyzed at present. This has prompted development of automatic analysis algorithms. We describe the Automated Nondestructive Testing Array Evaluation System (ANTARES), a software package developed at Argonne National Laboratory to detect and characterize steam generator tubing degradation from data acquired by eddy current array probes. The package consists of four modules: data preprocessing, defect detection, defect characterization, and tube burst pressure estimation. The focus of this paper is on the algorithms for defect detection and characterization. The defect detection module is based on the Sequential Probability Ratio Test (SPRT) and image processing algorithms. SPRT is a statistical hypothesis test that examines one observation at a time and at some point makes a decision and selects a hypothesis. Normal signal behavior (background) is the null hypothesis. The alternative hypothesis corresponds to the defect signal. The defect map for each test frequency is formed as a union of defects. This leads to false alarms, which are reduced by morphological imaging operations. The alarm map is used to mask the regions with defects. The background is extended over the boundaries using interpolation methods. This final background image is subtracted from the original image and used in characterization stage. At each frequency, nonlinear regression is performed between the amplitude and the phase of the defects in the training set and their maximum depth. The maximum depth for a new defect is determined using the regression parameters, the estimated amplitude and phase at selected frequencies, and a set of heuristic rules.

Automatic Guided Waveform Multi-Mode Sorting

---**Mark K. Hinders**, Jidong Hou, and Kevin R. Leonard, Department of Applied Science, College of William & Mary, Williamsburg, VA 23187-8795

---In many guided-wave ultrasonic applications it's impractical to generate a single isolated mode. Accurately identifying several guided wave modes can allow their varying senstivities to different types of flaws to be used to improve the measurement. Mode conversion at flaws and overlapping of modes often frustrates automated guided wave signal interpretation algorithms. The Dynamic Wavelet Fingerprint (DWFP) technique has the ability to extract arrival times for guided waveforms containing several modes. However, destructive interference between two modes may cause one of the modes to seemingly disappear in the signal. Because the DWFP algorithm assumes that the modes remain in the same arrival order throughout the scan, this causes an arrival time that belongs in the second or third mode series to appear in the first or second mode series respectively. The goal of the sorting algorithm presented in this work is to counteract this by using multiple frequency scans -- also known as frequency walking -- to sort the arrival times into their correct mode series. Thus enabling more accurate and clearer reconstructions from multiple modes.

Directional Filter Bank Technique for NDE Image Segmentation

---Gokul Swamy, **Krishnan Balasubramaniam**, and C. V. Krishnamurthy, Centre for Nondestructive Evaluation and Department of Mechanical Engineering,Indian Institute of Technology Madras, Chennai 600 036, India

---This paper introduces a Directional Filter Bank (DFB) for segmentation of C-Scan images from fiber-reinforced composites. The DFB is a two-channel decomposition employing the Quincunx sampling matrix and the Diamond Half Band filter pair. The design of analysis and synthesis filters satisfying the alias free reconstruction property is discussed. The incident ultrasonic field on a fiber-reinforced composite is backscattered by the fibers leading to the appearance of a characteristic pattern (oriented along the fiber direction) in the C-Scan image. The fiber pattern can cloud the defects, such as delaminations etc, thus making their detection difficult. The DFB is a sub-band coding technique that has been applied to segment the fiber pattern from the defect features in the C-Scan image of the composite. Additionally, images from Magnetic Flux Leakage, Shearography and Eddy Current inspections were also used to demonstrate the technique.
---This work has been funded by the US Air-Force Research Laboratory through UTC, Dayton, OH.

Air-Coupled Ultrasound Scanning Sensors for Mobile Robots

---**Mark K. Hinders** and Wen Gao, College of William and Mary, Department of Applied Science, Williamsburg, VA 23187-8795

---The goal of our work is to automate the fusion and interpretation of multiple sensor data streams to enable autonomous mobile robot operation in a wide variety of unstructured outdoor environments. Multiple sensing modalities make the narrow-AI scene interpretation algorithms robust enough for many real-world applications. Combining complimentary active and passive imaging systems provides unique challenges but this approach has the greatest potential for significant payoff. For many mobile robotics applications passive imaging via visible-light and infra-red cameras, along with active imaging via air-coupled ultrasound (usually called sonar) is the most appropriate combination given the length scales involved. We describe here a method to automatically distinguish trees from round metal poles by a 50kHz sonar scanning system packaged as a sensor head on a mobile robot. A 5th order polynomial interpolation of the square root of the backscattered sonar signal energy vs. scan angle is first plotted. Asymmetry and fitting error are then extracted from each scan across the object, giving a single point in an abstract phase space. In this phase space round metal poles are nearer to the origin than are trees, which scatter the sonar more irregularly due to lobulations and/or surface roughness of the bark. Results are shown for 20 trees and 10 metal poles scanned about our campus.

Geometrical Recoveries and Positionings for Flaws of Infrastructures using Electrical Potential Method

---Fumio Kojima and **Yoshitaka Hirabayashi**, Graduate School of Science and Technology, Kobe University, Kobe, Hyogo Japan; Hirotsugu Fujiwara, Sumitomo Metal Industries,Ltd., Amagasaki, Hyogo, Japan; Takeshi Kitamura, Sumitomo Metal Industries,Ltd., Sakai, Osaka, Japan

---This paper is concerned with a computational method for estimating exact positioning and sizing of defects in infrastructures. Suitable maintenance of infrastructures is an important issue for their safety operations. Our concern in this issue is directed to the use of electrical potential method. There have been crucial practical problems for detecting adjacent defects separately. In this paper, we propose a computational method for recovering and positioning adjacent cracks inside material systems. Based on finite element method related to electrical potential problem, the inverse analysis for the problem has been developed. To this end, the proposed algorithms are composed of two steps. One step is to estimate the location of corrosion damages and the second step is to characterize their amplitudes. In step1, the matching technique is used for detecting number of corrosions. In step2, corrosion profiles can be identified by applying conventional least square error analysis. Quasi-Newton method is adopted for practical implementation of computational algorithm. The successive computational experiments will be summarized in the session.

SESSION 7

NONLINEAR ACOUSTICS

J. H. Cantrell and W. T. Yost, Co-Chairpersons
Parker Ballroom B

8:30 AM **Substructural Organization and Acoustic Harmonic Generation in Fatigued Wavy Slip Metals**
---**J. H. Cantrell**, 245 East Queens Drive, Williamsburg, VA 23185

8:50 AM **Investigation of Accumulated Fatigue Damage Using Nonlinear Acoustic Parameter Measurement in Nickel Base Super Alloy**
---E. Burke, **S. Sathish**, and N. Ashbaugh, University of Dayton Research Institute, 300 College Park, Dayton, OH 45469-0127

9:10 AM **Simulations of Microdamage Depth Profiling Using Nonlinear Rayleigh Wave Propagation in Media with Stratified Hysteretic Nonlinearity**
---**K. Van Den Abeele** and S. Vanaverbeke, Interdisciplinary Research Center, K. U. Leuven Campus Kortrijk (KULAK), Kortrijk, Belgium

9:30 AM **Experimental Detection of Structural Damage in Natural Building Stones Using Nonlinear Wave Modulation Spectroscopy**
---**N. Wilkie-Chancellier** and K. Van Den Abeele, Interdisciplinary Research Center, K. U. Leuven Campus Kortrijk (KULAK), Kortirijk, Belgium

9:50 AM **Probing Granular Media Via Nonlinear Acoustic Effects**
---V. Tournat[1], **V. Gusev[1]**, V. Zaitsev[2], V. Nazarov[2], and B. Castagnede[1], [1]Av. O. Messiaen, Université du Maine, Le Mans, Cedex 9, France; [2]Institute of Applied Physics, Russian Academy of Science, Russia

10:10 AM ***Coffee Break***

10:30 AM **Nonlinear Elastic Wave NDE I: Nonlinear Resonant Ultrasound Spectroscopy (NRUS) and Slow Dynamics Diagnostics (SDD)**
---**P. J. Johnson**, Los Alamos National Laboratory, Los Alamos, NM 87545; A. Sutin, Stevens Institute of Technology, Hoboken, NJ and Artann Laboratories, NJ 07030

10:50 AM **Nonlinear Elastic Wave II: Nonlinear Wave Modulation Spectroscopy (NWMS) and Nonlinear Time Reversed Acoustics (NTRA)**
---**A. M. Sutin**, Stevens Institute of Technology and Artann Laboratories, Hoboken, NJ 07030; P. J. Johnson, Los Alamos National Laboratory, NM 87545

11:10 AM **Nonlinear Modulated Angle Beam Ultrasonic Spectroscopy of Adhesive Bonds**
---S. I. Rokhlin and L. Wang, The Ohio State University, Edison Joining Technology Center, 1248 Arthur E. Adams Drive, Columbus, OH 43221; B. Xie, V. A. Yakovlev, and **L. Adler**, Adler Consultants, 1275 Kinnear Road, Columbus, OH 43212

11:30 AM **The Nonlinear Response of Elasto-Plastic Interfaces: A Comparison Between Theory and Experiments**
---**C. Pecorari** and M. Poznic, Marcus Wallenberg Laboratory, Royal Institute of Technology, Teknikringen 8, 100 44 Stockholm, Sweden

11:50 AM **Use of Capacitive Detection to Measure Harmonic Generation and the Nonlinearity Parameter in Liquids**
---**W. T. Yost**, Structures and Materials Competency, NASA Langley Research Center, Hampton, VA 23681-2199

12:10 PM ***Lunch***

Substructural Organization and Acoustic Harmonic Generation in Fatigued Wavy Slip Metals

---**John H. Cantrell**, 245 East Queens Drive, Williamsburg, VA 23185

---Organized substructural arrangements of dislocations sequentially formed in wavy slip metals during high cycle fatigue are shown analytically to generate a substantial acoustic harmonic signal from wave-substructure interactions. It is found that the acoustic nonlinearity parameter for a given fatigue state is highly sensitive to the volume fractions of veins and persistent slip bands (PSBs), PSB internal stresses, dislocation multipole configurations, dislocation loop lengths, dipole heights, and the densities of primary and secondary dislocations in the substructures. The effects of vacancy, microcrack, and macrocrack formation are also addressed. The model is applied to calculations of the nonlinearity parameter for fatigued polycrystalline nickel (for which substantial microstructural data are available) as a function of percent life to fracture. For cyclic stress-controlled loading at 241 MPa the model predicts a monotonic increase in the nonlinearity parameter of roughly 360 percent over the total fatigue life due to substructural evolution. An additional large, monotonic increase due to crack growth is predicted to occur late in the fatigue process - after approximately 90 percent total fatigue life. The results are in excellent agreement with experimental measurements of aluminum alloy 2024-T4, fatigued in an equivalent cyclic loading regime, after accounting for differences in the material constants.

Investigation of Accumulated Fatigue Damage Using Nonlinear Acoustic Parameter Measurement in Nickel Base Super Alloy

---Eric Burke, **Shamachary Sathish**, and Noel Ashbaugh, University of Dayton Research Institute, 300 College Park, Dayton, OH 45469-0127

---Nonlinear acoustic parameter measurement is a promising nondestructive tool for evaluation of accumulated fatigue damage. It has been demonstrated in a few materials like, aluminum (Al2024-T3), titanium alloy (Ti-6Al-4V) and stainless steel (410Cb). In an attempt to evaluate the effectiveness of the methodology for nickel base super alloy, measurement have been performed a using a capacitive detector before and after subjecting the samples to a fixed number of cyclic loading. The nonlinear acoustic parameter has been observed to increases with the number of fatigue cycles. In an effort to extend the methodology to predict the location of failure, measurements were performed across the length of the sample subjected to cyclic loading. Large increases in the nonlinear acoustic parameter have been observed in the middle of the gauge section. The results of the measurement are discussed to show applicability of the nonlinear acoustic method to evaluate the accumulated fatigue damage and to predict the possible location of failure.

Simulations of Microdamage Depth Profiling Using Nonlinear Rayleigh Wave Propagation in Media with Stratified Hysteretic Nonlinearity

---**Koen Van Den Abeele** and Sigfried Vanaverbeke, Interdisciplinary Research Center, K. U. Leuven Campus Kortrijk (KULAK), Kortrijk, Belgium

---Many historical monuments throughout Europe are suffering from severe microdamage spreading inwards from the stone surface and reaching several millimeters in depth. In this paper, we report on numerical experiments of Rayleigh wave propagation along the surface of a microcracked solid. At the microlevel, we simulate microcracks by trigger like elements with a two state nonlinear stress-strain relation. Applying a generalization of the Preisach-space model for multidimensional hysteretic elasticity, we then upscale the microscopic state relation on the mesoscopic level, and use a staggered grid formulation to predict the macroscopic response to an arbitrary excitation signal. Using this multiscale model, we investigated the influence of the degree of microdamage, the location and the extend of the damaged zone on the surface wave velocity and its response amplitude (linear technique), on the amplitude (nonlinear) dependence of the velocity, and on the generation of harmonics. We found that the nonlinear measures are far superior in assessing microdamage than the linear characteristics. We illustrate this with a comparison of the results for linear and nonlinear depth profiling techniques by evaluating the linear and nonlinear response for excitation signals at different frequencies in the case of a stratified medium with spatially varying hysteresis properties.

Experimental Detection of Structural Damage in Natural Building Stones Using Nonlinear Wave Modulation Spectroscopy

---**Nicolas Wilkie-Chancellier** and Koen Van Den Abeele, Interdisciplinary Research Center, K. U. Leuven Campus Kortrijk (KULAK), Kortirijk, Belgium

---Natural building stones in historical monuments are subject to aggressive environmental conditions which initiate microdamage at the outer stone surface. Till now, no adequate non-destructive technique has been proposed to quantify this type of deterioration in situ. Lately, it has been well illustrated that observations of acoustic nonlinearity may be used for the detection of structural microdamage. Nonlinear wave modulation spectroscopy is one of the methods in this class of dynamic nondestructive evaluation techniques. It consists of generating two signals of two separate frequencies in a sample, and inspecting the generation of sum and difference frequencies. This paper deals with experimental work, carried out in laboratory conditions on damaged and intact samples of natural building stones used in restoration projects throughout Europe. The samples are excited with a high frequency sinusoidal wave (order of 100 kHz). Intermodulation phenomena are created by the simultaneous generation of a low frequency signal (impact). Consistent observations were obtained on various samples and geometries: bars and blocks. Undamaged materials are essentially linear in their response to the two waves, while the same materials, when damaged, become highly nonlinear, manifested by sideband generation. This technique has a high potential to discern material damage in building stones.

Probing Granular Media Via Nonlinear Acoustic Effects

---V. Tournat[1] **Vitalyi Gusev[1]**, V. Zaitsev[2], V. Nazarov[2], and B. Castagnede[1], [1]Av. O. Messiaen, Université du Maine, Le Mans, Cedex 9, France; [2]Institute of Applied Physics, Russian Academy of Science, Russia

---Nonlinear acoustic experiments in unconsolidated granular packing are reported. Probing of a granular medium by a parametric emitting antenna is tested. Shear waves are used for this purpose. Nonlinear dilatancy is found, which produces conversion of high-frequency shear waves into low-frequency demodulated longitudinal waves and follows quadratic or Hertzian power law in pump wave amplitude. In the acoustic amplitude-range, the nonlinear term dominates and is not a correction to the conventionally considered linear dilatancy. Strong anisotropy of nonlinearity for shear waves with different polarizations is observed. Excitation of longitudinal acoustic wave at the second harmonic by sinusoidal shear acoustic wave in a granular materials is found. The amplitude of the second harmonic exhibits beatings which are observed not as a function of the distance from the emitter but with increasing amplitude of the primary wave. The effect is attributed to the role of the contribution of clapping inter-grain contacts to the total nonlinearity of the medium. This contribution, varying with increasing pump amplitude, modifies the effective length of the nonlinear interaction. Observation of subharmonics excitation and significant increase in noise level caused by propagation of the acoustic wave is reported. The bifurcation phenomenon, taking place above a critical level of acoustic excitation (and opening the subharmonic root to chaos) is attributed to the interaction of acoustic wave with distributed system of highly nonlinear inter-grain contacts. In the clapping (tapping) regime, each of these contacts individually is similar to an impact oscillator, for which the scenario of period doubling cascade and the transition to chaotic behavior has been predicted theoretically and observed experimentally earlier. The experiments confirm the nonlinear interactions of acoustic waves in granular assemblages are highly sensitive to the fraction of weakly loaded (and weakly “unloaded”) contacts. Evidence is given that a significant portion of weak contact forces is localized below 0.01 of the mean force – a range previously inaccessible by other experiments.

Nonlinear Elastic Wave NDE I. Nonlinear Resonant Ultrasound Spectroscopy (NRUS) and Slow Dynamics Diagnostics (SDD)

---**Paul J. Johnson,** Los Alamos National Laboratory, Los Alamos, NM 87545; Alexander Sutin Stevens Institute of Technology, Hoboken, NJ and Artann Laboratories, NJ

---Existing theoretical and experimental results applying nonlinear elastic wave techniques demonstrate that the detection of damage is extremely sensitive. The nonlinear elastic response of materials (e.g., generation of higher harmonics, amplitude-dependent resonance frequency shift, generation of sum- and difference-frequency signals from interacting waves at two different frequencies, and slow dynamical response), is much more sensitive to the presence of damage than the linear response such as the signal damping, sound speed variation, or impedance. An overview of the four primary nonlinear elastic wave methods used in damage detection are presented in this and the following paper. 1. Nonlinear Resonant Ultrasound Spectroscopy (NRUS) is based on measurement of the nonlinear response of one or more resonant modes in a test sample. Resonance frequency shift, together with wave damping in resonance, is analysed as a function of the peak strain amplitude; 2. Slow Dynamics Diagnostics (SDD) are manifest by an alteration in the material dissipation and elastic modulus after application of relatively high-amplitude wave that slowly recovers in time (103 - 104 seconds). The onset of slow dynamics in particular can be a powerful damage diagnostic. Slow dynamics was first observed in homogeneously nonlinear materials, such as - rock, concrete, sintered metals, that have a small volume of elastically soft constituents (bonds) distributed within a rigid matrix (e.g., grains in a rock). In contrast, in damaged materials slow dynamics are due to localized elastic features, e.g. a crack.

Nonlinear Modulated Angle Beam Ultrasonic Spectroscopy of Adhesive Bonds

---S. I. Rokhlin and L. Wang, The Ohio State University, Edison Joining Technology Center, 1248 Arthur E. Adams Dr., Columbus, OH 43221; B. Xie, V. A. Yakovlev, and **L. Adler,** Adler Consultants, 1275 Kinnear Road Columbus, OH 43212

---An experimental method incorporating high frequency pulsed angle beam ultrasonic measurements modulated by low frequency vibrations of a bonded structure is described. This method uses parametric/nonlinear mixing between high and low frequencies to characterize adhesive degradation. It is demonstrated that good quality (undamaged) bonds exhibit little dependence of ultrasonic signature on the overlay of low frequency vibration loads; however, environmentally degraded or imperfect bonds exhibit strong modulation of the resonance frequency of the ultrasonic signal reflected from the bond. The results are interpreted using a model for normal and oblique wave interaction with two nonlinear interfaces separated by an adhesive layer under quasi-static stress modulation.

The Nonlinear Response of Elasto-Plastic Interfaces: A Comparison Between Theory and Experiments

---**Claudio Pecorari** and Milan Poznic, Marcus Wallenberg Laboratory, Royal Institute of Technology, Teknikringen 8, 100 44 Stockholm, Sweden

---Theoretical models predict the nonlinear acoustic response of elastic interfaces formed by rough surfaces in contact to be largest when $K_N \cong \omega\rho V_T$. They also show the second harmonic component to be the dominant feature of the nonlinear signature of such interfaces. The generation of the second harmonic component due to a longitudinal wave incident on steel-steel and Plexiglas-Plexiglas interfaces with various degrees of roughness has been experimentally investigated as a function of the applied load. The results follow the trend predicted by the model, but systematically display the effect of plasticity. A model recently developed by Kim *et al*. for a linear elasto-plastic interface, has been extended to the case of a nonlinear interface. An improved agreement between theory and experiments is obtained, although the model appears to overestimate the amplitude of the second harmonic during unloading, particularly towards the end of the cycle. Of relevance for future applications to the NDE of imperfect interfaces and partially closed cracks is the measured magnitude of the second harmonic component generated by a steel-steel interface, which reaches values as high as 30 dB above the noise threshold, and continues to be measurable even at pressure levels as high as 200 MPa.

Use of Capacitive Detection to Measure Harmonic Generation and the Nonlinearity Parameter in Liquids

---**William T. Yost**, Structures and Materials Competency; NASA-Langley Research Center, Hampton, VA 23681-2199

---Capacitive detectors have been employed for some time for absolute measurement of particle displacement amplitudes in solids. The solid's surface has been used as one of the capacitor's plates, and a conductor riding within a few microns above the surface as the other plate. In this arrangement we place a conductive membrane in contact with the liquid and place the other electrode a few microns above the membrane. Using this device we have successfully measured the particle displacement amplitude of fundamental and harmonic waves in a liquid. Particle displacements in the picometer range have been successfully measured. Data for measurements of fundamental and harmonic waves generated in water are presented and analyzed. Corrections for the membrane and other effects related to measurements in liquids are presented. From these data the nonlinearity parameter is calculated and presented.

SESSION 8

MATERIAL PROPERTIES I

P. Panetta, Chairperson
Parker Ballroom A

8:30 AM **Influence of Spatial Correlation Function on Ultrasonic Attenuation and Backscatter**
---**J. A. Turner** and G. Ghoshal, University of Nebraska-Lincoln, Department of Engineering Mechanics, W317.4 NH, Lincoln, NE 68588-0526; P. Haldipur, F. J. Margetan, and R. B. Thompson, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

8:50 AM **Ultrasonic Attenuation in Zircaloy-4**
---M. P. Gómez, Departamento de Ingenieria Eléctrica, FRBA, Universidad Tecnológica Nacional, Buenos Aires (1179), Argentina; D. Banchik, Grupo LMFAE, Centro Atómico Ezeiza, Comisión Nacional de Energia Atómica, Buenos Aires, Argentina; J. E. Ruzzante, Grupo de Ondas Elásticas, UA ENDE, Centro Atómico Constituyentes, San Martin Buenos Aires, Argentina; **M. I. López Pumarega**, Grupo de Ondas Elasticas – UA ENDE, Centro Atómico Constituyentes, Comisión Nacional de Energia Atómica, San Martin, Buenos Aires, Argentina

9:10 AM **Internal Friction in a Diffuse Field Used as a Measure to Characterize Material Properties**
---**Pranaam Haldipur**[1], Dan Barnard[1], R. B. Thompson[1], Paul Panetta[2], [1]Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011; [2]Pacific Northwest National Laboratory, Richland, WA 99352

9:30 AM **A Formal Theory on the Backscattered Grain Noise Correlation**
---**R. B. Thompson**, L. Yu, and F. J. Margetan, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

9:50 AM **Aberrations in Polycrystalline Materials**
---**J. A. Hernandez**, M. Clark, S. D. Sharples, and M. G. Somekh, School of Electrical & Electronic Engineering, University of Nottingham, Nottingham, United Kingdom

10:10 AM ***Coffee Break***

10:30 AM **Nondestructive Characterization of Hydrogen Concentration in Zircalloy**
---**C.-H. Yang**, M.-F. Huang, and Y.-A. Lai, Department of Mechanical Engineering, Chang Gung University, Taoyuan, Taiwan, Republic of China

10:50 AM **Profiles of Material Properties in Induction-Hardened Steel Determined Through Inversion of Resonant Acoustic Measurements**
---**Ward L. Johnson** and Sudook A. Kim, National Institute of Standards and Technology, 325 Broadway, Boulder, CO 80305; Stephen J. Norton, Geophex, Ltd., 605 Mercury St., Raleigh, NC 27603

11:10 AM **A New Analysis of Minor Hysteresis Loops and QNDE**
---**S. Takahashi**, L. Zhang, Y. Kamada, H. Kikuchi, and K. Ara, Nondestructive Evaluation and Science Research Center, Faculty of Engineering, Iwate University, 4-3-5 Ueda, Morioka, Iwate 020-8551, Japan

11:30 AM **Texture Asymmetry in Cubic Sheet Metals**
---**M. D. G. Potter** and S. M. Dixon, Department of Physics, Warwick University, Coventry, United Kingdom; G. Kong and C. L. Davis, School of Metallurgy and Materials, The University of Birmingham, Birmingham, United Kingdom

11:50 AM **True-3D Strain Mapping for Assessment of Material Deformation by Synchrotron X-Ray Microtomography**
---**J. Ahn**, H. Toda, M. Ninomi, and T. Kobayashi, Department of Production Systems Engineering, Toyohashi University of Technology, Toyohashi, Aichii, 441-8580, Japan

12:10 PM ***Lunch***

Influence of Spatial Correlation Function on Ultrasonic Attenuation and Backscatter
---**Joseph A. Turner**, Goutam Ghoshal, University of Nebraska-Lincoln, Department of Engineering Mechanics, W317.4 NH, Lincoln, NE 68588-0526; Pranaam Haldipur, Frank J. Margetan, and R. Bruce Thompson, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---Ultrasonic measurements of quantities related to wave scattering, such as attenuation and backscatter, are regularly used on polycrystalline materials for microstructural characterization and flaw detection. Theoretical models of the scattering process require specification of the spatial correlation function of material properties. An exponential form for this function is often used for convenience although such a form may not always be the most appropriate. In this presentation, the influence of the form of the spatial correlation function is discussed with respect to ultrasonic attenuation and backscatter for incident longitudinal and shear waves. Several different functional forms are examined including an exponential form and a Percus-Yevick form. Other functions considered include those constructed from Voronoi polycrystal models with uniform and Poisson grain distributions and those measured from material micrographs. Theoretical values of attenuation as a function of frequency are compared with experimental results and with results from numerical models based on the Voronoi polycrystal. Results covering materials with differing degrees of scattering strength are examined as well. Implications for interpreting ultrasonic measurements are also discussed.---Work supported by DOE and the FAA through ETC.

Ultrasonic Attenuation in Zircaloy-4
---Martin P. Gómez, Departamento de Ingeniería Eléctrica, FRBA, Universidad Tecnológica Nacional, Buenos Aires (1179), Argentina; David Banchik, Grupo LMFAE, Cenro Atómico Ezeiza, Comisión Nacional de Energía Atómica, Buenos Aires, Argentina; José E. Ruzzante, Grupo de Ondas Elásticas, UA ENDE, Centro Atómico Constituyentes, San Martín Buenos Aires, Argentina; **Maria I. López Pumarega**, Grupo de Ondas Elasticas – UA ENDE – Centro Atómico Constituyentes – Comisión Nacional de Energía Atómica, San Martin, Buenos Aires, Argentina

---The aim of this work was to study the relationship between Zircaloy-4 grain size and ultrasonic attenuation for longitudinal waves. With this purpose, the attenuation was studied as a function of frequency. Five samples with different mechanical and heat treatments having large recrystallized and Widmanstatten structures with different grain size were made. The ultrasonic attenuation coefficient was measured in the pulse echo technique for longitudinal waves in the frequency range 10 MHz-90 MHz. The attenuation of a polycrystalline material in most cases is determined almost entirely by grain scattering. The attenuation behavior was analyzed by scattering models like Rayleigh, Stochastic or Difussion scattering, depending on grain size, wavelength and frequency. For Zircaloy-4, Rayleigh and Stochastic were the expected regimes in the studied range of frequency. Measured attenuation versus frequency points lie between Rayleigh and Stochastic regions for samples with high grain size, and in Stochastic region for samples with low grain size. It was found that the ultrasonic scatterer grains were domains, and not individual platelets, in the Widmanstatten structure.

Internal Friction in a Diffuse Field Used as a Measure to Characterize Material Properties

---**Pranaam Haldipur**[1], Dan Barnard[1], R. B. Thompson[1], Paul Panetta[2], [1]Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011; [2]Pacific Northwest National Laboratory, Richland, WA 99352

---Ultrasonic attenuation values of metals deduced using conventional pulse/echo methods contain contributions from both grain scattering and energy absorption (arising from internal friction). In contrast, diffuse field measurements are believed to be insensitive to scattering, and hence provide information on internal friction only. In this work several metal specimens are studied, some of which have attenuation values in good agreement with the predictions of grain-scattering models, and others which do not. The diffuse field decay rate of each specimen is measured, and used to deduce an attenuation value associated with energy absorption. We then compare attenuation values measured by the pulse/echo and diffuse field techniques to those predicted by scattering models, with the goal of establishing the extent to which energy absorption accounts for the difference.---This material is based upon work supported by the Federal Aviation Administration under Contract #DTFA03-98-D-00008, Delivery Order #IA029 and performed at Iowa State University's Center for NDE as part of the Engine Titanium Consortium program, through the Airworthiness Assurance Center of Excellence.

A Formal Theory for Correlations of Backscattered Ultrasonic Grain Noise

---**R. Bruce Thompson**, Linxiao Yu, and Frank J. Margetan, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---The correlation of backscattered grain noise has important implications in practical inspections. For example, the spatial correlation length (SCL) of the backscattered noise is a crucial quantity in designing advanced de-noising algorithm in imaging processing, and the temporal correlation length (TCL) of the grain noise is important to evaluate the distribution of the gated peak noise (GPN), which in turn is indispensable for the estimation of probability of detection (POD) or frequency of false calls. The grain noise correlations, both spatial and temporal, depend both on the microstructure and the beam pattern of the ultrasonic transducer. In this paper, existing backscattered grain noise theories will be extended to study these correlations, leading to a formal theory predicting both the SCL and TCL of the backscattered noise in terms of the microstructure and beam pattern. The results will be based on the assumption of single scattering and the Born approximation. Experimental measurements will be presented to verify the theory and numerical simulations will be used to provide insight into its predictions.---This material is based upon work supported by the Federal Aviation Administration under Contract #DTFA03-98-D-00008, Delivery Order #IA029 and performed at Iowa State University's Center for NDE as part of the Engine Titanium Consortium program, through the Airworthiness Assurance Center of Excellence.

Aberrations In Polycrystalline Materials

---**Jose A. Hernandez**, Matthew Clark, Steve D. Sharples, and Mike G. Somekh, School of Electrical & Electronic Engineering, University of Nottingham, Nottingham, United Kingdom

---Many common engineering materials contain a random microstructure (for instance grains in metals). This microstructure can have an adverse effect on ultrasonic measurements (reducing signal strength, increasing noise, reducing accuracy and probability of defect detection) through scattering and aberration of the acoustic field. In order to gain insight into the aberrating properties of stochastic materials we have developed a phase screen model alongside the stochastic wave equation for the random medium. These two models turn out to be physically equivalent and the statistics of the acoustic field are numerically compared. This two fold approach allows us to directly model the field and new techniques such as adaptive correction and to characterize the material from the statistical properties of experimental measurements. Currently the stochastic medium is modelled as a Gaussian random field which is delta-correlated in the direction of propagation. This leads to simple expressions for the spatial coherence function of the acoustic field in the stochastic medium. These expressions may be widely applicable for predicting the performance of ultrasonic systems in random materials. Experimental measurements on metals at high frequency taken with an optical scanning acoustic microscope show good agreement with the theory and model and demonstrate how material properties may be determined from the statistics of heavily aberrated measurements.

Nondestructive Characterization of Hydrogen Concentration in Zircalloy

---**Che-Hua Yang**, Ming-Fong Huang, and Yu-An Lai, Department of Mechanical Engineering, Chang Gung University, Taoyuan, Taiwan, ROC

---Zircaloy is commonly used as a cladding material in nuclear industry. While in the reactor service, the Zircalloy cladding can undergo considerable changes in mechanical properties. One of these changes is a loss of ductility. Neutron irradiation plays an important role in the deduction of ductility, and hydrogen uptake from the cladding waterside corrosion reaction play the second role. It is therefore an important task to characterize the hydrogen concentration (HC) of Zircaloy cladding materials during the course of reactor service. Currently, the characterization of the HC in Zircaloy cladding is achieved by off-line characterization techniques such as an inert-gas fusion, hot-vacuum extraction method, or quantitative metallographic analysis and other destructive techniques in laboratories. These techniques first suffer the drawbacks of destructive operation for cladding materials and require substantial sampling efforts, and therefore are time-consuming and costly. Poolside nondestructive evaluation (NDE) technique offers a potential alternative for the characterization of HC in the cladding materials. In this research, two ultrasound-based NDE techniques are reported for the characterization of HC in Zircalloy cladding. The first technique is a low-frequency acoustic microscope with a PVDF/LFB transducer, and the second technique is a laser ultrasound technique. These two techniques are applied for the characterization of HC in Zircaloy tubes with HC ranging from 0 to 1200 ppm. Measured dispersion curves for the guided modes propagating along the axial direction of claddings are used to characterize the HC. It is shown that the influences on the dispersion spectra due to a change of HC are well characterized by the 2 NDE techniques.

Profiles of Material Properties in Induction-Hardened Steel Determined Through Inversion of Resonant Acoustic Measurements

---**Ward L. Johnson** and Sudook A. Kim, National Institute of Standards and Technology, 325 Broadway, Boulder, CO 80305; Stephen J. Norton, Geophex, Ltd., 605 Mercury St., Raleigh, NC 27603

---Noncontacting electromagnetic-acoustic resonance is used to measure the shifts in resonant axial-shear frequencies of induction-hardened automotive half-shafts relative to an unhardened shaft having the same geometry. Spatial profiles of the shear constants and densities are determined under the assumption of specific forms of the radial dependence using an inversion algorithm that employs a perturbation expression for the relative frequency changes. Parameters determined with the inverse calculations are compared with measurements of hardness determined by indentation and with measurements of elastic constants performed on sections of specimens using conventional resonant ultrasound spectroscopy. The results suggest that two physical effects with different radial profiles contribute to variations in elastic constants and densities. The depths and widths of the radial transitions arising from one of these effects closely approximate those of the hardness profiles. Therefore, this contribution appears to be associated with the variation in microstructure of the material. The other contribution is consistent with the expected effect of residual stress.

A New Analysis of Minor Hysteresis Loops and QNDE

---**Seiki Takahashi**, Lefu Zhang, Yasuhiro Kamada, Hiroaki Kikuchi, and Katsuyuki Ara, NDE and Science Research Center, Faculty of Engineering, Iwate University, Morioka, 020-8551 Japan

---A new analysis of minor loops has bee found recently, that can be applied to the non-destructive evaluation of degradation in ferromagnetic materials. In the analysis six parameters are found to be sensitive to lattice defects such dislocations and they are independent of the magnetic field amplitude H_a. These parameters give us the information about the crest and trough in the domain wall potentials. This method has several advantages compared with the traditional method by the major hysteresis loop. The new parameters contain much more information about lattice defects such as dislocations, grain boundaries and Cu precipitation. Their sensitivity is higher than the traditional property such as the coercive force. The measurement can be carried out by the low magnetic field. In A533B steel, for example, the measurement is possible in less than 20 Oe. We shall introduce the new analysis of minor loops according to the data of the Fe single crystal with plastic deformation.

Texture Asymmetry in Cubic Sheet Metals
---**Mark D. G. Potter** and Steven M. Dixon, Department of Physics, Warwick University, Coventry, England; Gaoning Kong and Claire L. Davis, School of Metallurgy and Materials, The University of Birmingham, Birmingham, England

---We report on the ultrasonic measurement of crystallographic texture in cold rolled cubic sheet metals of thicknesses ranging from 0.05mm to 4 mm. Conventional theory suggests that this texture can be described by three Orientation Distribution Coefficients of crystallite orientation. A consequence of this is that the sheet will exhibit a combination of two and four fold symmetries in the anisotropy of the in-plane elastic coefficients of the sheet. We find evidence of significant deviation from this symmetry in sheet steel and aluminium. Texture measurements were performed using electro magnetic acoustic transducers (EMATs) to measure the velocity of S0 mode Lamb waves as a function of angle to the rolling direction. Comparison with the effects of applied strain on ultrasonic velocity anisotropy is made. Through thickness shear waves are used to obtain a measure of the homogeneity of texture across a single sheet (since this technique averages over a much smaller area than Lamb waves). The effects of annealing on this asymmetry are observed, and comparison is made with pole figures obtained from X-ray diffraction and Electron Backscattered Diffraction. The observed asymmetries are found to fall into two categories: A net rotation of symmetry axes away from the rolling and transverse directions, and a 450 asymmetry. This second asymmetry bears some resemblance in form to that induced by in plane stress.---*This work will also be presented in Thursday's poster session.*

True-3D Strain Mapping for Assessment of Material Deformation by Synchrotron X-ray Microtomography
---**JeongJu Ahn**, Hiroyuki Toda, Mitsuo Ninomi, and Toshiro Kobayashi, Department of Production Systems Engineering, Toyohashi University of Technology, Toyohashi, Aichi, 441-8580, Japan

---Recently, thanks to rapid development of the electrodevice manufacturing technology, the miniaturization of a product has been being accelerated. So, in order to use such miniature product more safely than now, the material strength assessment of such miniature product is needed. In the present study, as the first step for developing the technique being to evaluate the material strength of the micro-miniature products, three-dimensional local deformation behavior of the pure aluminum wire (purity of 99.6%) with diameter of 800§-, length of 1§®, as model material, was examined using synchrotron radiation CT microtomography technique at Super Proton ring-8 (Spring-8), Japan. Multipurpose in-situ tester was used to investigate real-time tensile deformation behavior of such Al wire under synchrotron radiation CT. Tensile test was carried out under the stroke mode that is, strokes of 0, 0.005§®, 0.001§® and 0.015§®. Three-dimensional local deformation (including strain or stress) evaluation of the Al wire of an interested portion could be done through synchrotron radiation CT microtomography technique: Local deformation behavior of the Al wire was quite different with its macro deformation behavior, that is, some place was compressed in spite of tensile test and the other place has great deformation amount compared to macro deformation. This diverse deformation by position was pronouncedly detected three-dimensionally using synchrotron X-ray CT microtomography technique.

SESSION 9

INVERSION, RECONSTRUCTION, AND CLASSIFICATION I

M. Spies, Chairperson
Parker Ballroom C

8:30 AM **Numerical Modeling and Inverse Scattering in Nondestructive Testing: Recent Applications and Advances**
---**R. Marklein**, K. J. Langenberg, and J. Miao, University of Kassel, Department of Electrical Engineering and Computer Science, Electromagnetic Theory, D-34109 Kassel, Germany; V. Schmitz, IZFP, University of Saarland, Bldg. 37, D-66123 Saarbrucken, Germany

8:50 AM **Lamb Wave Tomography with Frequency Compounding**
---**M. K. Hinders** and K. R. Leonard, Applied Science Department, College of William & Mary, Williamsburg, VA 23187-8795

9:10 AM **Recent Developments in Thermal Tomography**
---V. Bakirov and **R. Kline**, San Diego Center for Materials Research, San Diego State University, San Diego, CA 92182

9:30 AM **Flaw Imaging with Ultrasound: The Time Domain Topological Gradient Method**
---**N. Dominguez** and J.-L. Arnaud, Quality-Non Destructive Investigations, AIRBUS France, Toulouse, France; V. Gibiat, Laboratoire d'Acoustique Métrologie et Instrumentation, Université Toulouse 3, Toulouse, France

9:50 AM **Defect Shape Reconstruction from an SH-Wave Array Ultrasonic Data Using Time Domain Linearized Inverse Scattering Method**
---**K. Kimoto**, S. Hirose, and T. Matsue, Dept. of Mech. and Environ. Informatics, Tokyo Institute of Technology, Room 301, West 8 Building, 2-12-1, Ookayama, Meguro-ku, Tokyo, 152-8552, Japan

10:10 AM ***Coffee Break***

10:30 AM **Simulating Angular Flaw Scattering Responses Using a Hierarchical Triangular Meshing Method**
---**H.-J. Kim**[1] and Lester W. Schmerr Jr.[1,2], [1]Center for NDE and the [2]Dept. of Aerospace Engineering, Iowa State University, Ames, IA 50011

10:50 AM **Characterization of Surface Cracks Using Rayleigh Waves**
---**B. Masserey** and E. Mazza, Institute of Mechanical Systems, ETH Zurich, Ch-8092 Zurich, Switzerland

11:10 AM **Highly Accurate Defect Profiling for Stress Corrosion Cracks of SUS Sample Using Electromagnetic Inverse Problems**
---**F. Kojima** and N. Kawai, Kobe University, Graduate School of Science and Technology, 1-1, Rokkodai, Nada-ku, Kobe 657-8501, Japan

11:30 AM **Application of TOFD Technique to Thin Sections Using ESIT and PSCT**
---G. Baskaran and C. L. Rao, Department of Applied Mechanics, Indian Institute of Technology, Madras, Chennai, India; G. Swamy, **K. Balasubramaniam**, and C. V. Krishnamurthy, Center for NDE, Department of Mechanical Engineering, Indian Institute of Technology Madras, Chennai, India

12:10 PM ***Lunch***

Numerical Modeling and Inverse Scattering in Nondestructive Testing: Recent Applications and Advances

---**Rene Marklein**, Karl J. Langenberg, and Jinghong Miao, University of Kassel, Department of Electrical Engineering and Computer Science, Electromagnetic Theory, D-34109 Kassel, Germany; Volker Schmitz, Institute for NDE (IZFP), University of Saarland, Building 37, D-66123 Saarbrücken, Germany

---This paper presents recent advances and future challenges of the application of different linear and nonlinear inversion algorithms in acoustics, electromagnetics, and elastodynamics. The presented material can be understood as an extension of our previous work on this topic. The inversion methods considered in this presentation vary from linear schemes, like the Synthetic Aperture Focussing Technique (SAFT), to nonlinear schemes, like the Contrast Source Inversion (CSI) combined with different regularization approaches. Inversion results of the above mentioned inversion schemes are presented and compared for instance for experimental time-domain ultrasonic data from the Fraunhofer-Institute for Nondestructive Testing (IZFP, Saarbrücken, Germany). A comparison of the inversion results using the linear time-domain inversion scheme SAFT and well tested nonlinear frequency-domain inversion schemes demonstrates the considerable potential to extend and improve the ultrasonic imaging technique SAFT while consulting the mathematics of wavefield inversion, yet, in particular if the underlying effort is considered, the relatively simple and effective SAFT algorithm works surprisingly well. Since SAFT is a widely accepted imaging tool in ultrasonic NDE it seems worthwhile to check its formal restrictions and assumptions whether they could be overcome and whether they would outperform the standard and original SAFT algorithm.

Lamb Wave Tomography with Frequency Compounding

---**Mark K. Hinders** and Kevin R. Leonard, Applied Science Department, College of William & Mary, Williamsburg, VA 23187-8795

---Lamb waves allow large sections of thin-wall structures to be rapidly inspected for structural flaws such as disbonds, corrosion and delaminations. However, extracting quantitative information from Lamb wave data usually involves highly trained personnel with a detailed knowledge of mechanical waveguide physics. Our work focuses on tomographic reconstruction to produce quantitative maps that can be easily interpreted by technicians or fed directly into structural integrity and lifetime prediction codes. In this talk we discuss a spatial compounding technique similar to what is often used in medical ultrasound imaging. In the traditional ultrasonic B-scan, varying slightly the location of the source and compounding the resulting data, allows speckle noise to be reduced in the final image. We employ this same technique with our Lamb wave tomographic reconstructions, but instead of using different source locations, we vary the frequency of the source slightly and thus utilize what we call tomographic frequency compounding. After compounding multiple frequency scans noise is reduced in the reconstructions and the flaw becomes more pronounced.

Recent Developments in Thermal Tomography

---Vadim Bakirov and **Ron Kline**, San Diego Center for Materials Research, San Diego State University, San Diego, CA 92182

---Tomographic analysis of thermal images offers the capability of obtaining quantitative material property information from heat conduction experiments. This approach requires a localized thermal source, such as a high power laser, and a thermal imaging system to acquire surface temperature data. Previously, we have shown that diffusion based tomographic imaging algorithms can be developed for nondestructive evaluation purposes. The main drawback to this approach is the time required for material property reconstruction due to the computationally intensive nature of the process. In this work, we extend our earlier results to include full field, three dimensional material property reconstruction. The use of parallel processing to reduce computational time to a tractable level is also explored.

Flaw Imaging With Ultrasound: The Time Domain Topological Gradient Method

---**Nicolas Dominguez** and Jean-Louis Arnaud, Quality-Non Destructive Investigations, AIRBUS France, Toulouse, France; Vincent Gibiat, Laboratoire d'Acoustique Métrologie et Instrumentation, Université Toulouse 3, Toulouse, France

---Finding the shape and position of one or several flaws embedded in an elastic material given ultrasonic measurements performed with a linear array of sensors is a present day challenge in Non Destructive Evaluation. We propose a topological gradient method adapted to the intrinsic transient nature of pulse-echo techniques. It consists in minimizing a cost function which evaluates the adequation between the measurements obtained for the inspected material and measurements performed on a reference material known as safe. The topological gradient involves an adjoint problem whose mathematical solution corresponds to a time reversal operation. The refocusing properties of time reversal then strengthen the confidence into the method. Numerical results are shown that confirm the efficiency of this approach.

Defect Shape Reconstruction from an SH-Wave Array Ultrasonic Data Using Time Domain Linearized Inverse Scattering Method

---**Kazushi Kimoto**, Sohichi Hirose and Tsuyoshi Matsue, Department of Mechanical and Environmental Informatics, Tokyo Institute of Technology, Room 301, West 8 Building, 2-12-1, Ookayama, Meguro-ku, Tokyo, 152-8552, Japan

---Linearized inverse scattering method in the time domain is formulated for an array ultrasonic wave data, and is applied to a shape reconstruction of defects in a thick plate. Time domain formulation instead of the one in the frequency is used here because of its computational efficiency and simplicity. In this study, we firstly carry out a sensitivity analysis by reconstructing shapes of defects from an array wave data simulated by solving the forward problems by the boundary element technique. Specifically, the effect of an aperture limitation and the use of multiple wave paths on the shape reconstruction is investigated. The method is then applied to imaging of an artificial defect embedded in a thick steel plate for validation. A commercial array probe of a contact type is used for the required data collection. The defect shape is estimated by both the linearized inverse scattering method and the conventional synthetic aperture focusing technique (SAFT). The two results are compared, and it is shown that the linearized inverse scattering method gives better image of the artificial defect than the SAFT.

Simulating Angular Flaw Scattering Responses Using a Hierarchical Triangular Meshing Method

---**Hak-Joon Kim**[1] and Lester W. Schmerr Jr.[1,2], [1]Center for NDE and the [2]Dept. of Aerospace Eng., Iowa State University, Ames, IA 50011

---Classifying flaws from their measured ultrasonic responses is a problem of fundamental interest in ultrasonic NDE. In many previous studies, this classification has been attempted using the characteristics of the flaw's A-scan signals at one or more transducer locations. However, there is also considerable information to be gained by looking at flaw responses as a function of the incident and/or scattered wave directions as these angular responses are often very indicative of the flaw geometry present. The development of array transducers now makes it possible to acquire such information in a much more precise and cost-effective manner. To examine the information content of such angular scans we have developed an ultrasonic measurement model based on Auld's reciprocity relation that has been coupled to a method for simulating a wide range of flaw geometries called the hierarchical triangular meshing (HTM) method. This HTM method can generate flaws of various shapes and sizes using a large number of planar triangular facets. To obtain the flaw response, one then needs to place the total wave field velocity and stress fields on these facets. Presently, these fields are being evaluated being by use of the Kirchhoff approximation. Using this approach we will simulate the flaw scattering responses and demonstrate the typical angular patterns seen for pores, cracks, and stringer-like flaws.---This work was supported by the NSF Industry/University Cooperative Research Center at Iowa State University.

Characterization of Surface Cracks Using Rayleigh Waves

---**Bernard Masserey** and Edoardo Mazza, Institute of Mechanical Systems, ETH Zurich, Ch-8092 Zurich, Switzerland

---The characterization of surface cracks in steel specimens using surface acoustic waves is investigated. In the experiments Rayleigh wave is generated by a standard wedge technique and the surface displacement is measured pointwise by means of a heterodyne laser interferometer. The presence of a crack in the acoustic field leads to an amplitude increase due to the scattering of the surface wave at the defect. Two different methods are investigated for crack depth determination. The time-of-flight method is validated for crack depth bigger than the wavelength of the incident wave and extended to smaller defects. Based on 2D-finite difference simulations the time delay of the transmitted wave is correlated with the depth of the crack. The method provides good results for crack depths down to 0.2mm and reveals a threshold ratio crack depth/wavelength < 1 by which the delay vanishes. The second method, based on time reversal acoustics, makes use of the wave diffracted at the crack tip during the scattering phase. The displacement histories are measured on the surface, reversed in time and used as excitation in the simulation. The wave interference at the tip location allows the determination of the crack depth.

Highly Accurate Defect Profiling for Stress Corrosion Cracks of SUS Sample Using Electromagnetic Inverse Problems

---**Fumio Kojima** and Nobuhiro Kawai, Kobe University, Graduate School of Science and Technology, 1-1, Rokkodai, Nada-ku, Kobe 657-8501, Japan

---Our recent efforts on 3D defect reconstruction from 2D surface magnetic images are reported. Detection and characterization of multiple cracks embedded in structures are crucial issues in maintenance of nuclear power plants. Based on the availability of high sensitive magnetic measurements, inverse analyses on electromagnetic problems are effectively used for identifying multiple cracks. Applying the adaptive regularization technique to a natural crack in SUS sample, the defect is divided into a couple of segments. The natural defect is then composed of several segments provided with its width, length, and depth of each segment. Our inverse analysis is to reconstruct 3d images of defect by synthesizing set of segments provided with their estimated geometries. Candidate sets of the crack detection are given by finite elements of suspect region of sample with quantitative and qualitative properties. Virus evolutionary genetic algorithm (VEGA) and the fast eddy current simulator both developed in our laboratory are effectively used to our inverse analysis. Detailed discussions on computational experiments will be reported.

Application of TOFD Technique to Thin Sections Using ESIT and PSCT

---G. Baskaran and C. Lakshmana Rao, Department of Applied Mechanics, Indian Institute of Technology Madras, Chennai, India; Gokul Swamy, **Krishnan Balasubramaniam**, and C. V. Krishnamurthy, Center for NDE, Department of Mechanical Engineering, Indian Institute of Technology Madras, Chennai, India

---It is difficult to accurately size the defects that are oriented at an angle (that is not normal to the wave) using conventional amplitude based ultrasonic techniques. Since Time of Flight Diffraction (TOFD) is based on the diffraction of ultrasound at defect edges, defect sizing using this technique is amplitude independent. However, most of the TOFD based assessment relies on manual sizing, whose accuracy depends on quality of image and the operator's experience. Also, the utilization of TOFD for sections less than 15 mm has reportedly several difficulties. In this paper, we report our attempts to size the vertical and inclined defects using an in-house TOFD system built to inspect thin sections (6-10 mm). To improve sizing, automated defect sizing techniques termed Embedded Signal Identification Technique (ESIT) and Point Source Correlation Technique (PSCT) were developed. A ray tracing based model was also developed for a) optimizing the experimental parameters for thin sections, b) interpreting the received signals. Experiments were conducted on 10 mm thick samples with EDM defects and 6-7 mm welded maraging steel samples. The results obtained using pulse echo, manual and automated techniques were compared. Our comparisons lead us to believe that the automated defect sizing techniques can provide accurate and reliable results for thin sections.

SESSION 10
NEW SENSORS AND PROBES
R. Challis, Chairperson
Parker Ballroom D/E

8:30 AM **Fluid Characterization Using the Quasi-Scholte Mode**
---**F. B. Cegla**, P. Cawley, and M. J. S. Lowe, Imperial College, RCNDE, Mechanical Engineering, Room 564, Exhibition Road, London SW7 2AZ, United Kingdom

8:50 AM **Transmission of Longitudinal and Transverse Ultrasonic Waves Using Dry-Coupled Transducer Modules**
---**I. N. Komsky**, Center for Quality Engineering and Failure Prevention, Northwestern University, 2137 Tech Drive, Evanston, IL 60208

9:10 AM **Development of Ultrasonic Transducer for Nondestructive Evaluation of Whole Fruits**
---**K.-B. Kim**, S. S. Lee, and M.-Y. Choi, Center for Environment & Safety Measurement, Korea Research Institute of Standards and Science, Daejon, Korea; M. S. Kim, Department of Bio-Industrial Machinery Engineering, Chungnam National University, Daejon, Korea

9:30 AM **A Dual-Function Inductive Sensor for Imaging Steel, Corrosion Products and Graphite Based Materials**
---**G. Miller**, P. Gaydecki, M. Zaid, B. Fernandes, and V. Torres, Department of Instrumentation and Analytical Science, UMIST, P. O. Box 88, Manchester M60 1QD, United Kingdom

9:50 AM **Magnetic Study of Martensitic Transformation in Austenitic Stainless Steels by Low Field Hysteresis Loops Analysis**
---**L. Zhang**, S. Takahashi, Y. Kamada, H. Kikucki, K. Mumtaz, K. Ara, and M. Sato, Nondestructive Evaluation and Science Research Center, Faculty of Engineering, Iwate University, Ueda 4-3-5, Morioka 020-8551, Japan

10:10 AM ***Coffee Break***

10:30 AM **New Magnetostrictive Sensor Materials Based on Manganese-Doped Cobalt Ferrite for Nondestructive Evaluation Applications**
---J. A. Paulsen, **C. C. H. Lo**, A. P. Ring, and D. C. Jiles, Center for NDE, Iowa State University, Ames, IA 50011; J. E. Snyder, Materials and Engineering Physics Program, Ames Laboratory, USDoE, Iowa State University, Ames, IA 50011

10:50 AM **PCB Conductor Dimension and Alignment Inspection with GMR Based ECT Probe**
---**S. Yamada**, K. Chomsuwan, and M. Iwahara, Institute of Nature and Environmental Technology, Kanazawa University, 2-40-20 Kodatsuno, Kanazawa 920-8667, Japan; H. Wakiwaka, Shinshu University, 4-17-1 Wakasato, Nagano 380-8553, Japan; S. Shoji, TDK Corporation, 543 Otai, Saku-shi, Nagano 3805-8555, Japan

11:10 AM **Detection of Subsurface Flaws in Metals with GMR Sensors**
---**J. K. Na** and M. A. Franklin, Systems Integration, General Dynamics, 2700 Indian Ripple Road, Dayton, OH 45440

11:30 AM **Laser Scanning Thermal Probe: A Novel Approach to NDE**
---**J. T. Kephart**, J. Chen, and H. Zhang, Mechanical Engineering Department, Rowan University, Glassboro, NJ 08088

11:50 AM **Exo-MRI: Sensor for Quantitative Nondestructive Evaluation**
---**S. Bobroff** and P. J. Prado, Quantum Magnetics, 15175 Innovation Drive, San Diego, CA 92128

12:10 PM ***Lunch***

Fluid Characterization Using the Quasi-Scholte Mode

---**Frederic B. Cegla**, Peter Cawley, and Mike J. S. Lowe, Imperial College, RCNDE, Mechanical Engineering, Room 564, Exhibition Road, London SW7 2AZ, United Kingdom

---In the food industry many millions of litres of complex fluids are produced daily. These fluids mainly are suspensions and emulsions, whose texture greatly influences the taste of the products. Thus ultrasonic particle sizing is of importance in process and quality control. Current methods consist of ultrasonic test cells. However these test cells are difficult to incorporate into reaction vessels and in highly attenuating fluids only very small flow rates can be achieved through the cell. An attractive alternative could be to insert a simple measurement “dipstick” into the fluid; this paper investigates that possibility. The quasi-Scholte mode on an immersed plate is employed. The measured quasi-Scholte group velocity and attenuation are related to the longitudinal velocity and attenuation of the embedding fluid. The attenuation of the quasi-Scholte mode is caused by two mechanisms: shear leakage and attenuation due to the bulk longitudinal attenuation of the embedding material. In a calibration test the bulk longitudinal velocity and viscosity of glycerol were determined experimentally. Measurements agreed well with results from conventional methods and literature data. For a Newtonian liquid like glycerol the shear leakage and longitudinal bulk attenuation are both related to viscosity. To demonstrate the sensitivity to non-viscous attenuation mechanisms, measurement results on fluids that mainly exhibit attenuation due to scattering are presented. The next step is to use a strip as the waveguide, rather than a plate, in order to produce a “dipstick” sensor that can perform real time measurements in harsh environments.

Transmission of Longitudinal and Transverse Ultrasonic Waves Using Dry-Coupled Transducer Modules

---**Igor N. Komsky**, Center for Quality Engineering and Failure Prevention, Northwestern University, 2137 Tech Drive, Evanston, IL 60208

---Several techniques and fixtures have been developed in the past to overcome the problems that are associated with the application of liquid or gel couplants. The dry-coupled systems have generally been used as water-filled wheel probes or liquid-filled plastic boots. However, most of the systems operated at relatively low (300 kHz-1.5 MHz) frequency range due to the attenuation loss and high background noise in the coupling membranes. Novel dry-coupled rolling modules were developed at Northwestern University for the transmission of both longitudinal and transverse ultrasonic waves at frequencies up to 10 MHz. Two types of the dry-coupled modules are under development. Cylindrical base transducer modules include solid core cylindrical rotors with flexible polymer substrates that rotate around the stators with ultrasonic elements. Dry-coupled modules with elongated bases contain solid core stators and flexible track-like polymer substrates that rotate around the stators as rotors of the modules. Some designs of the dry-coupled rolling modules contain several ultrasonic elements with different incident angles or a variable angle unit for rapid adjustments of incident angles.---This material is based upon work supported by the Federal Aviation Administration under Contract # DTFA03-98-D-00008, Delivery Order # DTFA03-01-F-IA049 and performed at Northwestern University as part of the Center for Aviation Systems Reliability program through the Airworthiness Assurance Center of Excellence.

Development of Ultrasonic Transducer for Nondestructive Evaluation of Whole Fruits

---**Ki-Bok Kim**, Seung Seok Lee, and Man-Yong Choi, Center for Environment & Safety Measurement, Korea Research Institute of Standards and Science, Daejeon, Korea; Man Soo Kim, Department of Bio-industrial Machinery Engineering, Chungnam National University, Daejeon, Korea

---In this study, the ultrasonic transducers for contact measurement of whole fruits were developed. The design parameters for ultrasonic transducer such as acoustical impedance of fruits, kinds of piezoelectric materials, ultrasonic wave frequency, and transducer diameter were investigated. In order to match the impedance between piezoelectric material and fruit, various materials were evaluated. And to control the bandwidth of ultrasonic wave of the transducer, various backing materials were fabricated and evaluated. Especially, the wear plate of the transducer was designed and fabricated considering curvature of fruit. Three kinds of transducers such as 100 kHz of central frequency with 400 mm diameter, 200 kHz of central frequency with 200 mm diameter and 400 kHz of central frequency with 100 mm diameter were developed and evaluated. Nondestructive evaluation of the fruit will be possible with the developed transducers for whole fruit.

A Dual-Function Inductive Sensor for Imaging Steel, Corrosion Products and Graphite Based Materials

---**Graham Miller**, Patrick Gaydecki, Muhammad Zaid, Bosco Fernandes, and Vladimir Torres, Department of Instrumentation and Analytical Science, UMIST, P.O. Box 88, Manchester M60 1QD, United Kingdom

---An inductive sensor is described that combines both Q-detection and heterodyne technology. It may be used for imaging steel reinforcing bars, surface corrosion and, generally, materials with differing permeability and conductivity ratios. Real time digital signal processing (DSP) is used to improve the signal to noise ratio of the sensor and to provide a feedback stabilisation mechanism for the reduction of long-term drift. At present a single coil sensing system is used whereby a time varying magnetic field is generated around it. When a conductive or permeable target is exposed to the sensing coil, a corresponding change in its impedance takes place. As a consequence, conductive targets cause the resistive part to change and permeable targets cause the inductive part to change. This results in a respective change in Q-factor and frequency. The typical imaging range of the sensor is 50 mm but varies depending upon the application. The system has been employed in the past to image steel reinforcing in concrete, but recent experiments have confirmed its ability to distinguish between different grades of graphite material, and to image hairline cracks almost invisible to the naked eye. The sensor is therefore appropriate in the nuclear power generation testing industry.

Magnetic Study of Martensitic Transformation in Austenitic Stainless Steels by Low Field Hysteresis Loops Analysis
---**Lefu Zhang**, Seiki Takahashi, Yasuhiro Kamada, Hiroaki Kikuchi, Khalid Mumtaz, Katsuyuki Ara, and Masaya Sato, Non-destructive Evaluation and Science Research Center, Faculty of Engineering, Iwate University, Ueda 4-3-5, Morioka, 020-8551, Japan

---Magnetic method is previously used to evaluate the volume percentage of martensitic phase by measuring saturation magnetization in austenitic stainless steels, and it is said to be a candidate NDE method. However, the nondestructive measurement of saturation magnetization by a common magnetic yoke sensor seems very difficult because the lack of power in generating high magnetic field. Ignited by our development of a new method for analyzing minor hysteresis loops in iron and steels, we would also intend to apply minor hysteresis loop analysis technique in the NDE of austenitic stainless steel. In the current work, magnetic major and minor hysteresis loops were measured in austenitic stainless steels type SUS 304 after mechanical deformation to study the magnetic properties of martensitic transformation. Some sensitive properties were found by using minor loop method which can reveal the martensitic transformation in austenitic stainless steel. A yoke sensor was designed and used to measure the minor loops in a nondestructive way. The results were compared with saturation magnetization by VSM, and were found to have good coincidence.

New Magnetostrictive Sensor Materials Based on Manganese-Doped Cobalt Ferrite for Nondestructive Evaluation Applications
---Jason A. Paulsen, **Chester C.H. Lo**, Andrew P. Ring, and David C. Jiles, Center for NDE, Iowa State University, Ames, IA 50011; John E. Snyder, Materials and Engineering Physics Program, Ames Laboratory, USDoE, Iowa State University, Ames, IA 50011

---Cobalt ferrite and its composites have a unique combination of high permeability and high magneto-elastic coupling that make them ideal for magnetostrictive stress-sensing and adaptive “smart materials” applications. Their magnetization changes in response to applied stresses and such changes can be detected by measuring the magnetic field at the materials surface. However composites made of the parent cobalt ferrite can show an undesirable magnetomechanical hysteresis below 60°C. Reducing the Curie temperature of cobalt ferrite to near operational temperatures could enhance reversible magnetomechanical response. We report results of an investigation of a new family of CoMnxFe2-xO4 in which we have studied the variation of magnetization with temperature and the variation of magnetostriction with magnetic field for various chemical compositions. The substitution of manganese for iron dramatically lowers the Curie temperature by up to 250°C, while still maintaining a high magnetostriction. The results indicate the possibility of controlling the magnetic and magnetoelastic properties of cobalt ferrite composites through control of chemical composition. This will allow control and reduction of the magnetomechanical hysteresis for stress sensor applications over a range of operational temperatures.---This research was supported by the National Aeronautics and Space Administration (NASA) under award No NAG-1-02098.

PCB Conductor Dimension and Alignment Inspection with GMR Based ECT Probe

---**Sotoshi Yamada**[1], K. Chomsuwan[1], M. Iwahara[1], H. Wakiwaka[2], T. Taniguchi[3], and S. Shoji[4], [1]Kanazawa University, 2-40-20 Kodatsuno, Kanazawa 920-8667, Japan; [2]Shinshu University, 4-17i-1 Wakasato, Nagano 380-8553, Japan; [3]The University of Electro-Communications, 1-5-1 Chofugaoka, Chofu, 182-8585, Japan; [4]TDK Corporation, 543 Otai, Saku-shi, Nagano 3805-8555, Japan

---Inspection of bare printed circuit boards (PCBs) is importance not only imperfection on the PCB conductor but also PCB conductor dimension and alignment. ECT technique is an interesting method for defect inspection on bare PCBs that has been proposed by us. In this paper, ECT probe consisted of spin-valve giant magneto-resistance (SV-GMR) device as magnetic sensor and meander coil as excitation coil was applied to PCB conductor dimension and alignment inspection. The high-frequency excitation up to 18 MHz is allowed to inspect the thin PCB conductor (less than 10 μm). Furthermore, the SV-GMR sensor with an effective area of 100*93 μm and high-resolution scan pitch (2 μm) enable the examination of high-density PCB model with 100 μm conductor width and gap. The proposed ECT probe characteristics and its configuration for this purposed were presented in this paper. In addition, PCB conductors with soldering point inspection are also shown alignment inspection. The inspection results indicate that the proposed ECT probe will provide an accurate measurement.

Detection of Subsurface Flaws in Metals with GMR Sensors

---**Jeong K. Na** and Mark A. Franklin, Systems Integration, General Dynamics, 2700 Indian Ripple Road, Dayton, OH 45440

---Subsurface flaws in metals have been detected and measured with Giant Magnetoresistive (GMR) sensors. Nonferrous metallic plates made of aluminum and titanium alloys with a thickness up to 165 mil have been tested. This is a noncontact NDI method with a lift off distance close to 1 mm. Experimental results show a clear indication of detecting a flaw located as deep as 125 mil in the material. With set of simulated flaw samples, a quantitative correlationship between the flaw size (length and depth) and signal response from a GMR sensor has been attempted to be made as a part of probability of detection (POD)studies.

Laser Scanning Thermal Probe: A Novel Approach to NDE

---**Jacob T. Kephart**, John Chen, and Hong Zhang, Mechanical Engineering Department, Rowan University, Glassboro, NJ 08088

---Infrared (IR) thermography and, more recently, thermosonics have proven to be viable means of qualitative nondestructive evaluation (NDE). However, structural defects such as cracks observed through thermosonics can only be identified as "hot spots" indicating a general location of a defect without an accurate depiction of the dimensions or shape of the defect. This paper introduces a new technique dubbed Laser Scanning Thermal Probe, LSTP, which combines thermography with the use of heat application in strategic locations to observe the heat flow patterns. LSTP provides the ability to record heat propagation across a defect area with temperature discontinuities forming due to differences in defect thermal diffusivity, thus providing information, which can be used to characterize the defect. Gradient processing of the recorded images allows the visualization of relatively higher temperature changes as compared to adjacent temperature differences. This method demonstrates the ability to observe cracks with more detail than that provided by current thermosonic techniques alone.

Exo-MRI: Sensor for Quantitative Nondestructive Evaluation

---**Serge Bobroff** and Pablo J. Prado, Quantum Magnetics, 15175 Innovation Drive, San Diego, CA 92128

---Nuclear Magnetic Resonance (NMR) and Magnetic Resonance Imaging (MRI) has many properties that are advantageous for material control and analysis in engineering. Unfortunately, the technique is usually expensive and cumbersome: the sample has to be brought to the MR spectrometer and designed to fit its specifications. QM has designed and built a single sided portable NMR-MRI instrument for quantitative and nondestructive in-situ material assessment: the Exo-MRI. Although limited in its applications (non-magnetic or non-conductive materials only) our machine can monitor and image non-destructively samples to be inspected in the field. Typical applications are (but not limited to) cement curing, wood moisture content and food quality. The actual prototype head is about 5 inches x 5 inches x 3 inches and weighs about 6 kg. The usable region for NMR measurements and imaging covers a region of 1 inch in diameter and 1 inch in depth. The sensor head is connected to the control unit via a flexible shielded multi-conductor cable. The spectrometer fits in a rack smaller than a portable ultrasound instrument.

SESSION 11
STUDENT POSTER COMPETITION
Green Center

NOTE: Student posters are to be mounted Monday, July 26th from 4:00-6:00 PM for Monday evening judging only-*not public display*. During this period, no identification (author names, institutional names etc.) will be shown on the posters in order to preserve anonymity during judging. They will be open for public viewing with author and institutional titles during the regular Poster Session 11 on Tuesday, July 27th from 1:30-3:00 PM

Resonance-EMAT Measurements on Aluminum Sheets With Monoclinic Texture

NPD, A Low Cost Ultrasonic Static Array System for Improved POD

Inversion Procedure for Eddy Current Profiling of the Near-Surface Residual Stress in Shot-Peened Metals

Differential Reassignment Algorithm for Lamb Wave Characterization

Characterization of the Microstructure of Cement-Based Materials Using Ultrasonic Attenuation

Empirical Modeling of Surface Crack Detection in Concrete Using an Open-Ended Rectangular Waveguide

Interpreting Complex Wave Propagation

Size Evaluation of Corrosion Precursor Pitting Using Near-Field Millimeter NDT Methods

Ultrasonic Attenuation to Predict the Damage State of a Polycrystalline Material

Development of the Dispersion Relationship of a Plate Using Permanently Mounted Piezoelectric Sensors

Enhanced Flaw Detection Using Linear Array Hall Probes

3:10 PM ***Coffee Break***

Resonance-EMAT Measurements on Aluminum Sheets with Monoclinic Texture

---Sheet metals are usually assumed to have orthorhombic texture symmetry, with the rolling direction (RD), transverse direction (TD) and normal direction (ND) being axes of 2-fold rotational symmetry. This assumption often serves as the starting point for theoretical analysis of ultrasonic measurements on sheet metals. In X-ray measurement of texture, pole figures are also routinely symmetrized so that the resulting orientation distribution function (ODF) will possess orthorhombic sample symmetry, although the raw data would sometimes show significant deviations from the orthorhombic assumption. To examine what effects such deviations may have on interpretation of measurement results, we cold-rolled plate samples of a commercial AA 5754 aluminum alloy, in various thickness reductions, along a direction that makes an angle of 45 degrees with respect to the original rolling direction. We conducted X-ray and through-thickness resonance-EMAT measurements on the samples before and after cold-rolling. Then we analyzed the measurement data using two different assumptions on the texture symmetry of the cold-rolled samples: (1) All the cold-rolled samples are orthorhombic with the new RD, TD, and ND being the axes of 2-fold rotational symmetry. (2) The cold-rolled samples are monoclinic with ND as the only 2-fold symmetry axis. In this paper we will present and compare the results of data analysis based on the two different assumptions. We will re-examine the orthorhombic assumption in light of our findings.

NPD, A Low Cost Ultrasonic Static Array System for Improved POD

---The aim of this project was to investigate the potential within a current multi-probe ultrasonic Non-Destructive Testing (NDT) system installed at a steel mill. Extensive laboratory experiments were carried out using existing online transducer array geometry, to extract additional information from passive probes. The technique devised involves the transmission from a single transducer and reception on several adjacent transducers, with the aim of detecting a diffracted signal from a discontinuity. The technique has been termed Normal Probe Diffraction (NPD). The process also employs Digital Signal Processing (DSP), to improve the Signal to Noise Ratio (SNR), which is essential for small signal recognition. This paper describes the theory of NPD with reference to SAFT and TOFD and shows how the technique maximizes the scanned volume within the material to under inspection without the loss of resolution, also how it can effectively locate defects using simple geometric methods.

Inversion Procedure for Eddy Current Profiling of the Near-Surface Residual Stress in Shot-Peened Metals

---Because of their frequency-dependent penetration depth, eddy current measurements are capable of mapping the near-surface depth profile of the electrical conductivity. This technique can be used to nondestructively characterize the subsurface residual stress distribution in certain types of shot-peened metals, e.g., in nickel-base superalloys. For quantitative evaluation of the experimental results, analytical and computational techniques are needed to solve the direct and inverse problems, i.e., to predict the frequency-dependent apparent eddy current conductivity from the depth profile of the frequency-independent intrinsic electrical conductivity of the specimen and vice versa. Simple analytical approximations are presented for both the direct and inverse eddy current problems by exploiting two specific features of the subsurface electrical conductivity variation caused by near-surface residual stresses in shot-peened metals. First, compressive residual stresses are limited to a shallow surface region of depth much less than typical probe coil diameters. Second, the change in electrical conductivity due to residual stresses is always very small, typically less than 1%. The proposed approximations are verified by numerical comparison to much more complicated numerical solutions.

Differential Reassignment Algorithm for Lamb Wave Characterization

---The spectrogram (energy density spectrum of the short-time Fourier transform) has proven to be an effective time-frequency representation (TFR) to characterize guided ultrasonic Lamb waves. Spectrograms suffer from the Heisenberg uncertainty principle, making it impossible to simultaneously have perfect resolution in both time and frequency. The reassignment method overcomes this drawback by rearranging the time-frequency particles, and thus localizing the energy. Unfortunately, an unwanted side-effect of the reassignment method is the generation of spurious peaks. This research modifies an existing differential reassignment algorithm to develop a procedure that does not produce these spurious, noise-like, peaks. First, the direction of steepest image curvature is used to modify the reassignment vectors in such a way that time-frequency particles are only moved towards, but not along, the ridges. Second, anisotropic diffusion is incorporated into the reassignment algorithm to ensure that noise is diffused along the ridges, while still preserving the ridges themselves. An important advantage of the proposed procedure is that this differential reassignment algorithm can be represented with a single partial differential equation.

Characterization of the Microstructure of Cement-Based Materials Using Ultrasonic Attenuation

---Ultrasonic techniques have the potential to provide quantitative information about the microstructure of cement-based materials. A critical parameter in describing ultrasonic wave propagation is attenuation. Attenuation refers to the energy loss associated with both scattering and absorption. It has been observed that the two major sources of ultrasonic attenuation are absorption due to the viscoelastic effects of the medium and the scattering from inhomogeneities. This research considers the propagation of ultrasonic waves through an isotropic, viscoelastic medium containing randomly distributed spherical voids; this medium is a representation of a cement paste matrix containing a moderate percentage (on the order of 10%) of approximately 1mm-diameter spherical inclusions (i.e., entrained air to resist freeze/thaw damage). An analytical model is used to predict attenuation under the assumption of no scattering interaction between the air voids. Experimental measurements are made on samples prepared with varying amounts of air entrainer, and these results are compared to analytical predictions. There is good agreement between measured and predicted values, and these results are used to quantify the effect of microstructure on the attenuation of ultrasonic waves in cement-based materials.

Empirical Modeling of Surface Crack Detection in Concrete Using an Open-Ended Rectangular Waveguide

---Microwave nondestructive testing and evaluation (NDT & E) of surface-breaking and internal cracks in cement-based materials, employing open-ended rectangular waveguide probes, has the potential to be a viable approach for the purpose of structural health monitoring. A crack characteristics signal, which is the signal reflected by a sample under test as a function of scanning distance, is dependant on several parameters including the dielectric property of the material, crack dimensions (width and depth), probe aperture dimensions, and the standoff distance between the probe and the sample under test. This paper discusses model developed for simulating crack characteristic signal as a function of these parameters. Two cubical mortar samples were used to produce simulated cracks with various widths (i.e., crack opening). This arrangement was scanned by an open-ended rectangular waveguide for various crack-widths and standoff distances. The magnitude and phase of reflection coefficient was measured using an HP8510C vector network analyzer. This paper presents a set of measurement results along with the results of the simulations, and a comparison between the simulated and the measured crack characteristic signals.

Interpreting Complex Wave Propagation

---The majority of commercially available ultrasonic transducers used to excite and measure wave propagation in structures can be coupled only to a free surface. While convenient, this method is likely to excite multiple structural modes, making data interpretation difficult. Furthermore, the many modes excited make predicting the structure's response a computationally intensive task. Here the dynamic radial displacement induced by a transient radial point load is calculated at more than 230,000 points on the outer surface of a virgin steel pipe to simulate a typical experimental setting. The displacement field is calculated by convoluting the Green's functions of the pipe with the transient load. These functions are calculated on personal computers (in a distributed arrangement) by employing modal summation. The mode shapes are obtained from a Semi-Analytical Finite Element formulation used in conjunction with a separation of variables. The results are presented in a four dimensional animation, providing easier interpretations and insight into how to best select observation points for the detection of defects. The accuracy of the calculated displacements is verified experimentally. Agreement is good when magnitude and phase corrections are incorporated from the frequency response curves of the transducers used.

Size Evaluation of Corrosion Precursor Pitting Using Near-Field Millimeter NDT Methods

---Early detection of corrosion precursor pitting under paint and thin dielectric coatings, in critical aircraft structural components, is an important practical issue when considering maintenance and repair cost saving. Near-field microwave nondestructive techniques have been successfully used for detection of corrosion precursor pitting under paint. Close estimation of pitting overall dimensions, in particularly its depth, directly affects the required effort and cost associated with repair and maintenance of an affected region. This paper presents different millimeter wave probes, such as open-ended rectangular waveguides and dielectric-loaded waveguides, used to detect and evaluate pitting dimensions. The dimensions of the pitting is directly related to the magnitude and/or phase of the reflected signal from a pit at selected frequencies and as a function of the particular probe used. The effect of standoff distance and different coatings on estimating pit dimensions is also discussed.

Ultrasonic Attenuation to Predict the Damage State of a Polycrystalline Material

---Ultrasonic attenuation is frequently used to characterize microstructure properties such as grain size, shape and orientation. The current research develops an analytical model to relate ultrasonic attenuation to the damage state of a material. Total attenuation is divided into two parts: attenuation due to the undamaged microstructure, and attenuation due to material defects and damage. The undamaged microstructure contribution is calculated by solving an integral equation for the energy scattered at the grain boundaries, including the effects of multiple scattering. The contribution of damage to attenuation (which also calculated with an integral equation) considers the effect of micro-voids and -cracks, including their size, shape and distribution. The total attenuation is then expressed in terms of the scattering area. This analytical model is used to predict attenuation for a variety of damage states, which can then be used to predict remaining structural life.

Development of the Dispersion Relationship of a Plate Using Permanently Mounted Piezoelectric Sensors

---Guided wave techniques have great potential for the structural health monitoring of plate-like components. Previous research has demonstrated the effectiveness of combining laser-ultrasonic techniques with time-frequency representations to experimentally develop the dispersion relationship of a plate; the high fidelity, broad bandwidth and point-like nature of laser ultrasonics are critical for the success of these results. Unfortunately, laser ultrasonic techniques are time and cost intensive, and are impractical for many in-service applications. The current research develops a complementary methodology that uses permanently mounted piezoelectric sensors instead of optical devices. This study first characterizes the spatial and temporal affects of mounted piezoelectric sensors, and then develops a procedure to compensate for any distortion caused by their limited bandwidth and finite size. The proposed procedure is then used to develop the dispersion relationship of a plate with a fidelity and bandwidth similar to results possible with laser ultrasonics, but made using permanently mounted piezoelectric sensors.

Enhanced Flaw Detection Using Linear Array Hall Probes

---This article describes a new probe technology with enhanced flaw detection capability. In addition, using multi-sensor field measurements can accelerate inspections. The work is motivated by a need to improve flaw detection and the need to reduce inspection time in a cost-effective way. The objective is accomplished through the development of novel linear array eddy-current probes based on high-sensitivity Hall sensors. The combination of thin layer techniques and novel semiconductor materials has been shown to produce device with a much higher sensitivity than those generally available from component manufactures. The sensors is obtained in their unencapsulated form, which enable us to take advantage of the small size of the sensitive region (typically 100 microns or less) to mount sensors in the small space between the induction coil and the part under test. The array probe has sixteen Hall sensors in a linear array excited by a racetrack coil. The new probes can interface with commercially available eddy current test equipment for single or multi-frequency inspection. Electric hardware is developed to interface probes to conventional rotary probe test instruments.

Tuesday, July 27, 2004

SESSION 11 – POSTERS

UT, SIGNAL PROCESSING, ELECTROMAGNETIC METHODS, MATERIAL PROPERTIES

Green Center

1:30 PM

UT

The Effect of Material Inhomogeneity on Ultrasonic Phased Array Performance
---**L. Yu**, J. H. Friedl, F. J. Margetan, and R. B. Thompson, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

Investigation of Time Reversal Techniques to Enhance Flaw Detectability
---**H.-J. Kim**, J. H. Friedl, and R. B. Thompson, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

Ultrasonic Waves Reflected from Finite-Sized Shapes with Simple Curvatures
---**T. P. Lerch** and G. Raman, Central Michigan University, Industrial and Engineering Technology Department, IT 100, Mt. Pleasant, MI 48859

Generation of the Basis Sets for Multi-Gaussian Beam Models
---H.-J. Kim[1] and **L. W. Schmerr Jr.**[1,2], [1]Center for NDE and the [2]Department of Aerospace Engineering, Iowa State University, Ames, IA 50011

Ultrasonic Generation and Optimization for EMAT
---X. Jian, **S. Dixon**, and R. S. Edwards, Department of Physics, University of Warwick, Coventry CV4 7AL, United Kingdom

Modal Wave Solved in Complex Wave Number
---W.-J. Xu, **F. Jenot**, and M. Ourak, IEMN, Département OAE (UMR CNRS 8520), Université de Valenciennes et du Hainaut Cambrésis, 59313 Valenciennes Cedex 9, France

Models of Standard Ultrasonic Reference Reflectors and Their Experimental Validation
---**A. Lopez-Sanchez***, H.-J. Kim, and L. W. Schmerr, Jr.*, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011; *Department of Aerospace Engineering

The Effect of Slowness Surfaces on the Beam Propagation in General Anisotropic Materials
---**R. Huang** and L. W. Schmerr, Jr., Iowa State University, Center for NDE and Department of Aerospace Engineering, 1915 Scholl Road, Ames, IA 50011; A. Sedov, Lakehead University, Department of Mechanical Engineering, Thunder Bay, Ontario, P7B 5E1 Canada

Simulation of Bulk Ultrasonic Waveform Excited for Two Layer Medium by Using Finite Element Method
---G. Chen, **X. R. Zhang**, and J. C. Chen, State Key Laboratory of Modern Acoustics and Institute of Acoustics, Nanjing University, 210093 Nanjing, China

Signal Processing

Index Size Determination with Varying Coil Diameters for Improved Automated Eddy Current Inspections on Aerospace Engine-Component
---R. T. Ko, B. Frock, A. P. Berens, D. L. Petricola, and **R. W. Martin**, Structural Integrity Division, University of Dayton Research Institute, Dayton, OH 45469-0120; M. Rambo, Advanced Information Engineering Services, Inc., A General Dynamics Company, Dayton, OH 45469

Decision Making of Aircraft Engine Blades Condition Based on Bispectral Analysis of the Vibroacoustical Signal
---N. I. Bouraou, **A. G. Protasov**, O. V. Zazhistskiy, and Y. V. Sopilka, Department for Nondestructive Testing, National Technical University of Ukraine, Kiev Politechnical Institute, 37 Prospect Peremohy Street, Box 1760, Kiev 3056, Ukraine

Variable-Precision Arithmetic for Solving Inverse Problem of Electrical Impedance Tomography
---H. Tian, **S. Yamada**, and M. Iwahara, Division of Biological Measurement and Applications, Institute of Nature and Environmental Technology, Kanazawa University, Kodatsuno 2-40-20, Kanazawa 920-8667, Japan; H. Yang, The Key Laboratory of High Voltage and New Technology, Education of Ministry, Chongqing University, Congqing 400044, China

Electromagnetic Methods

Model Based Study of Three-Point Calibration Standard for Eddy Current Testing
---**B. P. C. Rao** and N. Nakagawa, Iowa State University, Center for NDE, Ames, IA 50011

Comparison of ECT Signals and Calibration Procedures for Absolute and Differential Probes in Steam Generator Tubes
---**Y.-K. Shin** and Y.-T. Lee, School of Electronic and Information Engineering, Kunsan National University, San 68, Miryong-dong, Kunsan, Chonbuk 573-701, Korea; M.-H. Song, Korea Institute of Nuclear Safety, 19 Kusong-Dong, Yousung-Ku, Taejon 305-338, Korea; T.-E. Chung, Korea Advanced Inspection Technology, P. O. Box 105, Yousung-Ku, Taejon, 305-600 Korea

Scheme for Characterization of Metal-Loss Defects Using MFL Signal from Pipeline Inspection
---**V. P. Lunin**, Electrical Engineering and Introscopy Department, Moscow Power Engineering Institute (Technical University), 14 Krasnokazamennaja, 111250, Russia

Application of Near-Field Microwave and Millimeter Wave Nondestructive Testing for Evaluation of Fiber Breakage and Orientation in Carbon Composite Structures
---**S. Kharkovsky** and R. Zoughi, Applied Microwave Nondestructive Testing Laboratory, Electrical and Computer Engineering Department, University of Missouri-Rolla, 228 Emerson Electric Co. Hall, 1870 Miner Circle, Rolla, MO 65409-0040

Material Properties

Evaluating the Degree of Degradation of Resistance of Material in "Hot Spots" of Active Structures to Crack Propagation
---**V. Makhnenko**, E. O. Paton Electric Welding Institute of the National Academy of Sciences of Ukraine, 11 Bozhenko Street, 03680, Kyiv, Ukraine

Computation of Grain-Noise Scattering Coefficients for Ultrasonic Pitch/Catch Inspections of Metals
---**F. J. Margetan**, L. Yu, and R. B. Thompson, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

Nondestructive Testing of Aeronautical Bearing Ceramic Balls by Resonant Ultrasound Spectroscopy
---S. Petit, M. Duquennoy, M. Ouaftouh, and **F. Jenot**, IEMN, Département OAE (UMR CNRS 8520), Université de Valenciennes et du Hainaut Cambrésis, 59313 Valenciennes Cedex 9, France; S. Petit and J. Gualandri, SNRA, Al. No. 2 Batterie 900 Rouvignies, 59309 Valenciennes France

Hidden Corrosion Detection in Aircraft Metallic Structures Using Lamb Waves
---C. Titry, F. Lepoutre, **N. Terrien**, and A. Déom, Department Mécanique du Solide et de l'Endommagement, Office National d'Etudes et de Recherches Aérospatiales, Châtillon, France

Two-Dimensional Thermoelastic Analysis of Diamond/Si Structures Heated by a Pulsed Gaussian Laser Beam
---X. B. Mi and **S. Y. Zhang**, Laboratory of Modern Acoustics, Institute of Acoustics, Nanjing University, Nanjing 210093, China

Mean Grain Size Determination in Marbles by Ultrasonic Velocity Techniques
---**I. H. Sarpun,** Physics Department, Afyon Kocatepe University, Afyon, Turkey; M. S. Kilickaya, Physics Department, Osmangazi University, Eskisehir, Turkey; S. Tuncel, Marmara Research Center, TUBITAK, Kocaeli, Turkey

Spectral Study of Ultrasonic Waves in a Beta-C Titanium Alloy
---**B. L. Buitrago**, I. A. Irausquin, and J. A. Mendoza, Dpto. De Tecnologia Industrial, Universidad Simón Bolivar, Sede del Litoral, Caracas 1080, Venezuela

Materials Characterization for Prognostic Structural Diagnostic
---**B. B. Djordjevic**, Johns Hopkins University, 810 Wyman Park Drive, Suite G010, Baltimore, MD 21211 and S. Kenderian, Jet Propulsion Laboratory, Pasadena, CA

High Temperature Monitoring of Refractory Wall Recession Using Frequency-Modulated Continuous-Wave (FM-CW) Radar Techniques
---B. Varghese, C. DeConick, G. Cartee, and **R. Zoughi**, Applied Microwave NDT Laboratory, Electrical and Computer Engineering Department, University of Missouri-Rolla, Rolla, MO 65409; M. Velez and R. Moore, Ceramic Engineering Department, University of Missouri-Rolla, Rolla, MO 65409

Analysis of Microstructure Using Thermoelectric Diagnostics for Nondestructive Evaluation of Materials
---**Y.-D. Park**, V. Kaydanov, B. Mishra, and D. L. Olson, Colorado School of Mines, Department of Metallurgical and Materials Engineering, Golden, CO 80401

3:10 PM ***Coffee Break***

The Effect of Material Inhomogeneity on Ultrasonic Phased Array Performance

---**Linxiao Yu**, Jon H. Friedl, Jr., Frank J. Margetan, and R. Bruce Thompson, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---Ultrasonic phased array technology has gained more and more attention from various industrial communities because of the attractive features it can offer, such as beam multiplexing, beam steering, dynamic focusing, etc. However, for most present commercial ultrasonic phased array system, the algorithms behind these features assume the material to be inspected is homogeneous and can be characterized by a single average velocity. The goal of this exploratory research is to study how the material inhomogeneity can affect phased array performance. To emphasize material inhomogeneity, two specimens cut from titanium billet alloy are used in our experiments. For the signal received by each array element, material inhomogeneity tends to distort its waveform and vary its time delay. We first scan the array probe along the back-wall at different beam focal conditions, and the back-wall echo received by each array element at each probe location is collected. The statistical distributions of the back-wall signal peak amplitude and time delay are then investigated for different specimens and different focal conditions. Further efforts, in both the time and frequency domains, are made to demonstrate how we can improve ultrasonic phased array focusing.---This material is based upon work supported by the Federal Aviation Administration under Contract #DTFA03-98-D-00008, Delivery Order #IA029 and performed at Iowa State University's Center for NDE as part of the Engine Titanium Consortium program, through the Airworthiness Assurance Center of Excellence.

Investigation of Time Reversal Techniques to Enhance Flaw Detectability

---**Hak-Joon Kim**, Jon H. Friedl, and R. Bruce Thompson, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50010

---The focusing of an ultrasonic wave on a target in an inhomogeneous medium or through a non-planar interface is important in order to enhance flaw detectability. Phased array transducers are often used to attain high focusing performance. But the focusing can be strongly degraded by geometrical distortion of field radiated by the array transducers or by sound speed fluctuations in the propagating medium. So, the detection of small defects with ultrasonic techniques is especially difficult when the inspected object is inhomogeneous and has complex geometry. In recent years, the time reversal mirror (TRM) technique has been proposed. This technique is claimed to be a very robust technique to focus through inhomogeneous medium as compared to conventional focusing techniques. However, the TRM technique generally requires special hardware. Fortunately, a computational approach has been proposed to produce the same results. The D.O.R.T (French acronym for Decomposition of the Time Reversal Operator) method is a detection technique that is derived from the mathematical analysis of the iterative time reversal process, and allows the simultaneous detection and separation of several defects. In this paper, we will first describe the basic principles and procedures of the time reversal technique including the TRM technique and the D.O.R.T method. Then, the performance and limitations of the D.O.R.T method will be considered based on experimental studies of focusing on simple scatterers in anisotropic and inhomogeneous materials. Furthermore, we will introduce a variable, pre-focused DORT, in order to overcome limitations of the D.O.R.T method. The results will be compared to results obtained by conventional focusing methods.---This work was supported by the NSF Industry/University Cooperative Research Center at Iowa State University.

Ultrasonic Waves Reflected from Finite-Sized Shapes with Simple Curvatures

---**Terence P. Lerch** and Giri Raman, Central Michigan University, Industrial and Engineering Technology Department, IT 100, Mt. Pleasant, MI 48859

---Ultrasonic transducer beam models are developed to predict the average received pressure reflecting from the front surface of finite-sized shapes with simple curvatures. First, a general surface integral model is derived which combines the Rayleigh-Sommerfeld integral with the method of stationary phase and the Kirchhoff approximation. Numerical evaluation of the 2-D surface integral is simplified by employing the edge element technique and ray tracing that obeys Snell's Law. Algorithms are developed which determine the Snell's Law ray path for a ray reflected from spherically or cylindrically curved interfaces between any given point source and field point. On-axis scans of the average pressure received at the transducer of the front surface reflections from spheres and cylinders of various sizes are calculated and compared with scans of planar interfaces and point scatterers.

Generation of the Basis Sets for Multi-Gaussian Beam Models

---Hak-Joon Kim[1] and **Lester W. Schmerr Jr.**[1,2], [1]Center for NDE and the [2]Dept. of Aerospace Eng., Iowa State University, Ames, IA 50011

---An ultrasonic beam model is one of key ingredients of an ultrasonic measurement model. A number of ultrasonic beam models have been developed using a superposition of either spherical waves, plane waves, or Gaussian beams. Among those models, the multi-Gaussian beam model is a very attractive choice since it can easily treat transmission and reflection at multiple curved interfaces and propagation through complex media such as anisotropic solids. A key element in the multi-Gaussian model is having the ability to simulate a transducer by superimposing a small number of Gaussian beams (on the order of ten), making it very computationally efficient. Originally, this very limited number of Gaussians was generated by directly fitting the transducer aperture field for a planar, circular transducer to a set of Gaussians using a non-linear least squares fitting procedure. More recently, a similar fitting was done in the k-space domain at the aperture for planar rectangular transducers. Here, we will compare these two fitting procedures and the quality of results they produce for circular, rectangular and elliptical transducers (either planar or focused).---This work was supported by the NSF Industry/University Cooperative Research Center at Iowa State University.

Ultrasonic Generation and Optimization for EMAT

---Xiaoming Jian, **Steve Dixon**, and Rachel S. Edwards, Department of Physics, University of Warwick, Coventry CV4 7AL, United Kingdom

---We present a model for transient ultrasonic wave generation by Electromagnetic Acoustical Transducers (EMATs). Analytical solutions are currently available only for few kinds of sources and our model combines these analytical solutions and numerical computation to predict the ultrasonic field generated by arbitrary sources. This model can be used to calculate bulk waves within samples as well as surface waves on sample surfaces with the advantages of explicit physical meaning and quick processing speed over pure numerical calculations such as the Finite Element Method (FEM). We use the model to explain how static and dynamic magnetic fields generate ultrasonic waves in a sample. We also wish to characterize the EMAT source in detail in order to tailor sources for optimal configurastion for specific NDE applications. A Michelson laser interferometer is used to measure out of plane, surface displacement on the surface, and results are compared to the modelling simulation. Good agreement is observed. Although the modelling is used for EMAT and laser ultrasonic generation here it can be used for any arbitrary source.

Modal Wave Solved in Complex Wave Number

---W.-J. Xu, **F. Jenot**, and M. Ourak, IEMN, Département OAE (UMR CNRS 8520), Université de Valenciennes et du Hainaut Cambrésis, 59313 Valenciennes Cedex 9, France

---Wave propagation in a particular structure is usually studied in its eigen wave solution. These eigen modes are explicitly or implicitly expressed by a characteristic equation. This equation contains real solutions corresponding to harmonic propagation (or resonance) modes and the complex solutions corresponding to evanescent modes (for examples in the case of leaky wave or absorbing media). Many numerical methods are efficient for finding real roots of the equation, but are often difficult to determine complex roots especially when the equation is given implicitly. We propose a numerical method for complex roots research for a complex characteristic equation. In principle, this method is valuable for any complex equation system without restrict conditions. With this method, we studied the modal solution in several particular cases as plate leaky waves in isotropic or anistropic media, and in multi-layered structure as composite materials.

Models of Standard Ultrasonic Reference Reflectors and Their Experimental Validation
---**Ana Lopez-Sanchez**, Hak-Joon Kim, and Lester W. Schmerr, Jr., Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011; Ana Lopez-Sanchez and Lester W. Schmerr, Jr., Dept. of Aerospace Engineering

---In this paper, models of pulse-echo ultrasonic response immersion of three types of reference reflectors are given. These models all result from reciprocity based measurement models. The reference reflectors that will be considered are a flat-bottom hole (FBH), a side-drilled hole (SDH) and a spherical void (SPH). Measurement models suitable for large size reflectors that account for variations of the incident fields over the surface of the reflector are considered as well as measurement models that neglect those variations, which are suitable for small size reflectors. The model-based waveforms for different size and type of reflectors are compared with experimentally determined responses.---Ana Lopez-Sanchez was supported in this work by the National Council for Science and Technology (CONACYT) and also thanks the National Center of Metrology (CENAM). Hak-Joon Kim and Lester W. Schmerr were supported by National Science Foundation Industry/University Cooperative Research Center Program at the Center for NDE at Iowa State University.

The Effect of Slowness Surfaces on the Beam Propagation in General Anisotropic Materials
---**Ruiju Huang** and Lester Schmerr, Jr., Iowa State University, Center for NDE and Department of Aerospace Engineering, 1915 Scholl Road, Ames, IA 50011-3042; Alexander Sedov, Lakehead University, Department of Mechanical Engineering, Thunder Bay, Ontario, P7B 5E1 Canada

---The wave field generated by a transducer radiating through a fluid-solid interface into anisotropic materials is studied. It is well-known that the geometries of the interface have complex effects on the wave propagating through it. Here, the corresponding complex effects of slowness surfaces on the wave propagation in anisotropic materials are illustrated for multi-Gaussian beam models. On-axis and cross-axis responses are given for normal incidence when the interface is not aligned with the particular symmetric plane of the anisotropic materials.---This work was supported by the National Science Foundation Industry/University Cooperative Research Center program at Iowa State University. A. Sedov was supported by the Natural Sciences and Engineering Research Council of Canada.

Simulation of Bulk Ultrasonic Waveform Excited For Two Layer Medium by Using Finite Element Method

---G. Chen, **X. R. Zhang**, and J. C. Chen, State Key Lab. of Modern Acoustics and Institute of Acoustics, Nanjing University, 210093 Nanjing, China

---In this paper, we simulate the bulk waves excited in a two isotropic layer medium with the finite element method in thermo-structural couple field. The results show that: The amplitude of longitudinal wave is related with the position where the laser pulse loaded, such as loading at the surface of the top layer or at the interface between the tow layers, the amplitude of longitudinal wave for the laser loading at medial interface is much bigger than the one for the surface laser loading, while that of transverse waves have not any difference. The top layer medium impedance strongly influence on the waveform of the longitudinal wave received at the central of the sample bottom, but no influence on the transverse waves received at the same point. The longitudinal wave directly arriving, probed at the bottom of sample, is a waveform with some oscillatory amplitudes when the impedance of the top layer is much higher than that of the substrate. The finite element method plays an important role throughout all of our researches, so it is proved efficient in thermo-structural couple research field.

Index Size Determination With Varying Coil Diameters For Improved Automated Eddy Current Inspections On Aerospace Engine-Component

---Ray T. Ko, Brian Frock, Alan P. Berens, David L. Petricola, and **Richard W. Martin,** Structural Integrity Division, University of Dayton Research Institute, Dayton, OH 45469-0120; Matthew Rambo, Advanced Information Engineering Services, Inc., A General Dynamics Company, Dayton, OH

---The effect of index size and coil size on eddy-current inspection throughput rate, and resulting Probability of Detection (POD), are being examined using the Eddy Current Inspection System (ECIS) developed under the USAF's Retirement for Cause (RFC) program. The index size (distance between adjacent scan lines) is typically set to a small fraction of the coil diameter. The inspection throughput rate could be increased by enlarging the index size. To estimate this extended index size, without adversely affecting the POD, one could make a series of tests on reliability specimens, but this is time consuming and cost ineffective. In this study, the line-spread functions of coils of different diameters were experimentally determined by acquiring data with a fine index size on a know target. Estimates of potential maximum index sizes were made by applying a sampling and shifting algorithm to the experimental data. These new maximum indexes were then tested on the reliability specimen for the comparison of POD results with those from the regular index sizes. In addition, better estimates of the new maximum index sizes were obtained by fitting Gaussian functions to the experimentally determined line-spread functions and by applying a low-pass filtering and interpolation algorithm to the experimentally determined line-spread functions.

Decision Making of Aircraft Engine Blades Condition Based on Bispectral Analysis of the Vibroacoustical Signal

---Nadiya I. Bouraou, **Anatoliy G. Protasov**, Olexander V. Zazhistskiy, and Yuriy V. Sopilka, Department for Nondestructive Testing, National Technical University of Ukraine “Kiev Politechnical Institute”, 37 Prospect Peremohy St., Box 1760, Kiev 3056, Ukraine

---This paper is dedicated to further development of low-frequency vibration and vibroacoustical diagnostic methods which are used for the monitoring, diagnosis and evaluation of small fatigue cracks in aircraft engine blades at its stationary and non-stationary operating modes. Low-frequency vibrating and acoustical noises (0-25 kHz) are considered as diagnostic information. These noises are radiated by blades of a rotor which rotates with steady or varying frequency. In this paper the simulation of vibroacoustical signals radiated by the engine turbine at the stationary vibration excitation is carried out for situations when one turbine blade has a small fatigue crack and doesn't have one. Bispectral analysis is used for diagnostic information processing. It demonstrates that appearance and evolution of the fatigue crack in a blade change intensity of global and local extremums of bispectral modules. The results of bispectral processing and Probability Neural Network (PNN) are used to recognize of the turbine blades condition. The efficiency factor is used for precision analysis. This factor is probability of regular recognition and depends on the PNN spread parameter. Efficiency factor dependencies on the spread parameter and the number of learning set images are investigated. The situations when the neural network recognizes incipient cracks in a blade are defined. Obtained results are new and can be used for development of the vibroacoustical monitoring system of the aircraft engine rotary components condition.

Variable-Precision Arithmetic for Solving Inverse Problem of Electrical Impedance Tomography

---Haiyan Tian, **S. Yamada**, and M. Iwahara, Division of Biological Measurement and Applications, Institute of Nature and Environmental Technology, Kanazawa University, 2-40-20 Kodatsuno, Kanazawa 920-8667, Japan; Hao Yang, The Key Laboratory of High Voltage and New Technology, Ministry of Education, Chongqing University, Chongqing 400044, China

---Electrical Impedance Tomography (EIT) is a nondestructive imaging technique, which reconstructs the electrical characteristic tomographs of the object by making electrical measurements on the periphery of the object. In EIT an array of electrodes is connected around the object. Alternating electrical currents are injected through theses electrodes and boundary electrical potentials are measured. Unlike the wave propagation method, EIT gives an approximation of the spatial distribution of impedance (or conductivity) within the detected object, employing the data of injected electrical currents and boundary electrical potentials. The prospect of this technique is to detect flaw inside metal materials or to provide medical images because of its advantages, such as portable, real-time, and safe without radiation. Since EIT belongs to inverse problem of low frequency current field, its reconstruction calculation suffers from ill-posed nonlinear characteristic. In this paper, we propose variable-precision arithmetic to improve the precision of conventional finite-difference in Newton Method. Comparing to exact symbolic arithmetic and floating-point arithmetic, variable-precision arithmetic achieves a good tradeoff between accuracy and computing complexity. The experiment results illustrate that variable-precision arithmetic is valid for solving inverse problem of EIT.

Model Based Study of Three-Point Calibration Standard for Eddy Current Testing

---**B. P. C. Rao** and N. Nakagawa, Center for NDE, Iowa State University, Ames IA 50011

---An eddy current standard is now being developed for standardizing inspections of aerospace structures using pencil type probes, and covers a wide range of materials, instruments and test situations. In order to assess the utility of 3-point calibration and to examine the relationship between signal amplitude and notch depth, boundary element model simulations were carried out. Eddy current signals were predicted from 3 calibration notches for ranges of materials, probes, and frequencies specified in the standard. Specific conclusion were drawn concerning the expected amplitude range for each of the three notches and the suitability of using vertical component or amplitude or phase angle alone for defect detection and characterization. Toward supporting the predicted observations, validation studies were carried out on two sets of calibration standards available. Details of the standard, modeled parameter space and results from the simulation studies are discussed in the paper. The importance of this study comes from the fact that a complete experimental study seeking the above information is rather extensive and prohibitively expensive if one attempts to cover the entire ranges of materials and the other variables. The model based study being presented here is, on the other hand, efficient and inexpensive.---This material is based on the work supported by the Federal Aviation Administration, and performed at Center for NDE, Iowa State University, as a part of the Center for Aviation Systems Reliability program.

Comparison of ECT Signals and Calibration Procedures for Absolute and Differential Probes in Steam Generator Tubes

---**Young-Kil Shin** and Yun-Tai Lee, School of Electronic and Information Engineering, Kunsan National University, San 68, Miryong-dong, Kunsan, Chonbuk, 573-701, Korea: Myung-Ho Song, Korea Institute of Nuclear Safety, 19, Kusong-Dong, Yousung-Ku, Taejon, 305-338, Korea: Tae-Eon Chung, Korea Advanced Inspection Technology, P. O. Box 105, Yousung-Ku, Taejon, 305-600, Korea

---Eddy current testing (ECT) is widely used in the inspection of steam generator (SG) tubes. There are basically two types of bobbin probes; one is differential and the other is absolute. Differential probes are frequently used for fast inspection of free span and their signals are obtained by subtracting two coil impedances. However, signal interpretation of differential signal is not easy since they are processed to eliminate common factors influencing the two coils. Absolute signals, on the other hand, are rather straightforward to analyze, but they are apt to be influenced by numerous factors. In this work, calibration procedures for the two signals are compared and their equivalence will be discussed. Also, the two signals from a same defect will be compared and advantage of one signal over the other for certain defects will be discussed.

Scheme for Characterization of Metal-Loss Defects Using MFL Signal From Pipeline Inspection

---**Valery P. Lunin**, Electrical Engineering and Introscopy Department, Moscow Power Engineering Institute (Technical University), 14 Krasnokazarmennaja, 111250, Russia

---Magnetic flux leakage (MFL) technique is widely used inspecting method. It is particular used in intelligent pigs for detection and characterization of metal-loss defects, mainly due to corrosion, in ferromagnetic oil/gas pipelines. Accurate analysis of obtained MFL inspection data is quite difficult task which requires a huge amount of work by experienced operator. This is quite expensive therefore MFL automatic characterization scheme is needed to effectively aid the analysts. Such quantitative characterization scheme have been successfully created and implemented including signal preprocessing, classification and parameterization components. Series of experiments was performed on test pipe (wall thickness 8mm and outer diameter 530 mm) with more than 50 metal-loss defects (corrosion-type and cracks) of different shapes and sizes. Comparison of MFL signals from these experiments with appropriate model-based calculations is presented too.

Application of Near-Field Microwave and Millimeter Wave Nondestructive Testing for Evaluation of Fiber Breakage and Orientation in Carbon Composite Structures

---**Sergey Kharkovsky** and Reza Zoughi, Applied Microwave Nondestructive Testing Laboratory, Electrical and Computer Engineering Department, University of Missouri-Rolla, 228 Emerson Electric Co. Hall, 1870 Miner Circle, Rolla, MO 65409-0040

---Composite structures with carbon fiber reinforced polymer (CFRP) laminates are increasingly used in many critical applications including those in the airspace industry, civil infrastructure, etc. CFRP laminates provide additional flexural and shear strengths to the structure to which they are bonded. However, the presence of defects in the form of disbond, delamination, impact damage, and fiber breakage can significantly degrade their usefulness. Multi-laminate CFRP in which fibers may be misaligned, with respect to the desired strengthening direction, can significantly decrease the effectiveness of load transfer. Near-field microwave and millimeter wave nondestructive testing and evaluation techniques have the ability to detect and evaluate these defects and to check for fiber misalignment and breakage. This paper presents the results of an investigation into the use of near-field microwave and millimeter wave nondestructive testing and evaluation techniques for detecting and characterizing CFRP laminates consisting of discontinues such as fiber breakages, gaps, etc. Microwave images of these discontinues are obtained by raster scanning a variety of CFRP laminates. Single fiber bundles are also scanned to obtain characteristic images of discontinues, which are then used for analyzing images obtained above. The results show that these defects are easily detected and evaluated, in addition to detecting laminate alignment with high degree of accuracy.

Evaluating the Degree of Degradation of Resistance of Material in "Hot Spots" of Active Structures to Crack Propagation

---**Vladimir Makhnenko**, E. O. Paton Electric Welding Institute of the National Academy of Sciences of Ukraine, 11 Bozhenko Street, 03680, Kyiv, Ukraine

---Evaluation of the state of durable structures operating under conditions that cause changes in material properties requires diagnostics of the ability of the material to resist this or that type of fracture. In this respect, of great importance is the possibility to generate data on resistance of the material in "hot spots" of the structures to propagation of a corresponding type of cracks (fatigue, corrosion, creep or combinations of the above three canonical types). The paper gives examples of the impact of service conditions on changes in resistance of welded joints in load-carrying structures of steam generators at nuclear power units to growth of stress corrosion cracks. The issue of application of non-destructive evaluation methods for predicting the degree of degradation of resistance of metal within the zone of welded joints to growth of stress corrosion cracks is discussed.

Computation of Grain-Noise Scattering Coefficients for Ultrasonic Pitch/Catch Inspections of Metals

---**F. J. Margetan**, Linxiao Yu, and R. B. Thompson, Center for NDE, Iowa State University, 1915 Scholl Road, Ames, IA 50011

---One limiting factor in the detection of internal defects in metals is so-called "grain noise" which arises from the scattering of sound by microstructural boundaries. For pulse/echo inspections, independent-scatterer models (which ignore multiple scattering events) have been developed and applied successfully to predict backscattered grain noise characteristics in many situations of practical importance, such as inspections of jet-engine billets and forgings. In this paper we consider the extension of the independent-scatterer noise models to pitch-catch geometries. Signal-to-grain-noise (S/N) ratios for small internal defects depend principally on three quantities: (1) a grain-noise scattering coefficient η which is a property of the microstructure alone; (2) the scattering ability of the defect; and (3) the volume of insonified grains which can produce grain-scattered signals arriving at the same time as the defect signal. In this work we focus on the calculation of η which is a function of frequency, scattering angle, and the incident and scattered wave types. For simple single-phase cubic and hexagonal metals, formulas are developed which express η in terms of the single-crystal elastic constants and the mean grain diameter. We examine the dependence of η on scattering angle and wave type, and briefly describe how the results might be of use when designing inspections.---This work was jointly supported by Pratt & Whitney, a United Technologies Company, and by the Federal Aviation Administration under Contract #DTFA03-98-D-00008, Delivery Order #IA029 and performed at Iowa State University's Center for NDE as part of the Engine Titanium Consortium program, through the Airworthiness Assurance Center of Excellence.

Nondestructive Testing of Aeronautical Bearing Ceramic Balls by Resonant Ultrasound Spectroscopy

---S. Petit, M. Duquennoy, M. Ouaftouh, and **F. Jenot**, IEMN, Département OAE (UMR CNRS 8520), Université de Valenciennes et du Hainaut Cambrésis, 59313 Valenciennes Cedex 9, France; S. Petit and J. Gualandri, SNRA, Al. n°2 Batterie 900 Rouvignies, 59309 Valenciennes, France

---The bearing ceramic balls are progressively introduced in the aeronautic and spatial sectors. But the small defects in the ceramic materials (silicon nitride) are critical and they are particularly prejudicial when they are located close to the surface. It is the raison why we propose a nondestructive testing method enable to analyze all the surface of the ball with very short times. This method is based on the resonant ultrasound spectroscopy. The spheroidal vibrations in the ball are excited with a piezoelectric transducer on a large range of frequency (500kHz-45Mhz) and the resonances are detected with a laser interferometer probe. The elastic parameters of balls and the velocities of surface waves are determined from resonance spectrum. The high frequency resonances enable to test the very near zone of the ball surface.

Hidden Corrosion Detection in Aircraft Metallic Structures Using Lamb Waves

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---A nondestructive and noncontact method using Lamb waves is presented to detect back surface corrosion in plate-like structure. Lamb waves are resonant waves and propagate on long distances allowing inspections of very large area such as planes. In this work Lamb waves are generated by a pulsed laser in an aluminum 2024 T3 aeronautical structure, and the out of plane displacements produced by ultrasonic waves are measured by a heterodyne interferometer. A time-frequency representation of the signal is used. The continuous wavelet transform and its scalogram allow the identification of the modes and a direct observation of dispersion curves. The presence of corrosion is characterized by the attenuation of S1 and S0 modes. In order to improve the optimization of S1 and S0 generation a particular shape is given to the spot of the laser. The study of some zones on the scalogram allows the cartography of a corroded area located on a piece of wing with a clear differentiation of the presence of the stiffeners.

Two-Dimensional Thermoelastic Analysis of Diamond/Si Structures Heated by a Pulsed Gaussian Laser Beam

---X. B . Mi and **S. Y. Zhang**, Lab of Modern Acoustics, Institute of Acoustics, Nanjing University, Nanjing, 210093, China (PRC)

---Firstly, a 2D thermoelastic displacement model for multilayered thin films irradiated by a Gaussian laser beam is presented. Then by using the finite element method (FEM), the transient temperature filed and thermoelastic displacement of the bilayered structures of transparent thin diamond films deposited on opaque silicon substrates are numerically obtained. Besides, for verifying the theory, the thermoelastic analysis is also performed for the bilayerd structures of ZnO film deposited on silicon substrate. For both of the films the longitudinal and transverse waves are well simulated and the results also show that due to its high thermal diffusivity, generally the thermal diffusion of the diamond film cannot be neglected any more. Moreover, the influences of the heat conductivity variations of the diamond film and silicon substrate on the normal displacement of the surface of the bilayered structures are also performed. The results show that the normal displacement does change with the variation of the heat conductivity of the diamond film and silicon substrate. However, due to the high heat conductivity of the diamond film, the influence of the heat conductivity variation of diamond film on the normal displacement is much bigger than that of the silicon substrate.

Mean Grain Size Determination in Marbles by Ultrasonic Velocity Techniques

---**Ismail H. Sarpun**, Physics Dept., Afyon Kocatepe University, Afyon, Turkey; M. Selami Kilickaya, Physics Dept., Osmangazi University, Eskisehir, Turkey; Sabri Tuncel, Marmara Research Center, TUBITAK, Kocaeli, Turkey

---In this paper we have studied mean grain size determination of some marbles by using ultrasonic velocity measurements. First we have measured ultrasonic longitudinal velocity in marble samples, after we have calculated mean grain size of marble samples. By using this data, we have represented ultrasonic velocity - mean grain size master graph. Using this graph we have compared mean grain size of marble samples by optic microscope images. At the end we have found that ultrasonic velocity technique is suitable for mean grain size determination in marble samples.

Spectral Study of Ultrasonic Waves in a Beta-C Titanium Alloy

---**Brenda L. Buitrago**, Ignacio A. Irausquin, and Johnny A. Mendoza, Dpto. De Tecnología Industrial, Universidad Simón Bolívar, Sede del Litoral, Caracas 1080, Venezuela

---Beta-C Titanium Alloys are widely used in aerospace industry. Since these components need to be inspected for possible damage due to in-service conditions, and since ultrasound is one of the inspection techniques that can provide a more thorough evaluation, it is necessary to understand the behavior of ultrasonic waves in these media. In order to do this a set of low power transducers, with frequencies of 1.5, 5 and 10 MHz, were used to determine the wave velocity, attenuation and broadening of ultrasonic pulses traversing Ti-3Al-8V-6Cr-4Zr-4Mo plates. Also, the spectral analysis performed on the returned pulses provided the necessary information to understand the pulse broadening observed at low frequencies. In these studies the ultrasonic pulses were generated by a modern ultrasound field equipment, whereas the spectral analysis was performed by a computer connected to a fast oscilloscope that was capturing the signal returning from the plates. The experimental data is presented as well as a discussion on the effects of the interaction of longitudinal ultrasonic waves in the Ti-3Al-8V-6Cr-4Zr-4Mo alloy. From this the proper inspection frequencies was obtained.

Materials Characterization for Prognostic Structural Diagnostic

---**B. Boro Djordjevic**, Johns Hopkins University, 810 Wyman Park Drive, Suite G010, Baltimore, MD 21211 and Shant Kenderian, Jet Propulsion Laboratory, Pasadena, CA

---Characterizing early material degradation and properties change to anticipate stages of damage can be achieved using advanced ultrasonic sensing and analysis methods. Incipient mechanical damage is sensed by advanced ultrasonic measurements of materials properties and material micro structural changes inclusive of onset of global damage such as cracks. Using measurements data the prognostic models can be developed to assess structural integrity and degradation of the structures. We have performed extensive development and application of ultrasonic to structural evaluation in transportation and aerospace applications. Measurements were applied for range of materials and structural tests using remote and non-contact transduction methods. This paper reviews the application of in-situ and hybrid non-contact remote ultrasonic sensing using laser generation and air-coupled detection arrangements for early diagnostic of material degradation. The test methodology is applicable for metal and composite materials. Data analysis is applied to measuring the incipient damage development such as loss of elastic modulus as well as the characterization of the defect developments such as cracks. The hybrid ultrasonic configurations enable improved test capability in 100 kHz to 2 MHz. This frequency regime is useful in practical materials and structures and has been successfully applied to range of structures tests including measurements on aircraft parts or testing of railway track. Spatially formed laser-source generation methods enable controlled directivity and waveform shape for select and enhance stress wave modes with improved acoustical energy partitioning in the test structures. The tests with advanced signal analysis enable single impulse testing of components including characterization of composite materials. The remote and non-contact acoustical sources are very flexible and enable generation of plate or surface waves that cannot be generated using conventional contact transducers. This paper presents sensing methodology, instrumentation and signal processing used in the ultrasonic application of in-situ and non-contact ultrasonic measurements for prognostic structural NDE.

High Temperature Monitoring of Refractory Wall Recession Using Frequency-Modulated Continuous-Wave (FM-CW) Radar Techniques

---Bivin Varghese, Chad DeConick, Greg Cartee, and **Reza Zoughi,** Applied Microwave NDT Lab., Electrical and Computer Engineering Department, University of Missouri-Rolla, Rolla, MO 65409; Mariano Velez and Robert Moore, Ceramic Engineering Department, University of Missouri-Rolla, Rolla, MO 65409

---Furnaces are the most crucial components in the glass and metallurgical industry. Like any other components in an industry, furnaces require periodic maintenance and repair. Higher fuel consumption, low production and safety are issues that accompany delayed maintenance. As a result of the competitive market facing these industries, longer furnace lifetime with shorter maintenance downtime are increasingly required. Consequently, there is a need to know the state of a refractory wall to prevent premature or unnecessary maintenance shutdowns. To this end a frequency-modulated continuos-wave (FM-CW) radar operating at X-band was designed and used for this purpose. Additionally, this radar was used to evaluate the thickness of refractory bricks as a function of temperature in a furnace used for laboratory research. It was found that this type of a radar system is capable of evaluating refractory wall thickness in a high temperature environment. Moreover, the results as a function of temperature, also depend upon the type of refractory used. The results of this investigation will be presented in this paper.

Analysis of Microstructure Using Thermoelectric Diagnostics for Nondestructive Evaluation of Materials

---**Yeong-Do Park**, Victor Kaydanov, Brajendra Mishra, and David L. Olson, Colorado School of Mines, Department of Metallurgical and Materials Engineering, Golden, CO 80401

---Measurements of thermoelectric power (TEP) were used to evaluate microstructural analysis in HSLA steel weldments and retained austenite volume fraction for TRIP steel. First, the measurements of TEP for weld microstructure across weldments have shown good correlation with the hardness profile. Also, TEP measurements on HSLA steel weld metal microstructures were conducted with different welding current levels, which changes the weld cooling rate. The different TEP values indicated that changes in weld microstructure can be correlated with measured TEP values. Second, it has been demonstrated that retained austenite volume fraction were well correlated to TEP measurements for transformation induced plasticity (TRIP) steels. The results suggest that TEP measurements can be correlated to retained austenite volume fraction for TRIP steels, which do not have the same chemical composition and thermal heat treatment processes. The retained austenite volume fraction also was measured by X-ray diffraction (XRD) method. Retained austenite has been correlated to increasing the hydrogen assisted and stress corrosion cracking problems in higher strength steels. With the introduction of these advanced TEP coefficient measurement techniques, the welding and steel industry will be using analytical tools similar to those instruments applied in the semi-conductor industry.

SESSION 12

TERAHERTZ NDE

H. Ringermacher, Chairperson

Parker Ballroom C

3:30 PM **Technology and Applications of Terahertz Imaging Nondestructive Examination: Inspection of Space Shuttle Sprayed on Foam Insulation**

---**D. Zimdars**, J. A. Valdmanis, J. S. White, G. Stuk, and S. Williamson, Picometrix, Inc., 2925 Boardwalk Drive, Ann Arbor, MI 48108; W. P. Winfree and E. I. Madaras, Nondestructive Evaluation Sciences Branch, NASA Langley Research Center, Hampton, VA 23681

4:10 PM **Detection and Characterization of Flaws in Foam with Pulsed Terahertz Frequency Electromagnetic Waves**

---**W. P. Winfree**, E. I. Madaras, and P. A. Howell, NASA Langley Research Center, MS 231, Hampton, VA 23681

4:30 PM **Characteristics of Terahertz Propagation in Porous Polymer and Ceramic Materials**

---**C. Dodson** and J. Spicer, Johns Hopkins University, Center for NDE, 3400 N. Charles Street, Baltimore, MD 21218

4:50 PM **Noninvasive Study of Explosive Materials by THZ Time Domain Spectroscopy**

---**F. Huang**, J. Federici, and D. Gary, Department of Physics, New Jersey Institute of Technology, Newark, NJ 07102; R. Barat, Otto York Department of Chemical Engineering, New Jersey Institute of Technology, Newark, NJ 07102; D. Zimdars, Picometrix, Inc., 2925 Boardwalk, Ann Arbor, MI 48104-6765

Technology and Applications of Terahertz Imaging Non-destructive Examination: Inspection of Space Shuttle Sprayed on Foam Insulation

---**David Zimdars**, J. A. Valdmanis, Jeffrey S. White, G. Stuk, and S. Williamson, Picometrix, Inc., 2925 Boardwalk Drive, Ann Arbor, MI 48108; William P. Winfree and Eric I. Madaras, Nondestructive Evaluation Sciences Branch, NASA Langley Research Center, Hampton, VA

---The technology and applications of time domain terahertz (THz) imaging to non-destructive examination (NDE) will be discussed. The principles, methods, and unique advantages of THz NDE will be described. THz imaging has shown great promise in 2 and 3 dimensional non-contact inspection of non-conductive materials such as plastics, foam, composites, ceramics, paper, wood and glass. THz imaging employs safe low power non-ionizing electromagnetic pulses, which produce images with lateral resolution <200 microns, and depth resolution <50 microns. In addition to density and attenuation measurements, THz pulses can be analyzed spectroscopically to reveal chemical content. Recently, highly integrated turn-key THz imaging systems have been introduced commercially. As an example application, we will demonstrate the detection of voids and disbonds intentionally incorporated within the sprayed on foam insulation of a space shuttle external tank mock-up segment using time domain terahertz (a.k.a T-Ray) imaging. An industrially hardened THz scanning system which has been deployed to scan the space shuttle tank with small remote THz transceiver on a 30 meter fiber optic umbilical, will be described. Additional terahertz security imaging applications for the detection of weapons and explosives will also be discussed, as well as the application of terahertz sensors for high speed industrial process monitoring and quality control.

Detection and Characterization of Flaws in Foam with Pulsed Terahertz Frequency Electromagnetic Waves

---**William P. Winfree**, Eric I. Madaras, and Patricia A. Howell, NASA Langley Research Center, Mail Stop 231, Hampton, VA 23681

---An emerging technology that may have broad application for quantitative evaluation of critical materials and structures is electromagnetic waves at terahertz frequencies. The short wavelengths of these terahertz pulses make them ideal for imaging flaws in dielectric materials. This paper examines the application of terahertz pulses for flaw detection in dielectric foams. Of particular interest is the detection of voids and delaminations, encapsulated in the foam or at the interface between the foam and a metal backing, often in the vicinity of geometrically complicated structures. The technique is shown to be capable of imaging voids and delaminations with lateral sizes of less than 1 cm through as much as 20 cm of foam. Methods for reducing the temporal responses of the terahertz pulses to improve flaw detection and yield quantitative characterizations of the size and location of the flaws are discussed.

Characteristics of Terahertz Propagation in Porous Polymer and Ceramic Materials

---**Caroline Dodson** and James Spicer, Johns Hopkins University, Center for NDE, 3400 N. Charles Street, Baltimore, MD 21218

---The fundamental nature of porous polymer and ceramic materials often leads to difficulties in making through thickness inspection of these materials. Often used for insulation applications, thermal imaging can be ineffective owing to the slow thermal diffusion that occurs. Acoustic imaging can be problematic since sound is successively scattered producing very large acoustic attenuations. Direct optical inspection is often difficult since these materials can be optically opaque. Terahertz radiation, because of its ability to penetrate most insulating materials, makes it a viable method to evaluate ceramics and polymers. Imaging of voids and defects in insulators is also possible. In this work we focus on the propagation of terahertz radiation in porous polymers and ceramics from which the optical properties at terahertz frequencies and physical structure of these materials can be determined. A terahertz time domain system with a GaAs photoconductive emitter and a ZnTe electro-optic detector was used to produce and collect the transmitted THz signal. Studies were conducted on polyimide foam, porous alumina and silicon carbide ceramics. Using the temporal delay, phase, amplitude, and frequency cut-off information the thickness, index of refraction, and other physical and optical properties of the various foamed/porous materials were determined.

Noninvasive Study of Explosive Materials by THz Time Domain Spectroscopy

---**Feng Huang**, John Federici, and Dale Gary, Department of Physics, New Jersey Institute of Technology, Newark, NJ 07102; Robert Barat, Otto York Department of Chemical Engineering, New Jersey Institute of Technology, Newark, NJ 07102; David Zimdars, Picometrix, Inc., 2925 Boardwalk, Ann Arbor, MI 48104-6765

---Transmission and reflection spectroscopy in the Terahertz (THz) range (~ 3 to 0.1 mm) is potentially useful for the detection of explosives and biological agents. This paper describes the use of THz time domain spectroscopy (TDS) applied in transmission to the 1,3,5 trinitro-s-triazine (RDX), C4, Ammonium Nitrate, etc. Samples were also subjected to Fourier Transform Infrared (FTIR) spectroscopy over the same range for comparison. General agreement confirms the absorption features found. We applied density function approach and transfer function for distinguishing spectral features. The nature of THz technology applied in the noninvasive detection of such material is discussed.

SESSION 13
MATERIAL PROPERTIES II
M. Greenwood, Chairperson
Parker Ballroom A

3:30 PM **Identification of Material Property Changes Due to Impact Testing by Ultrasonic Harmonic Measurement**
---**S. Lee**, K. Chang, B. Kim, and C. Shim, Korea Atomic Energy Research Institute, Daejeon, Korea

3:50 PM **Measurement of Elastic Moduli of a Fe-Si-B Amorphous Alloy Thin Film by EMAR and RUS**
---**R. Tarumi**, A. Shibata, H. Ogi, and M. Hirao, Graduate School of Engineering Science, Osaka University, Toyonaka Osaka, Japan; K. Takashima and Y. Higo, Precision and Intelligence Laboratory, Tokyo Institute of Technology, Yokohama, Kanagawa, Japan

4:10 PM **Angular Dependence of Wave Attenuation in Textured Media**
---**L. Yang** and J. A. Turner, Department of Engineering Mechanics, W317.4 Nebraska Hall, University of Nebraska, Lincoln, NE 68588-0526

4:30 PM **An Improved Model Description of the Stress Effects on Ferromagnetic Materials**
---**L. Li**, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

4:50 PM **Models of Ultrasonic Bulk Wave Propagation in Thermosets with Spatially Varying Viscoelastic Properties**
---**R. E. Challis**, F. Blarel, M. E. Unwin, and A. Kalashnikov, UNDE Laboratory, School of Electrical and Electronic Engineering, University of Nottingham, United Kingdom

Identification of Material Property Changes Due to Impact Testing by Ultrasonic Harmonic Measurement

---**SamLai Lee**, KeeOk Chang, ByoungChul Kim, and ChulMoo Shim, Korea Atomic Energy Research Institute, Daejeon, Korea

---Charpy impact testing involved in materials surveillance program of nuclear reactor pressure vessel is performed in order to evaluate the degree of degradation of reactor vessel material due to radiation embrittlement. However, a limited number of specimens are only available realistically during construction due to space limitation, causing shortage of sufficient information for maintaining integrity. Due to this limited number of specimens, broken specimens are sometimes reconstituted for more tests, although metallurgical changes might have been already occurred realistically. Ultrasonic analysis using the non-linearity measurement through a relative attenuation change at the different harmonic frequency for the unbroken as well as the broken Charpy impact specimens which were composed of base and weld metal has been performed in order to understand the metallurgical characteristics of the specimen after impact testing. The slope of the relative attenuation change measured by the fundamental, 2nd and 3rd harmonic frequency was studied for the unbroken as well as broken base and weld metal. The results showed that visible discrepancies in the slope of the relative attenuation change were observed near the broken area in the weld specimen compared to the base metal specimen for the harmonic frequencies, whereas no change was noticed in the fundamental frequency measurement for both specimens.

Measurement of Elastic Moduli of a Fe-Si-B Amorphous Alloy Thin Film by EMAR and RUS

---**Ryuichi Tarumi**, Akira Shibata, Hirotsugu Ogi, and Masahiko Hirao, Graduate School of Engineering Science, Osaka University, Toyonaka, Osaka, Japan; Kazuki Takashima and Yakichi Higo, Precision and Intelligence Laboratory, Tokyo Institute of Technology, Yokohama, Kanagawa, Japan

---It has been successively determined the elastic moduli of a Fe-Si-B amorphous alloy thin film using electromagnetic acoustic resonance (EMAR) and resonant ultrasound spectroscopy coupled with a modified laser-doppler interferometry (RUS/Laser). Using a thickness resonance EMAR technique, in-plane shear moduli of c44 and c55 are determined to be 73 and 71 GPa indicating that the amorphous alloy thin film has a transverse elastic isotropy (hexagonal type elastic symmetry). On the other hand, the other independent (hexagonal type) elastic moduli of c11, c13, c33, c66 are determined using a modified RUS/Laser technique. These are, c11 = 325, c13 = 168, c33 = 323 and c66 = 78 GPa, respectively. From Hill approximation of the elastic moduli, acoustic Debye temperature, is calculated as to be 486 K which is in good agreement with that of pure a-Fe (= 479 K) at a room temperature. Shear anisotropy between in-plane and out-of-plane directions becomes Ps = 0.92 which shows the existence of elastic anisotropy even in the amorphous structure. Origins of the elastic anisotropy have been discussed.

Angular Dependence of Wave Attenuation in Textured Media

---**Liyong Yang** and Joseph A. Turner, Dept. of Engineering Mechanics, W317.4 Nebraska Hall, University of Nebraska, Lincoln, NE 68588-0526

---Knowledge of the anisotropic nature of wave propagation and scattering in textured materials is critical for use with ultrasonic nondestructive techniques. In this presentation, a model for wave propagation and scattering in polycrystalline materials with texture is presented. The derivation is formulated using the anisotropic Green's dyadic. The angular dependence of wave attenuation of the three wave modes (quasi-longitudinal and two quasi-shear) is discussed for a general orthorhombic aggregate comprised of cubic crystallites. In particular, the dependence of attenuation on propagation direction and frequency is investigated for specific examples with given orientation distribution coefficients (ODCs). The contributions to the attenuation from texture are discussed as is the influence of wave polarization vectors. The results are anticipated to advance the field of materials characterization of textured media.---Work supported by DOE.

An Improved Model Description of the Stress Effects on Ferromagnetic Materials

---**L. Li**, Center for NDE, Iowa State University, Ames, IA 50011

---An accurate model description of the effects of stress on magnetic properties of materials has become increasingly important to quantitative analysis of magnetic NDE measurement results, and to the development of magnetostrictive sensors for NDE applications. The model of the magnetomechanical effect developed in the previous work provides the basis for describing changes of magnetization under stresses. However there is a need to further improve the model to deal with materials which have different magnetomechanical properties or anisotropy. We have recently performed modeling studies to investigate how stress induced magnetic anisotropy affects hysteretic and anhysteretic magnetization curves as they approach saturation. The result of this work has led to an improved model which takes into account the stress dependence of the input model parameters. The extended model was validated with respect to its capability of describing the changes of magnetization in response to varying mechanical stress under constant applied fields, and to varying magnetic field under constant applied stresses. Simulation results are compared to the measurement results obtained from materials with both positive and negative magnetostrictions, including steel and nickel.---This research was supported by the NSF Industry/University Cooperative Research Program of the Center for NDE at Iowa State University.

Models of Ultrasonic Bulk Wave Propagation in Thermosets with Spatially Varying Viscoelastic Properties

---**Richard E. Challis**, Fabien Blarel, Marion E. Unwin, and Alexander Kalashnikov, UNDE Laboratory, School of Electrical and Electronic Engineering, University of Nottingham, United Kingdom

---The quality and spatial uniformity of thermoset curing processes is of growing importance in the aerospace and other industries involved with safety critical assemblies. Due to local exotherm the extent of cure varies across the thickness of a thermoset to an extent which increases with the overall thickness dimension, bringing about spatial variation in viscoelastic properties. This paper develops an effective means to model ultrasonic bulk wave propagation across a specimen whose viscoelastic constants vary with depth, the motivation being to develop NDE methods for thick thermoset specimens likely to be found in passenger aircraft of the future. First, ultrasonic compression wave attenuation and phase velocity frequency domain spectra are analysed by fitting to empirical viscoelastic models base on Havriliak-Negami and Cole-Davidson formulations. These fits provide a dispersion parameter which, we believe, can be used as an index of molecular polydispersity in the curing material. A second fitting procedure then enables the identification of the time constants and weights of a group of single time constant (Debye) relaxation processes which model observed propagation data. The resulting Debye models are then converted into elemental electric circuit analogs which represent wave propagation through micron-scale elements of physical material. These elemental analogs are integrated into an overall circuit model in a manner which mimics property variation with spatial position. SPICE circuit simulation software is then applied to the overall circuit to give a simulation of acoustic wave propagation across a realistic depth of material.

SESSION 14
FILMS AND COATINGS
D. C. Hurley, Chairperson
Parker Ballroom B

3:30 PM **Ultrasonic Characterization of the Mechanical Properties of Nano-Structured Diamond-Like Carbon Thin Films**
---**F. Zhang** and S. Krishnaswamy, Northwestern University, Center for Quality Engineering Failure Prevention, Room 331, Catalysis Building, 2137 Tech Drive, Evanston, IL 60208

3:50 PM **Acoustical Methods to Determine Thin-Film and Nanoscale Mechanical Properties**
---**D. C. Hurley**, R. H. Geiss, M. Kopycinska-Mueller, J. Mueller, D. T. Read, and J. E. Wright, Materials Reliability Division, National Institute of Standards & Technology, Boulder, CO 80305-3328; N. M. Jennett and T. S. Maxwell, Materials Centre, National Physical Laboratory, Teddington, Middlesex, United Kingdom

4:10 PM **Brillouin Scattering and Laser-SAW Technique for Elastic Property Characterization of Micrometer DLC Films**
---**P. V. Zinin**, SOEST, University of Hawaii, Honolulu, HI 96822-2219; S. Berezina, University of Zilina, Zilina, Slovak Republic; D. Fei and D. A. Rebinsky, Technical Center, Caterpillar Inc., Peoria, IL 61629

4:30 PM **Identification of AE Bursts by Classification of Physical and Statistical Parameters**
---J. I. Mieza, M. E. Oliveto, **M. I. López Pumarega**, M. Armeite, and J. E. Ruzzante, Ensayos No Destructivos y Estructurales, Comisión Nacional de Energia Atómica, San Martin, Buenos Aires, Argentina; R. Piotrkowski, Escuela de Ciencia y Tecnologia, Universidad Nacional General San Martin, San Martin, Buenos Aires, Argentina

4:50 PM **Characterization of Imperfect Bond Between Coating and Substrate**
---M. Doxbeck, **M. Hussain**, and J. Frankel, Watervliet Arsenal, Benet Labs, Watervliet, NY 12189

Ultrasonic Characterization of the Mechanical Properties of Nano-Structured Diamond-Like Carbon Thin Films

---**Feifei Zhang** and Sridhar Krishnaswamy, Northwestern University, Center for Quality Engineering, Rm. 331, Catalysis Building, 2137 Tech Drive, Evanston, IL 60208

---Diamond-like Carbon coatings are used in tribological applications because of their excellent mechanical performance as ultra-hard coatings. Unfortunately, the mechanical properties of these coatings are strongly dependent on the material composition as well as on manufacturing process. It is essential that techniques be developed for convenient, precise, in-situ characterization of the mechanical properties of DLC coatings that can be used during the manufacturing process. In this work, the elastic properties of Chrome and Tungsten DLC coatings are measured using three ultrasonic techniques: line-focus acoustic microscopy, guided-wave laser ultrasonics, and femtosecond ultrafast pump-probe technique. For the first two approaches, the dispersion curves for pure or leaky surface acoustic waves were measured over a wide frequency range and the elastic properties were derived by fitting the experimental dispersion curves to an appropriate model. The pump-probe technique provides direct information about the elastic moduli using bulk waves launched normally into the coatings. Of these methods, only guided-wave laser ultrasonics is potentially a real-time monitoring technique. Acoustic microscopy and pump-probe techniques are used here primarily to cross-correlate the results obtained using guided-wave laser ultrasonics. The mechanical properties obtained using the three ultrasonic methods are also compared with nano-indentation tests performed on the same specimens.

Acoustical Methods to Determine Thin-Film and Nanoscale Mechanical Properties

---**Donna C. Hurley**, Roy H. Geiss, Malgorzata Kopycinska-Mueller, Jens Mueller, David T. Read, and Joyce E. Wright, Materials Reliability Division, National Institute of Standards & Technology, Boulder, CO 80305-3328; Nigel M. Jennett and Tony S. Maxwell, Materials Centre, National Physical Laboratory,Teddington, Middlesex, United Kingdom

---As length scales continue to shrink, new tools are needed to measure mechanical properties. We are developing two such tools using different nondestructive acoustical techniques. Surface acoustic wave spectroscopy (SAWS) uses laser-ultrasonic methods to measure the phase velocity dispersion relation over several hundred megahertz. SAWS can accurately assess sub-micrometer-thick films, although it interrogates a centimeter-sized area. In contrast, atomic force acoustic microscopy (AFAM) has lateral spatial resolution of tens of nanometers. AFAM involves acoustical excitation of flexural resonances in the cantilever of an atomic force microscope. Here, we present AFAM and SAWS results for nickel films with thicknesses from 50 to 800 nm. For the thickest film, acoustical data are compared to results from microtensile testing and nanoindentation. Results are in only fair agreement if elastic isotropy is assumed. However, very good agreement is achieved using a transversely isotropic film model. This is consistent with a preferential <111> film texture, confirmed by x-ray analysis. We also discuss how SAWS results can be analyzed to obtain other information such as film thickness. Our results demonstrate how comparing results from several techniques yields more information about the film properties than that provided by any one measurement.

Brillouin Scattering and Laser-SAW Technique for Elastic Property Characterization of Micrometer DLC Films
---**Pavel V. Zinin,** SOEST, University of Hawaii, Honolulu, HI 96822-2219; Sofia Berezina, University of Zilina, Zilina, Slovak Republic; Dong Fei and Douglas A. Rebinsky, Technical Center, Caterpillar Inc., Peoria, IL

---Micron thick coatings and films are widely used in industry. However, measuring the elastic properties of these films is problematic because none of the well known techniques such as acoustic microscopy, surface Brillouin scattering (SBS), nanoindentation, and laser-SAW (surface acoustic waves) techniques are able to measure all elastic moduli of the coatings. For example, for films thicker than 500 nm, the wavelength of surface acoustic wave in the frequency range available for SBS is smaller than the film thickness, and the SBS measures only the Rayleigh wave of the film. The laser-SAW technique, on the other hand, measures only the low-frequency portion of the surface acoustic wave dispersion, and can estimate only one elastic modulus of the film (typically Young's modulus). In this work we have combined the two methods to determine both bulk and shear moduli of diamond-like carbon (DLC) films. It was found that reasonable estimates could be obtained for the velocities of the longitudinal waves and shear waves, and hence for bulk and shear moduli of the film. It was found that measurement error of the Poisson's ratio was relatively large.---This research was supported through a NIST Advanced Technology Program, cooperative agreement number 70NANBOH3048.

Identification of AE Bursts By Classification of Physical and Statistical Parameters
---Juan I. Mieza, Maria E. Oliveto, **Maria Isabel López Pumarega**, Maria Armeite, and Jose E. Ruzzante, Ensayos No Destructivos y Estructurales, Comisión Nacional de Energia Atómica, San Martin, Buenos Aires, Argentina; Rosa Piotrkowski, Escuela de Ciencia y Tecnologia, Universidad Nacional General San Martin, San Martin, Buenos Aires, Argentina

---Physical and statistical parameters extracted from Acoustic Emission (AE) bursts were analyzed. Bursts had been obtained during triaxial deformation tests on samples coming from seamless steel tubes used in the oil industry. Some of the samples were provided with a protective coating; the purpose of our work was to identify bursts originated in the breakage of the coating, from those originated in deformation and fracture mechanisms in the bulk steel matrix. Analysis was performed by statistical clustering and classification methods first applied to physical parameters like Amplitude (A), Duration (D), Rise-Time (R) and Ring-down (N) and then applied to parameters obtained by Principal Components Analysis. In the first case very good results were obtained in A-R-N three-dimensional graphs. Even when mean values for each test were considered, two perfectly separated subsets were obtained. Each of them was in a spherical region whose center was the mean of the mean values of each subset, and whose radius took into account data dispersion. For bursts coming from the coating breakage, the mean A parameter was higher, the R parameter was lower and the N parameter was higher than the corresponding parameters coming from the matrix deformation. Then statistical clustering was applied to physical and principal components parameters. In the second case better results were obtained and the classification of sources was achieved. Our work suggests that the presented methods would be profitable for industry applications since they are simple, fast and they could be easily implemented in neural network codes.

Characterization of Imperfect Bond Between Coating and Substrate

---M. Doxbeck, **M. Hussain**, and J. Frankel, Watervliet Arsenal, Benet Labs, Watervliet NY 12189

---Failure of the bonding of metallic coatings can be detrimental to the enhancement of component life. This can be due to the bond failing partly in its ability to transmit shear and/or normal stresses between coating and substrate. The shear failure can be considered as smooth contact. Similarly, part of the bond that has cleaved or cracked and which cannot transfer normal stresses but can transfer shear, can be considered separated. This transfer of shear across the interface may be due to rough nature of the damage. With 2 parameters, we consider combinations using the rule of mixtures, to simulate the percentage of damage. We approximate such a situation statistically as a rule of mixtures between three extreme cases: welded, smooth and separated. The dispersion characteristics of Rayleigh surface waves are used to characterize the quality of the bond between a coating and the metallic substrate. Theoretical velocity vs. frequency curves are obtained using the rule of the mixtures. The results are validated using a 3 layer system with the middle layer representing the bond being progressively weakened. A "laser wave" system was used to generate the ultrasonic surface wave along a circle. A Michelson interferometer is the means of detection for the surface waves at the center of the generated annulus. For an isotropic surface, the waves generated at the annulus all arrive at the center at the same time. The amplitude of the surface wave is enhanced, resulting in an improved S/N without ablation. Rayleigh surface waves become dispersive in the presence of a coating layer. Since each wave component propagates with a different phase velocity, the initial shape of the transient waveform is distorted in time. By determining the time of arrival of the various wave components as a function of the frequency, the group velocity vs. frequency curve can be extracted. Such dispersion gives the relation between frequency ω_n and group velocity v_n. Estimation of the dispersion curve is key in characterizing the quality of the bond. Since each packet is Gaussian in nature, a wavelet transform with a frequency modulated Gabor mother wavelet is thought to lead to an optimum correlation determination of dispersion curves.

SESSION 15

SENSORS AND TECHNIQUES

P. D. Wilcox and B. Koehler, Co-Chairpersons

Parker Ballroom D/E

3:30 PM **AC Modulated Magneto-Optic Sensor for Remote Investigation of Surface Deformation**
---**S.-J. Lee**, S. Hoon, and D. C. Jiles, Iowa State University, Center for NDE, 258H Metals Development Building, Ames, IA 50011; H. Hauser, Vienna University of Technology, Vienna, Austria

3:50 PM **Design and Evaluation of Two-Dimensional Phased Array Ultrasonic Transducers**
---**S. C. Mondal**, P. D. Wilcox, and B. W. Drinkwater, Mechanical Engineering, University of Bristol, Bristol, United Kingdom

4:10 PM **Sizing of Structures by Air-Solid Interface Wave Generated and Detected by Lasers**
---**F. Jenot**, M. Ouaftouh, M. Duquennoy, and M. Ourak, IEMN, Département OAE (UMR CNRS 8520), Université de Valenciennes et du Hainaut Cambrésis, 59313 Valenciennes Cedex 9, France

4:30 PM **Detecting Weld Zone Over Anticorrosion Painting by Rotating Uniform Eddy Current Probe**
---**H. Hoshikawa**, K. Koyama, and Y. Naruse, Nihon University, Izumicho Narashino Chiba 275-8575, Japan

4:50 PM **Fourier Interpolation and Neural Network Analysis for Accurate 3D Reconstruction of Images Produced by an Inductive Scanner**
---**M. Zaid**, P. Gaydecki, B. Fernandes, G. Miller, and V. Torres, UMIST, Department of Instrumentation and Analytical Science, P. O. Box 88, Manchester M60 1QD, United Kingdom

5:10 PM **The Potential of Ultrasonic Surface Waves for Rail Inspection**
---**D. Hesse** and P. Cawley, RCNDE, Department of Mechanical Engineering, Imperial College London, United Kingdom

AC Modulated Magneto-Optic Sensor for Remote Investigation of Surface Deformation
---**Seong-Jae Lee**, Sang Hoon, and David C. Jiles, Iowa State University, Center for NDE, 258H Metals Development Building, 1915 Scholl Road, Ames, IA 50011; Hans Hauser, Vienna University of Technology, Vienna, Austria

---A new magneto-optic (MO) detection scheme utilizing domain wall motion in a transparent MO thin film has been studied for evaluation of surface deformation created by subsurface and internal defects in either metallic or non-conducting composite specimens. The technique involves passing a polarized light beam through a MO film and measuring the ac modulated Faraday rotation of the laser beam reflected from the specimen surface using an analyzer and a photodetector. A stable two-domain structure with a single domain wall is produced in the MO film by placing two permanent magnets with opposite polarities near the MO film. An ac magnetic field is applied perpendicular to the surface of the MO film, causing the domain wall to move back and forth and as a result the Faraday rotation of the laser beam is ac modulated. The modulated signal as a function of time is very sensitive to the optical path of the reflected light beam and therefore any surface deformation of the specimen or internal defects can be detected remotely by monitoring the signal change. The new sensor system has the advantage that the signal amplitude is insensitive to variations in environmental conditions and the detected signal can be readily recorded on a PC for further numerical analysis.---This research was supported by the National Aeronautics and Space Administration (NASA) under award No NAG-1-02098.

Design and Evaluation of Two-Dimensional Phased Array Ultrasonic Transducers
---**S.C. Mondal**, P. D.Wilcox, and B. W. Drinkwater, Mechanical Engineering, University of Bristol, Bristol, United Kingdom

---Two-dimensional arrays which can perform volumetric imaging of components have a wide range of applications in NDE. The most obvious array configuration is to have a grid of elements fully covering the surface of the array but this very quickly leads to a large number of elements. This paper explores three alternative arrangements (i.e. single ring, double ring and cross patterns). The aim of these configurations is to increase the effective aperture for a given number of elements. Due to the multitude of possible array element configurations a model, based on Huygens' principle, has been developed to allow analysis and comparison of candidate array designs. In particular the ability of a given array to image in three-dimensions is assessed. In addition to the element configuration, key issues such as element size, spacing and frequency are discussed. The net result of this analysis is that all practical arrays should be designed with both the element spacing and the element dimensions below half a wavelength in size in order to remove the effects of grating lobes and side lobes. Results from the model are then compared with experimental results for one array configuration and good agreement obtained. Practical implications for the design of two-dimensional arrays are also discussed.

Sizing of Structures by Air-Solid Interface Wave Generated and Detected by Lasers

---**F. Jenot**, M. Ouaftouh, M. Duquennoy, and M. Ourak, IEMN, Département OAE (UMR CNRS 8520), Université de Valenciennes et du Hainaut Cambrésis, 59313 Valenciennes Cedex 9, France

---The first part of this paper deals with the results of some experiments and investigations about the optical detection of acoustic waves at the air-solid interface. The large amplitude observed for the Scholte wave (in comparison with the Rayleigh wave) is discussed and it appears clearly that the detection is mainly due to the optical index variations in air induced by the wave propagation. Consequently, the measurements can be achieved even if the surface of sample is very rough which is an important advantage when considering industrial samples. In the second part, the experimental work shows the potentialities in non destructive testing of this wave. The interaction with different defects is studied and it is notably shown that the thickness of glass plates put down on the sample can be well determined by times of flight analysis. In the same way, the amplitude of the reflected Scholte wave on a steel block coming out of the surface of the sample provides information about its position. This all-laser interface wave ultrasonic method may become a useful tool for easily sizing inaccessible part of industrial structures.

Detecting Weld Zone Over Anticorrosion Painting by Rotating Uniform Eddy Current Probe

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

---Demands are increasing for weld zones of steel structures such as oil-storage tanks and bridges to be nondestructively inspected periodically without removing anticorrosion paint. Conducting nondestructive testing needs tracing the weld zone above the anticorrosion paint. Thus the authors have developed a new method of detecting position and direction of weld zone in steel structures through the paint by using rotating uniform eddy current probe that utilizes the difference of electromagnetic characteristics between the base material and the weld zone. The probe is comprised of two large exciting tangential coils wound orthogonally to each other and a small detecting pancake coil. The alternating currents with 90 degrees out of phase in those two exciting coils induce rotating uniform eddy current in the material. The detecting coil generates a plus or minus signal according to its position from the weld zone center, making the signal zero at the center. The tilt between the probe direction and the weld zone causes to change the signal phase. The experimental results have shown that the probe lift-off from the material causes much less variation to the signal by the probe than to the signal by the conventional pancake probe. The fact means that the weld detection method by the probe is affected less by the variation of paint thickness over steel material and thus is promising for weld zone detection over painting.

Fourier Interpolation and Neural Network Analysis For Accurate 3D Reconstruction of Images Produced by an Inductive Scanner

---**Muhammad Zaid**, Patrick Gaydecki, Bosco Fernandes, Graham Miller, and Vladimir Torres, Department of Instrumentation and Analytical Science, UMIST, PO Box 88, Manchester M60 1QD, United Kingdom

---This paper reports on an inductive sensor that exploits the phenomenon of eddy current testing for imaging steel reinforcing bars embedded within concrete. Over the last several years, many problems relating to sensor design and image reconstruction have been overcome. However, principal problems such as speed of operation and dimensional information extraction remained unexplored. In this paper, a novel methodology is presented to reduce the scanning time and to extract bar dimensional information. Using a sparsely populated data set obtained from a reduced number of scan lines, high resolution images are generated using image interpolation techniques. Experiments show that this technique is faster than the traditional scanning protocol by at least a factor of ten; a large area scan of 0.5 m^2 can thus be produced in twelve minutes, rather than two hours. In addition, a method based on neural networks has been developed to extract bar dimensional information. Both networks have been trained on the peak parameters of six different bars scanned at 41 different bar depths. Depth and diameter measurements have been obtained for bars 58 mm away from the sensor, with errors that satisfy the requirements of the BS 1881 and the DIN 488 standards.

The Potential of Ultrasonic Surface Waves for Rail Inspection

---Daniel Hesse and Peter Cawley, RCNDE, Dept Mech Eng, Imperial College London, United Kingdom

---Surface cracks on the running surface of rails are a common problem in modern railways. In order to ensure that rail sections containing critical defects are identified and replaced in time, the rail network has to be inspected with efficient and reliable methods. Conventional ultrasonic wheel probes cannot always meet these criteria if the rail surface contains shallow damage (e.g. spalling or multiple small cracks) and therefore does not allow sufficient penetration of bulk waves into the material. In this case, the integrity of these 'shadow zones' cannot be assessed which might lead to unnecessary expensive rail replacement or critical defects remaining in the track. To overcome these problems the authors are investigating the use of short range guided waves which propagate along the rail surface and allow the inspection of problematic sections of rail from positions with good coupling at the probe/rail interface. This paper examines the basic properties of such ultrasonic surface waves at frequencies of the order of 250 kHz which is low enough to give sufficient penetration depth into the material. The propagation characteristics of the wave in the rail head differ substantially from high frequency Rayleigh waves and these issues are explored. Excitation of suitable wave modes, wave propagation along the railhead and interaction with a simple defect were investigated both experimentally and using Finite Element simulations.

SESSION 16
GUIDED WAVES
V. Kinra, Chairperson
Parker Ballroom D/E

8:30 AM **Leaky Quasi-A0 Mode in Curved Plates**
---**J. Fong** and M. J. S. Lowe, Imperial College, RCNDE, Department of Mechanical Engineering, Room 681, Exhibition Road, London SW7 2AZ, United Kingdom

8:50 AM **Guided Wave Scattering and Mixed Mode Conversions from 3-Dimensional Defects**
---**W. Luo** and J. L. Rose, The Pennsylvania State University, Department of Engineering Science and Mechanics, 212 Earth and Engineering Science Building, University Park, PA 16802

9:10 AM **Simulation and Measurement of Ultrasonic Waves in Elastic Plates Using Laser Vibrometry**
---**M. Ruzzene** and S. M. Jeong, School of Aerospace Engineering, Georgia Institute of Technology, 270 Ferst Drive, Atlanta, GA 30332-0150; T. E. Michaels, J. E. Michaels, and B. Mi, School of Electrical and Computer Engineering, Georgia Institute of Technology, Atlanta, GA 30332-0250

9:30 AM **Propagation of Lamb Waves on Rough Plates: Analysis of the Beam Section**
---**D. Leduc**, B. Morvan, P. Pareige, and J.-L. Izbicki, Laboratoire d'Acoustique Ultrasonore et d'Electronique (LAUE), UMR CNRS 6068, le Havre, France; C. Potel and C. Depollier, Laboratoire d'Acoustique de l'Université du Maine (LAUM), UMR CNRS 6613, Le Mans, France; A.-C. Hladky, Institute d'Electronique, de Microélectronique et de Nanotechnologie (IEMN), UMR CNRS 8520, Lille, France

9:50 AM **Ultrasound in an Anisotropic Cladding with Wavy Interface**
---**A. Bostrom**, T. Krasnova, and P.-A. Jansson, Department of Applied Mechanics, Chalmers University of Technology, Goteborg, SE-412-96 Sweden

10:10 AM ***Coffee Break***

10:30 AM **The Role of Material Absorption in Guided Wave Propagation**
---**F. Simonetti**, RCNDE, Department of Mechanical Engineering, Imperial College, London, United Kingdom

10:50 AM **Fe Modeling of Guided Waves Propagation and Diffraction in Structure with Weak Interfaces**
---**B. Hosten** and M. Castaings, Laboratoire de Mécanique Physique, Université Bordeaux 1, UMR CNRS 5469, 351 Cours de la Libération, 33405-Talence, Cedex France

11:10 AM **Dispersion Behaviors of Wedge Waves Propagating Along the Apex Line of Wedges with Bilinear Cross Section**
---C.-Z. Tsen and **C.-H. Yang**, Department of Mechanical Engineering, Chang Gung University, Taiwan, China

11:30 AM **Identification of Guided-Wave Mode in Pipe by Using Air-Coupled Transducer**
---**H.-M. Kim,** I.-K. Park, K.-Y. Jhang, Y.-H. Cho, and Y.-K. Kim, Department of Precision Mechanical Engineering, Graduate School of Han Yang University, #17 HeangDang-Dong, SungDong-Gu, Seoul, Korea

11:50 AM **Optimization of Corrosion Monitoring Using Lamb Waves**
---**N. Terrien** and M. Lepoutre, Office National d'Etudes et de Recherches Aérospariales, Département de Mécanique du Solide et de l'Endommagement, Unité "Mécanique Expérimentale et Contrõle Santé", BP 72 – 29 avenue de la Division Leclerc, 92322 Châtillon Cedex, France; M. Royer, Laboratoire Ondes et Acoustique, ES)PCI, 10 rue Vauquelin, 75231 Paris Cedex 05, France

12:10 PM ***Lunch***

Leaky Quasi-A0 Mode in Curved Plates

---**Jimmy Fong** and Mike J. S. Lowe, Imperial College, RCNDE, Department of Mechanical Engineering, Room 681, Exhibition Road, London SW7 2AZ, United Kingdom

---Many cylindrical engineering structures can be inspected effectively using a circumferential guided wave technique to cover the full circumference from a single location. This method can provide an alternative to the use of an axially propagating guided wave, especially where access to only part of the circumference is available. A study of the curvature effect on plate modes in vacuum was presented in this meeting last year and has also been shown by others. The influence on propagation properties is very small and the curved plate can generally be approximated by a straight plate model when the curvature is small. However, the differences can dramatically increase when the curvature becomes large. In this paper, a similar study of the curvature effect on modes in solid/fluid embedded plates is presented, the emphasis being on the attenuation difference, due to leakage, between straight and curved plates. This particular study is of much industrial interest, for example the inspection of pipes partially embedded in concrete or soil, or immersed in fluid. The study involves finite element modelling and some preliminary experimental studies.

Guided Wave Scattering and Mixed Mode Conversions from 3-Dimensional Defects

---**Wei Luo** and Joseph L. Rose, The Pennsylvania State University, Department of Engineering Science and Mechanics, 212 Earth and Engineering Science Building, University Park, PA 16802

---Ultrasonic guided waves have shown great potential for long range inspections of structures with large areas, such as pipes, vessels, rails, etc. The possibility of finding defects depends on whether scattered waves from a defect are detectable. For example, for a liquid-filled pipeline inspection using torsional waves, the incident waves may be converted to longitudinal waves, which could then leak into the liquid and become undetectable. Therefore, the wave mode conversion study of a defect, especially a 3-dimensional defect, becomes an interesting and valuable topic. Some researchers have studied the wave scattering and mode conversion of a through-wall hole in a plate. In this work, 3-D defects with arbitrary shapes in a plate will be considered for the study of mixed mode conversions from Lamb modes to SH modes and vice versa, utilizing a 3-D boundary element method and normal mode expansion technique. A parametric study based on defect size with respect to the wavelength, shape, as well as cross-section area, will be carried out for the mixed mode conversion study. Because, in reality, most defects are 3-dimensional with arbitrary shapes, therefore, this mixed mode study could provide very useful guidance for guided wave inspection methodology. It is also very helpful in algorithm development for defect discrimination and sizing.

Simulation and Measurement of Ultrasonic Waves in Elastic Plates Using Laser Vibrometry

---**M. Ruzzene** and S. M. Jeong, School of Aerospace Engineering, Georgia Institute of Technology, 270 Ferst Drive, Atlanta, GA 30332-0150; T. E. Michaels, J. E. Michaels, and B. Mi, School of Electrical and Computer Engineering, Georgia Institute of Technology, Atlanta, GA 30332-0250

---The propagation of Lamb waves in elastic plates is investigated analytically and experimentally. The detection of propagating waveforms is performed through a scanning Laser Doppler Vibrometer (LDV). The LDV detects out-of-plane displacement or velocity components of a vibrating surface by means of the Doppler effect. A scanning LDV system measures vibrations in predetermined scanning points and is able to provide information regarding vibration patterns over large surfaces. The scanning LDV technology is here applied to visualize transient waveforms propagating in a plate at ultrasonic frequencies. The waves are excited by a piezoelectric crystal glued to the plate actuated by sinusoidal pulses of varying frequency. The pulse sequence is triggered by the LDV internal controller so that phase and delay information are preserved. Such information allows visualization of the waveform pattern as it propagates over the plate surface. The experiment produces animated displacement maps which provide insight in the wave propagation in the considered structure. The interaction of the propagating wave with discontinuities in the plate such as defects becomes apparent. This capability suggests application of the LDV technique as part of a damage detection methodology which combines the sensitivity of ultrasonic waves with the localization of damage via wavefield visualization. The interpretation of the experimental results is aided by numerical simulations performed using a Local Interaction Simulation Approach (LISA), which represents a simple and effective numerical tool. The comparison between simulated and measured data validates the LISA code, which can be used for generation of simulated waveforms to then be employed in the development and validation of damage detection algorithms.

Propagation of Lamb Waves on Rough Plates: Analysis of the Beam Section

---**Damien Leduc**, Bruno Morvan, Pascal Pareige, and Jean-Louis Izbicki, Laboratoire d'Acoustique Ultrasonore et d'Electronique (LAUE), UMR CNRS 6068, le Havre, France; Catherine Potel and Claude Depollier, Laboratoire d'Acoustique de l'Université du Maine (LAUM), UMR CNRS 6613, Le Mans, France; Anne-Christine Hladky, Institute d'Electronique, de Microélectronique et de Nanotechnologie (IEMN), UMR CNRS 8520, Lille, France

---The goal of this work is the nondestructive study of the bonding between plates. The bonded surface has to be prepared: in many cases the surface is roughed in order to increase the quality of bonding. Here the problem of Lamb waves propagating on a rough plate is addressed. The attenuation of these waves is determined both experimentally and theoretically. This attenuation is caused by many phenomenons and among them the roughness. The transducer used for generating the waves has a finite size and then diffraction occurs and consequently the Lamb beam on the plate spreads: this fact contributes also to the attenuation. With an optical vibrometer, experiments are performed in order to analyze the section of the Lamb beam. Signal processing involving intercorrelation and evaluation of the energetic center of signals are performed. It is then possible to visualize the front wave and to determine the width of the beam. Different roughnesses are used and a physical explanation of the results is given. Two phenomenons are observed: the first one is the spreading of the beam and the second one is the reconcentration of the beam due to the Lamb wave multiscattering on roughness.

Ultrasound in an Anisotropic Cladding with Wavy Interface

---**Anders Bostrom**, Tatiana Krasnova, and Per-Ake Jansson, Department of Applied Mechanics, Chalmers University of Technology, Goteborg, SE-412 96 Sweden

---The 2D propagation of ultrasonic waves in a thick plate with an anisotropic cladding is considered. The interface is assumed to be wavy (sinusoidal) as is common in welded claddings. The null field approach is used to solve the problem. This method starts from the integral representations with the half-space Green's tensors and reduces the problem to a type of integral relations on the interface. Using the periodicity of the interface the problem is natuarally discretized. Numerical results are given as field plots. This will display the influence of the anisotropy and the height and period of the wavy interface.

The Role of Material Absorption in Guided Wave Propagation

---Francesco Simonetti, RCNDE, Department of Mechanical Engineering, Imperial College London, United Kingdom

---Ultrasonic guided waves have the potential to address the growing need for NDE of attenuative materials such as in the case of material rheology or NDT of coated structures and composite materials. Although a great deal of research has been conducted to characterize the vibrations of elastic waveguides over the past century, absorbing waveguides have been considered only recently. The modes of vibration of an elastic structure are usually divided into propagating and nonpropagating kinds. While nonpropagating modes characterize local vibrations nearby a perturbation source, which can be either an external force or a geometrical discontinuity, propagating modes carry energy along the waveguide and can be employed for the detection of defects far away from the source. On this basis, ultrasonic propagating modes have been used for the non-destructive long range inspection of large structures. This paper proposes a unified interpretation of the phenomena associated with vibrations of attenuative and perfectly elastic waveguides. By considering that the modes of an absorbing structure are always propagating, it is shown that each elastic mode consists of propagating and nonpropagating branches, which turn into a single propagating mode as soon as internal absorption is considered. Moreover, it is shown how introducing a little material damping leads to a rigorous and consistent system of the naming of elastic modes. In order to illustrate such arguments, the practical case of propagation in coated structures is considered.

Fe Modeling of Guided Waves Propagation and Diffraction in Structure with Weak Interfaces

---**Bernard Hosten** and Michel Castaings, Laboratoire de Mécanique Physique, Université Bordeaux 1, UMR CNRS 5469, 351 Cours de la Libération 33405 – Talence, Cedex, France

---The nondestructive evaluation and testing of interfaces quality is a key issue for the development of stratified structures in various domains as for instance aeronautics or car industry. Due to the complexity geometry of some structures, numerical methods must often be used instead of closed form solutions, to model the propagation of guided waves and their diffraction by obstacles, inhomogeneities or defects. This paper describes the use of a Finite Element code for modeling the effects of weak interfaces on the propagation of low order Lamb modes. The interface is modeled as a spring layer. Since, the thickness of an interface is very thin by definition, it increases excessively the number of meshing elements. It is shown that this thickness can be increased without lost of precision in a limit that will be defined. The method is tested by comparison with measurements that were presented in a previous QNDE conference. The interface was the contact between a rough elastomer with high internal damping loaded against one surface of a glass plate. Both normal and shear stiffnesses of the interface were quantified from the attenuation of A0 and S0 Lamb waves caused by leakage of energy from the plate into the elastomer and measured at each step of a compressive loading. The FE model is made in the frequency domain, thus allowing the viscoelastic properties of the elastomer to be modeled by using complex moduli as input data. By introducing these stiffnesses in the code, the predicted guided waves attenuations are compared to the experimental results to validate the numerical FE method.

Dispersion Behaviors of Wedge Waves Propagating Along the Apex Line of Wedges with Bilinear Cross Section

---Chun-Zen Tsen and **Che-Hua Yang**, Department of Mechanical Engineering, Chang Gung University, Taiwan, China

---This study is focused on the propagation behaviors of wedge waves (WW) propagating along the apex of a wedge with a bilinear cross section, or a wedge with two apex angles. WW propagating along a truncation free wedge is dispersion-free, and has an increasing slope in the dispersion curve while the truncation increases. However, this kind of dispersion behavior is only verified for a perfectly horizontal wedge truncation. In some applications, such as wedge-like machine tool blades, the wedge tip has more complex geometry, typically in a bilinear form. A laser ultrasonic technique is used to provide a non-contact, point-wise generation and detection of wedge waves. It is found that two groups of WWs supported by the two apex angles can be simultaneously observed for a bilinear wedge. Coupling behavior between the two groups of WWs are investigated.

Identification of Guided-Wave Mode in Pipe by Using Air-Coupled Transducer

---**Hyun-Mook Kim,** I.-K. Park, K.-Y. Jhang, Y.-H. Cho, and Y.-K. Kim, Department of Precision Mechanical Engineering ,Graduate School of Han Yang University,#17 HeangDang-Dong, SungDong-Gu, Seoul, Korea

---In order to inspect effectively and nondestructively the piping, the important component in the facility of power plant, guided wave was generated by a comb transducer and was received by a air-coupled transducer without the contact to piping. The mode of guided wave in piping is predicted from the theoretical dispersion curve and the component's gap of a comb transducer. Also, to receive the predicted mode, the receiving angle of air-coupled transducer is calculated by the theoretical phase velocity from the dispersion curve. The mode of guided wave in piping is identified by the result of time-frequency analysis by applying wavelet transform and two-dimensional FFT.

Optimization of Corrosion Monitoring Using Lamb Waves

---**N. Terrien** and M. Lepoutre, Office National d'Etudes et de Recherches Aérospariales, Département de Mécanique du Solide et de l'Endommagement, Unité "Mécanique Expérimentale et Contrõle Santé", BP 72 – 29 avenue de la Division Leclerc, 92322 Châtillon Cedex, France; M. Royer, Laboratoire Ondes et Acoustique, ESPCI, 10 rue Vauquelin, 75231 Paris Cedex 05, France

---Hidden corrosion in aircraft structures is difficult to detect at an early stage. Guided Lamb waves are sensitive to this damage and offer an important inspection potential compared to the point-by-point processes. To optimize the corrosion detection, it is important to understand the physical phenomenon governing the interaction between Lamb waves and corrosion. Observation of an aluminum corroded sample allowed us to highlight the properties of a corroded zone likely to attenuate certain Lamb modes. Experiments were carried out to check which characteristics of the corrosion influence the Lamb wave's propagation. This study allowed us to find few modes generated at particular frequencies which are sensitive to the corrosion's microstructure. The research of the Lamb modes which are the most sensitive to corrosion is performed by calculating the mode's energy distribution across the thickness of the plate. Indeed to detect a corroded zone efficiently, the energy flow of the generated Lamb mode must be located near the upper and lower parts of the plate. Generation and detection of Lamb modes must also be taken into account. Experimental studies correspond well with the prediction.

SESSION 17

NDE FOR RESIDUAL STRESS

P. B. Nagy and J. S. Knopp, Co-Chairpersons
Parker Ballroom C

8:30 AM **The Role of Residual Stresses in Honeywell's Turbine Disk Life Prediction System**
---**D. J. Greving** and M. Gorelik, Honeywell Engines Services and Systems, Materials Engineering Department, 111 S. 34th Street, P. O. Box 52181, MS 503-118, Phoenix, AZ 85072-2181

8:50 AM **Residual Stress Measurements to Assess Performance of Engineering Components Using X-Ray Diffraction Method**
---B. Raj and T. Jayakumar, Metallurgy and Materials Group, Indira Gandhi Centre for Atomic Research, Kalpakkam, Tamil Nadu, India (Presenter: **P. Kalyanasundaram**)

9:10 AM **Residual Stress Measurements for Quantitative Evaluation of Fretting Fatigue Damage**
---S. A. Martinez, **S. Sathish***, and M. P. Blodgett, Air Force Research Laboratory, Wright-Patterson Air Force Base, OH 45433; S. Mall, Air Force Institute of Technology, Wright-Patterson Air Force Base, OH 45433; *University of Dayton Research Institute, 300 College Park, Dayton, OH 45469

9:30 AM **Industrial Integration of Residual Stress Measuring NDT-Systems Based on Ultrasonics and Micromagnetics**
---I. Altpeter, G. Dobmann, R. Kern, E. Schneider, B. Wolter, and **M. Spies**, Fraunhofer-Institut Zerstörungsfreie Prüfverfahren IZFP, University Building 37, Saarbrücken, Germany

9:50 AM **Eddy Current Nondestructive Residual Stress Assessment in Shot-Peened Nickel-Base Superalloys**
---M. P. Blodgett, Ceramics and NDE Division, AFRL, Wright-Patterson Air Force Base, Dayton, OH 45432; F. Yu and **P. B. Nagy**, Department of Aerospace Engineering and Engineering Mechanics, University of Cincinnati, Cincinnati, OH 45221

10:10 AM ***Coffee Break***

10:30 AM **High Resolution Residual Stress Imaging Using MWM-Arrays with Precomputed Response Databases**
---N. Goldfine, V. Zilberstein, D. Schlicker, I. Shay, A. Washabaugh, D. Grundy, and R. Lyons, JENTEK Sensors, Inc., Waltham, MA 02453-7013

10:50 AM **Application of Various Magnetic Measurement Techniques to the Evaluation of Residual Stress**
---D. C. Jiles and **C. C. H. Lo**, Iowa State University, Center for NDE, Ames, IA 50011

11:10 AM **Characterization of Plastically Deformed Steels Utilizing Ultrasonic Velocity Measurements**
---P. D. Panetta[1], B. Francini[1], S. Ahmed[1], M. Morra[1], G. A. Alers[2], K. Johnson[1], and R. B. Thompson[3], [1]Pacific Northwest National Laboratory, Richland, WA 99352; [2]EMAT Consulting, San Luis Obispo, CA 93401; [3]Iowa State University, Center for NDE, Ames, IA 50011

11:30 AM **A Study of Correlation Between Conductivity Measurement and Surface Residual Stress**
---N. Nakagawa, Iowa State University, Center for NDE, Ames, IA 50011; A. M. Frishman, Iowa State University, Department of Physics, Ames, IA 50011

11:50 AM **Limitations of Nondestructive Subsurface Residual Stress Measurements by X-Ray Diffraction**
---D. J. Hornbach and P. S. Prevéy, Lambda Research, 5521 Fair Lane, Cincinnati, OH 45273

12:10 PM ***Lunch***

The Role of Residual Stresses in Honeywell's Turbine Disk Life Prediction System

---**Daniel J. Greving** and Mike Gorelik, Honeywell Engines Services and Systems, Materials Engineering Department, 111 S. 34th St., P. O. Box 52181, M/S 503-118, Phoenix, AZ 85072-2181

---Machining and surface processing operations, such as grinding, turning, and shot peening are well known producers of near surface compressive residual stresses. The aerospace industry, including Honeywell, experience shows that the magnitude and depth of the residual stress has a significant influence on the fatigue life of a component. At Honeywell, numerous programs have been conducted during the course of life methods development efforts to quantify the residual stresses and the fatigue life associated with various machining and surface processing techniques. In many cases, the resulting residual stresses are an intrinsic element in a component's fatigue life prediction system. This paper addresses a specific material design life system where residual stresses from machining and shot peening are an integral factor in a turbine disk's service life prediction. Details on the material, manufacturing processes, residual stresses, and validation of a fatigue life prediction system are presented. A critical element is the control and maintenance of the initial residual stresses used in the life prediction system. Therefore, additional details concentrate on the methods used by Honeywell to ensure that the appropriate level of residual stresses are present through the service life of the turbine disk.

Residual Stress Measurements to Assess Performance of Engineering Components Using X-Ray Diffraction Method

---Baldev Raj and Tammana Jayakumar, Metallurgy and Materials Group, Indira Gandhi Centre for Atomic Research, Kalpakkam, Tamil Nadu, India (Presenter: **P. Kalyanasundaram**)

---Residual stresses introduced during fabrication, heat treatment and in service influence the performance of engineering components. Generation and/or redistribution of residual stresses during fabrication and heat treatment may affect the dimensional stability and in service performance. In general, tensile residual stresses together with applied tensile stresses cause premature failure by overload, fatigue and stress corrosion cracking. The resistance of components to fatigue and stress corrosion cracking is enhanced by introducing compressive residual stresses in the surface regions by processes such as shot peening. X-ray diffraction (XRD) technique is widely used for measurement of surface residual stresses. In this paper, we discuss the application of XRD technique based residual stress measurements for assessment of (1) fatigue damage in fir-tree root regions of steam turbine blades and undercarriages of aircrafts, (2) influence of deep cryogenic treatment on improvement in fatigue crack initiation in AISI type 304 stainless steel and (3) performance of hardfaced (with Ni-base Co-free Colmonoy-5) AISI type 316LN austenitic stainless steel sleeves subjected to thermal cycling, before and after stress relieving treatment.

Residual Stress Measurements for Quantitative Evaluation of Fretting Fatigue Damage

---Sonia A. Martinez, **Shamachary Sathish***, and Mark P. Blodgett, Air Force Research Laboratory, Wright-Patterson Air Force Base, OH 45433; Shankar Mall, Air Force Institute of Technology, Wright-Patterson Air Force Base, OH 45433; *University of Dayton Research Institute, 300 College Park, Dayton, OH

---Fretting fatigue damage has been known to be the origin of premature failure of some of the aerospace engine components. Particularly susceptible region is the dovetail joint. Several nondestructive evaluation techniques are being used to detect the cracks due to fretting fatigue damage. Although partial success has been achieved very limited research has been performed to detect precursors to cracks due fretting fatigue damage. In this paper we present an x-ray diffraction residual stress measurements methodology that has potential to be used to evaluate precursor to cracking due to fretting fatigue. Residual stress has been measured in shot peened Ti-6Al-4V samples before and after subjecting to controlled amount of fretting fatigue damage. The results show relaxation of compressive residual stress as the number of fretting fatigue cycles increase. Complete relaxation of the residual stress has been found to occur near the end of the fretting fatigue life. Microstructure changes at different stages of accumulated fretting fatigue damage has been examined using Scanning Electron Microscope (SEM). The results of changes in residual stress, microstructure changes and fretting fatigue life are discussed to establish the potential of the x-ray diffraction as an NDE tool for evaluation of fretting fatigue damage.

Industrial Integration of Residual Stress Measuring NDT-Systems Based on Ultrasonics and Micromagnetics

---I. Altpeter, G. Dobmann, R. Kern, E. Schneider, B. Wolter, and **M. Spies,** Fraunhofer-Institut Zerstörungsfreie Prüfverfahren IZFP, University Building 37, Saarbrücken, Germany

---Concerning the fitness for use of industrial products the effect of residual stresses is twofold: The effect is positive in the case of compressional stress type - mainly by prolongating fatigue lifetime and negative in the tensile stress case supporting fatigue-crack initiation and growth as well as stress corrosion cracking. Fraunhofer-IZFP has developed over years and introduced into industrial practice residual stress characterizing NDT based on micro-magnetics and on ultrasonics. The ultrasonic time-of-flight measuring equipments (stationary and portable) with a number of 36 systems are well integrated in the quality surveillance strategies of the European railway companies, before and after residual stress annealing and reprofiling of wheel sets of freight trains. The micro-magnetic systems find their application mainly in the field of machinery building and car supplying industry in combination with case, inductive and LASER hardening and grinding for finishing. In newer projects the micro-magnetic NDT yield on the characterization of residual stresses induced by soldification of cast-iron motor engines. The contribution reports to these applications and documents the benefits for the industrial user which are mainly in safety and lifetime.

Eddy Current Nondestructive Residual Stress Assessment in Shot-Peened Nickel-Base Superalloys

---**Mark P. Blodgett**, Ceramics, and NDE Division, AFRL, Wright-Patterson Air Force Base, Dayton, Ohio 45432; Feng Yu and Peter B. Nagy, Department of Aerospace Engineering and Engineering Mechanics, University of Cincinnati, Cincinnati, Ohio 45221

---Shot peening and other mechanical surface enhancement methods improve the fatigue resistance and foreign-object damage tolerance of metallic components by introducing beneficial near-surface compressive residual stresses and hardening the surface. Modern aircraft turbine engine components are designed using a damage-tolerance philosophy that allows the prediction of a given component's useful service life based on fracture mechanics and structural analysis. However, the fatigue life improvement gained via surface enhancement is not explicitly accounted for in current engine component life prediction models because of the lack of accurate and reliable nondestructive methods that could verify the presence of compressive near-surface residual stresses in shot-peened hardware. In light of its frequency-dependent penetration depth, the measurement of eddy current conductivity has been suggested as a possible means to allow the nondestructive evaluation of subsurface residual stresses in surface-treated components. This technique is based on the so-called electroelastic effect, i.e., the stress-dependence of electrical conductivity. We found that, in contrast with most other materials, surface-treated nickel-base superalloys exhibit an apparent increase in electrical conductivity at increasing inspection frequencies, i.e., at decreasing penetration depths. Experimental results will be presented to illustrate that the excess frequency-dependent eddy current conductivity of shot-peened nickel-base superalloys can be used to estimate the absolute level and penetration depth of the compressive residual stress layer both before and after partial thermal relaxation.---This work was performed at the University of Cincinnati in cooperation with 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.

High Resolution Residual Stress Imaging Using MWM-Arrays with Precomputed Response Databases

---**Neil Goldfine**, Vladimir Zilberstein, Darrell Schlicker, Ian Shay, Andrew Washabaugh, David Grundy, and Robert Lyons, JENTEK Sensors, Inc., Waltham, MA 02453-7013

---This paper describes method for measuring residual stresses in and under coatings and for cold worked parts. This method uses precomputed databases of eddy current sensor responses to estimate absolute electrical conductivity and/or magnetic permeability and layer thickness (patents issued and pending). In application of this method, the layer thickness may be a coating thickness or the thickness of a process-affected zone (e.g., the plastic deformation layer of a shot peened component). The MWM-Array is a conformable eddy current sensor array specifically designed to minimize unmodeled contributions to the sensor response. The result is that layer thicknesses and absolute properties can be determined without the use of coating standards, as described in the new ASTM Standard E 2338-04 titled "Standard Practice for Characterization of Coatings Using Conformable Eddy-Current Sensors without Coating Reference Standards". This paper describes this multivariate property measurement method with specific examples for engine components and landing gear.

Application of Various Magnetic Measurement Techniques to the Evaluation of Residual Stress

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

---The problem of residual stress detection is one of the most recurrent themes in NDE. In this presentation we discuss how magnetic measurements can be used for this purpose and we show a new magnetic imaging system that has been developed to take advantage of this possibility. The system produces a multi-parameter contour plot of the spatial variations of a variety of magnetic properties such as coercivity, remanence, permeability and Barkhausen effect signal. These can then be used for the detection of material conditions such as residual stress or the presence of cracks, since the magnetic and mechanical properties of materials are closely related via the magnetoelastic coupling. For comparison hysteresis loops and BE signals were measured in materials subjected to various tensile and compressive stresses within the elastic limit. A magnetic model has also been developed which provides a self-consistent description of the effects of stress on hysteresis loop and Barkhausen effect signals. The Barkhausen effect signal was calculated based on the hysteretic-stochastic process model of domain wall dynamics, which has been extended to include the magnetomechanical effect.---This research was supported by the Center for NDE at Iowa State University, an Industry/University Cooperative Research Center.

Characterization of Plastically Deformed Steels Utilizing Ultrasonic Velocity Measurements

---**P. D. Panetta**[1], B. Francini[1], S. Ahmed[1], M. Morra[1], G. A. Alers[2], K. Johnson[1], and R. B. Thompson[3], [1]Pacific Northwest National Laboratory, Richland, WA 99352; [2]EMAT Consulting, San Luis Obispo, CA 93401; [3]Iowa State University, Center for NDE, Ames, IA 50011

---Maintaining the integrity of the nation's aging infrastructure is of primary importance. Specifically there is a desire to characterize plastically deformed regions in structures to monitor their integrity. Of particular importance is the accurate prediction of the lifetime of damaged natural gas pipelines due to outside force. In order to accurately characterize the degree of plastic deformation, it is essential to accurately determine the degree stress and strain in the damaged region. Currently, determination of the degree of stress and strain in damaged regions utilizing ultrasonic velocity measurements is complicated by the inherent texture variations in the alloys and the difficulty in separating these effects from the stress and strain contributions. We will report ultrasonic velocity measurements on plastically deformed steel specimens to elucidate the state of damage. Specifically, we have found the shear wave birefringence is directly related to the degree of plastic strain and combinations of SH wave velocities are independent of texture contributions in for elastic deformation. Ultrasonic results will be compared with analytical theories and finite element modeling calculation of the stress and strain distributions.---This work was supported by the Department of Energy, National Energy Technology Laboratory. Pacific Northwest National Laboratory is operated for the U.S. Department of Energy by Battelle under Contract DE-AC06-76RLO18310.

A Study of Correlation Between Conductivity Measurement and Surface Residual Stress

---**Norio Nakagawa**, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011; Anatoli M. Frishman, Iowa State University, Department of Physics, Ames, IA 50011

---This paper presents a conceptual survey of possible electromagnetic methods for characterizing surface residual stress created by shot peening on rotating engine components. The consideration starts with resistivity measurement methods such as eddy current and injection-current methods. Our working hypothesis is that the perceived residual stress arising from shot peening correlates directly with lattice constant changes, but not with modified grain boundaries or increased intergranular defects. It is argued that, because both lattice constant changes (=residual stress) and increased defects (=cold work) can modify the resistivity, resistivity measurements may not always reflect the residual stress condition. It is possible that one may find, practically, an indirect correlation which, however, must be demonstrated carefully with sufficient statistics in order to gain confidence in resistivity-based stress characterization. Following this line of thought, the paper next considers electron density measurements as a viable alternative for residual stress characterization, because they effectively reflect local volume changes. One such possibility is the thermoelectric effect which has been pursued by other researchers. Instead, we examine the possibility of Hall constant measurement as a means to characterize local electron density, and thus residual stress. We propose a van der Pauw method to measure Hall constants near metal surface without requiring strip or square specimen geometry, unlike the conventional Hall effect measurement. We will present signal estimations for high and medium frequency AC measurements to estimate the difference between surface and bulk Hall constants.---This work was performed at the Center for NDE at Iowa State University in part 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.

Limitations of Nondestructive Subsurface Residual Stress Measurements by X-Ray Diffraction

---Douglas J. Hornbach and Paul S. Prevéy, Lambda Research, 5521 Fair Lane, Cincinnati, OH 452273

---Rapid, nondestructive x-ray diffraction (XRD) residual stress measurement has been available since the development of the General Motors FastStress systems in the 1960's. The advent of compact electronics, position sensitive detectors, and computer data acquisition has made possible the variety of commercial portable XRD stress measurement instruments available today. Interest in NDI and control of residual stresses to minimize fatigue and stress corrosion failure has continually increased. Although computerized XRD apparatus may appear to reduce the time and training required for measurement, the fundamental principals of x-ray diffraction residual stress measurement and sources of error have not changed. The nature of the residual stress distributions that occur in practice often limit the usefulness of nondestructive surface measurements. Factors that affect the accuracy and utility of surface residual stress measurements are discussed drawing upon the extensive practical application experience. Potential errors in nondestructive XRD stress measurement, problems in interpretation of results, and the influence of common surface treatments that have limited practical application for decades are described. The XRD Integral Method quantifies subsurface stress distributions nondestructively. A modified form of the Integral Method developed at Lambda Research, allowing estimations of the subsurface stress residual stress distributions to a depth of ~ 50 μm in aluminum alloys is described. The method has been successfully demonstrated on AA7050-T6 with comparison to conventional layer removal methods. Extension of the integral method to titanium and nickel alloys Ti-6Al-4V and IN100 for NDI of turbine engine components has been investigated. The limitations on x-ray energy needed to increase penetration into the surface, and the tradeoff between measurement precision and penetration depth are described. Both theoretical and empirical results are presented defining the practical limits of the Integral Method, and nondestructive XRD stress measurement in general, in application to structural alloys.

SESSION 18
EDDY CURRENT MODELING AND PROBES
J. Bowler, Chairperson
Parker Ballroom B

8:30 AM **The Truncated Region Eigenvalue Expansion Method for the Solution of Boundary Value Problems in Eddy Current Nondestructive Evaluation**
---T. P. Theodoulidis[1] and J. R. Bowler[2], [1]University of West Macedonia, Department of Engineering and Management of Energy Resources, Kastorias & Fleming, 50100 Kozani, Greece; [2]Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

8:50 AM **Modeling the Perturbation Flux Density of Current Flowing Around a Small Surface Crack as Detected by a GMR Probe**
---**M. J. Sablik**, G. L. Burkhardt, and G. M. Light, Southwest Research Institute, San Antonio, TX 78228-0510

9:10 AM **Studies of Eddy Current NDE for Small Crack Detection Around Fasteners in Multi-Layer Structures**
---**J. S. Knopp**, Materials and Manufacturing Directorate, Air Force Research Laboratory, 2230 Tenth Street, Suite 1, Wright-Patterson Air Force Base, OH 45433-7817; J. C. Aldrin, Computational Tools, Gurnee, IL

9:30 AM **Studies into the Effects of Surface Roughness on Spatial Eddy-Current Data from Titanium and Nickel-Based Engine Alloys**
---**M. J. Johnson**, N. Nakagawa, S. Wendt, S. Hentscher, and D. C. Raithel, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

9:50 AM **A Study of Boundary Element Eddy Current Model Validation**
---**N. Nakagawa** and B. P. C. Rao, Iowa State University, Center for NDE, Ames, IA 50011

10:10 AM ***Coffee Break***

10:30 AM **Code Validation for Eddy Current Modeling: Tube Inspection with Reflection-Differential Probes**
---**A. Schumm**, Electricité de France, R&D Division, Clamart, France; N. Nakagawa, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

10:50 AM **Eddy Currents Induced by an Encircling Coil in a Finite Length Layered Rod**
---**H. Sun** and J. Bowler, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

11:10 AM **Subsurface Defect Detection in Metals with Pulsed Eddy Current**
---**Y. A. Plotnikov** and W. J. Bantz*, GE Global Research Center, Research Circle, Niskayuna, NY 12309-1135; *GE Aircraft Engines M&QTD, 10270 St. Rita Lane, Cincinnati, OH 45215

11:30 AM **EC Modeling of Ferrite-Core Probes**
---F. Buvat, **G. Pichenot**, and D. Premel, CEA SACLAY, Batiment 611, 91191 Gif-sur-Yvette, France; H. Voillaume, EADS, Suresnes, France

11:50 AM **An Approach for Characterization of Eddy Current Probes**
---**B. P. C. Rao** and N. Nakagawa, Iowa State University, 1915 Scholl Road, Ames, IA 50011

12:10 PM ***Lunch***

The Truncated Region Eigenvalue Expansion Method for the Solution of Boundary Value Problems in Eddy Current Nondestructive Evaluation

---**Theodoros P. Theodoulidis**[1] and John R. Bowler[2], [1]University of West Macedonia, Department of Engineering and Management of Energy Resources, Kastorias & Fleming, 50100 Kozani, Greece; [2]Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

---A number of complex problems in eddy current nondestructive evaluation have recently been solved analytically using the truncated region eigenvalue expansion method (TREE method). In a typical application of the method, the solution in a particular unbounded co-ordinate is expressed in an integral form such as a Fourier or Bessel integral. By truncating the domain of the problem, a modified solution is obtained expressed as a series expansion instead of an integral. Although one achieves a gain in computation efficiency in this way, the most significant advantage of the approach is the ability to match interface conditions across several boundaries simultaneously and thus obtain analytical solutions to complex problems with this method. We illustrate the approach using several examples of time harmonic boundary value problems such as a coil in the presence of a right-angled corner conductor and a coil above a hole in a plate.---This work was performed in part at the Department of Engineering and Management of Energy Resources, University of West Macedonia, Kastorias & Fleming, 50100 Kozani, Greece in cooperation with 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.

Modeling the Perturbation Flux Density of Current Flowing Around a Small Surface Crack as Detected by a GMR Probe

---**M. J. Sablik**, G. L. Burkhardt, and G. M. Light, Southwest Research Institute, San Antonio, TX 78228-0510

---Modeling was to assist with eddy current GMR probe design to detect small cracks. APPROACH: The problem was to (1) compute the eddy current flow generated by a planar coil and (2) then compute the perturbation flux density B' as the current flows around a surface crack. In the first part, the Dodd and Deeds analytic solution was adapted to the geometry of an N-turn horizontal coil. The current density J' in the plate at different depths was found for coils of various radii and liftoffs and for excitation currents of different magnitudes and frequencies. The computed J' from the first part was then used to compute B' due to current flowing around a surface crack with half-penny cross-section and oblate spheroidal 3D shape. Thus, for a given J', the B'components, detectable by the GMR probe, were found for cracks of different lengths and widths. RESULTS: It was determined what excitation current density and frequency was needed to produce a detectable signal from a 0.25 mm (0.01 in) crack, with experiment confirming. The B' component perpendicular to the crack and in the plane of the specimen surface exhibited inversion symmetry scanning across the crack and scanning across a perpendicular line through the crack center; whereas the B' parallel to the crack showed reflection symmetry. The GMR detector should be positioned about two-thirds of the way from the center of the excitation coil, where J' peaks.---Work supported by Materials and Manufacturing Directorate, Air Force Research Laboratory, Air Force Material Command, Wright-Patterson AFB. via subcontract through Universal Technology Corp.

Studies of Eddy Current NDE for Small Crack Detection Around Fasteners in Multi-Layer Structures

---**Jeremy S. Knopp**, Materials and Manufacturing Directorate, Air Force Research Laboratory, 2230 Tenth Street, Ste. 1, Wright-Patterson AFB, OH 45433-7817; John C. Aldrin, Computational Tools, Gurnee, IL

---The United States Air Force has a need to detect small cracks around fastener holes in multi-layer structures with the fasteners installed. Eddy current NDE has been used to detect cracks in multi-layer structures when the standard depth of penetration is large enough to interrogate subsurface layers and the sealant conditions are such that ultrasonic inspections tend to be unreliable. Although the application of eddy current NDE for this problem has met with some success, the ability to detect and characterize small corner cracks in the presence of inspection noise and variability is a significant issue. In recent work, simulations were constructed and validated to accurately represent eddy current measurements for sub-surface cracking around fastener sites. In this paper, a series of numerical studies using validated models are presented investigating the influence of probe design and geometric flaw parameters on the eddy current measurement response. Probe parameters investigated in this study include coil dimensions, core geometry, and frequency. Multiple quantitative features of the eddy current data from both spatial and frequency domains were evaluated. The goal of this study is to demonstrate the influence of these design parameters on the ability to resolve the flaw characteristics in the measurement data.

Studies into the Effects of Surface Roughness on Spatial Eddy-Current Data from Titanium and Nickel-Based Engine Alloys

---**M. J. Johnson**, N. Nakagawa, S. Wendt, S. Hentscher, and D. C. Raithel, Iowa State University, Center for NDE, Applied Science Complex II, 1915 Scholl Road, Ames, IA 50011

---Two dimensional eddy-current data has been gathered for Ti6-4 and In-718 specimens following the application of various bulk- and surface-modifying treatments. Treatments included shot peening, polishing, sanding and annealing. In addition, the specimens were analyzed using an optical profilometer. A Visual Basic database application was used to calculate and compare statistical parameters obtained from the eddy-current and profilometer measurements. Following application of the various treatments, Abbott Firestone, power-spectrum-density, root-mean-square roughness and variogram analyses were carried out and compared. The results of these comparisons can be used to distinguish between the two factors contributing to eddy-current impedance fluctuations, namely roughness and stress.---This material is based on work supported by NASA under award NAG-1-029-98.

A Study of Boundary Element Eddy Current Model Validation

---**N. Nakagawa** and B.P.C. Rao, Center for NDE, Iowa State University, Ames, IA 50011

---This paper discusses the results of on-going studies designed to validate the three dimensional boundary element model for eddy current testing. In order to predict eddy current data from a set of well characterized artificial notches in stainless steel and alloy 7075 plates, accurate probe internal data from X-ray CT data was given as input to the model. Likewise, quantitatively accurate, mechanically controlled measurement station was used for obtaining experimental data from an impedance analyzer and a commercial eddy current tester. Ferrite-core as well as air-core probes were investigated. In the experiment, a pre-defined lift off was maintained uniformly and the lift-off signals were aligned along the abssicca prior to scanning over the defects. Appropriate transfer functions were determined and validations were carried out at a range of frequencies and lift-off conditions. In general, a very good agreement was observed between model predictions and experimental data, particularly in signal amplitudes. Some discrepancies, observed especially at high frequencies, are under investigation in terms of crack opening effects, ferrite loss, and cable/connector joints effects. Necessary modifications are proposed.---This work was supported by the NSF Industry/University Cooperative Research program.

Code Validation for Eddy Current Modeling: Tube Inspection with Reflection-Differential Probes

---**Andreas Schumm**, Electricité de France, R&D Division, Clamart, France; Norio Nakagawa, Iowa State University, Center for NDE, Ames, IA 50011

---While code validation on canonical benchmark problems like the famous TEAM benchmark cases is an essential step in gaining confidence into a modelling code, code validation on real world problems is an important complement, as it takes into account real commercial probe characteristics, as opposed to the often idealized probe setups in benchmark problems. The Eddy current modeling code ECSIM, developed at CNDE, is examined in this paper. This numerical model is based on the boundary element method, and allows simulation of arbitrary probe construction and parameters. Part geometry can be equally arbitrary, except that there is a trade off between part geometry complexity and computation speed. This paper deals with one implementation of the model where the part geometry is restricted to plate geometry in favour of computational efficiency. In 2003, simulation results of ECSIM on an Inconel tube mock-up were compared to existing experimental results on inner and outer circumferential notches inspected at two different frequencies, observing the influence of a geometrical effect such as tube thickness. This set-up corresponds well to the code's limited scope to represent the object geometry, working on an infinite plate with variable thickness, into which a single crack-like defect can be inserted. The EC probe used for this setup represented a number of difficulties, such as a ferrite core for the excitation coil and a differential pickup coil arrangement with a small inner diameter. The results were instructive, showing that special care must be taken to generate highly symmetrical meshes, as minor differences are amplified by the differential setup. We present qualitative and quantitative results and focus on the lessons learned from this code validation exercise.

Eddy Currents Induced by an Encircling Coil in a Finite Length Layered Rod

---**Haiyan Sun** and John Bowler, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

---This article describes the calculation of eddy currents in a circular conducting rod of finite length due to a coaxial circular coil carrying an alternating current. The coil impedance variation with frequency is determined from the field for an arbitrary coaxial location of the coil. The electromagnetic field due to a coil encircling a cylindrical rod of infinite length has been known for some time, the solution being expressed in explicit form as a Bessel function integral. Similarly, the coil impedance variation with frequency is expressed in explicit integral form. For a finite length rod, additional boundary conditions must be satisfied at the ends of the rod. The end effects are accommodated here by recasting the problem in a finite domain that can be arbitrarily large thereby yielding results that are numerically as close to the infinite domain solution as desired. The solution is formulated in terms of the magnetic vector potential. With a finite domain, the magnetic vector potential can be solved using orthogonal eigenfunctions and expressed as a Bessel function summation instead of integration. Closed-form expressions are derived for both the homogeneous finite rod and the two-layer rod with different material properties in each layer.---This work was carried out under the NSF/IU/CRC Program at CNDE.

Subsurface Defect Detection in Metals with Pulsed Eddy Current

---**Yuri A. Plotnikov**, Inspection and Manufacturing Technologies, GE Global Research Center, Niskayuna, NY 12309-1135; Walter Bantz, Manufacturing and Quality Technology Department, GE Aircraft Engines, Cincinnati, OH

---The eddy current (EC) method is traditionally used for open surface crack detection in metallic components. Subsurface voids in bulk metals can also be detected by the eddy current devices. Taking into consideration the skin effect in conductive materials, a lower frequency of electromagnetic excitation is used for a deeper penetration. A set of special specimens was designed and fabricated to investigate sensitivity to subsurface voids. Typically, flat bottom holes (FBHs) are used for subsurface defect simulation. This approach is not very representative of real defects for eddy current inspection because the FBH depth extends to the bottom of the specimen. Two-layer specimens with finite depth FBHs were fabricated and scanned with conventional EC of variable frequency. Sensitivity and spatial resolution of EC diminish with flaw depth. The pulsed EC approach was applied for flaw detection at variable distance under the surface. The multi-frequency nature of pulsed excitation provides effective coverage of a thick layer of material in one pass. Challenging aspects of subsurface flaw detection and visualization using the EC technique are discussed.

EC Modeling of Ferrite-Core Probes

---F. Buvat, **G. Pichenot**, and D. Premel, CEA SACLAY, Batiment 611, 91191 Gif-sur-yvette, France; H. Voillaume, EADS, Suresnes, France

---The CEA has developed a fast code for the simulation of EC probes. It is based on a Volume Integral (VIM) approach. Within the framework of an EADS partnership, this code has been extended to the simulation of ferrite-core probes. Different kinds of ferrite-cores can be modeled with for example standard I, C and E shapes. The model gives the normalized impedance diagram for a probe over multi-layer materials. The response of a probe to a parallelepiped 3D flaw included in a conductive slab can be simulated. The model has been benchmarked with experimental data for several configurations. An excellent agreement has been achieved. The model can be used to design specific probes or to evaluate critical inspection parameters such as the lift-off effect in relation with the probability of detection.

An Approach for Characterization of Eddy Current Probes

---**B. P. C. Rao** and N. Nakagawa, Center for NDE, Iowa State University, Ames IA 50011

---A model-based approach is presented, in this contribution, to determine coil inner diameter, outer diameter and coil height of absolute cylindrical eddy current probes of air-core as well as ferrite-core types. This approach uses eddy current signal data obtained from 3-D boundary element model for a variety of probe dimensions. Specific signatures of predicted eddy current signals from a well characterized defect in a stainless steel plate at a frequency are given as input to a trained radial basis function neural network to directly determine the probe internal data and the probe type i.e. air-core or ferrite core. Performance of the approach is evaluated for data obtained from model as well as from experiments involving the use of HP impedance analyzer and a commercial eddy current tester. Appropriate transfer functions are determined for using the experimental data. For a few available probes, results obtained by this approach are compared with X-ray CT data. We show that, using the proposed approach, it is possible to accurately evaluate the probe type, coil ID and coil OD from a simple line-scan. Core-to-coil vertical spacing is expected to have an influence on the determination of coil height and we present ways to bring down the error in determination.---This work was supported by the NSF Industry/University Cooperative Research program.

SESSION 19

STRUCTURAL HEALTH MONITORING APPLICATIONS I

A. McNab, Chairperson
Parker Ballroom A

8:30 AM **A Wireless Sensor Network of Permanently Installed Structural Integrity Monitors**
---G. Benny, K. Steel, A. McNab, and G. Hayward, United Kingdom Research Centre for Non-Destructive Evaluation (UK RCNDE), Centre for Ultrasonic Engineering, University of Strathclyde, 204 George Street, Glasgow G1 1XW, Scotland, United Kingdom

8:50 AM **Guided Wave Tomography on an Aircraft Wing with Leave in Place Sensors**
---**H. Gao**, Y. Shi, and J. L. Rose, Department of Engineering Science and Mechanics, The Pennsylvania State University, State College, PA 16802

9:10 AM **Permanently Attached Single PZT Guided Wave Encoded Sensor for Flood Detection of Oil Rigs Cross Beams**
---R. Mijarez and **P. Gaydecki**, Department of Instrumentation and Analytical Science, UMIST, P. O. Box 88, Manchester M60 1QD, United Kingdom; M. Burdekin, The Fatigue Monitoring Bureau, Macclesfield, SK 10 5LX, United Kingdom

9:30 AM **Plate Waves Structural Health Monitoring of Composite Structures**
---R. Jagannathan, B. Somashekar, **K. Balasubramaniam**, and C. V. Krishnamurthy, Centre for Nondestructive Evaluation and Department of Mechanical Engineering, Indian Institute of Technology Madras, Chennai 600 036, India

9:50 AM **An Intelligent Sensor System for Monitoring Fatigue Damage in Welded Steel Components**
---**B. Fernandes** and P. Gaydecki, Department of Instrumentation and Analytical Science, UMIST, P. O. Box 88, Manchester M60 1QD, United Kingdom; M. Burdekin, The Fatigue Monitoring Bureau, Macclesfield, SK10 5LX, United Kingdom

10:10 AM ***Coffee Break***

10:30 AM **Self-Calibrating Ultrasonic Techniques for In-Situ Monitoring of Fatigue Crack Progression**
---**J. E. Michaels**, T. E. Michaels, B. Mi, and A. C. Cobb, School of Electrical and Computer Engineering, Georgia Institute of Technology, 777 Atlantic Drive NW, Atlanta, GA 30332-0250

10:50 AM **Visualization and Modeling of Short Wave Propagation by Using Genetic Algorithm and S-Transformation**
---X. Wang, **I. N. Tansel**, P. Chen, and N. Reen, Florida International University, Miami, FL 33174

11:10 AM **An Intelligent Sensing System for Detection and Evaluation of Particle Impact Damage**
---**A. Scott**, A. Batten, G. Edwards, T. Farmer, M. Hedley, N. Hoschke, P. Isaacs, M. Johnson, C. Lewis, A. Murdoch, D. Price, M. Prokopenko, P. Valencia, and P. Wang, CSIRO Industrial Physics, P. O. Box 218, Lindfield, NSW, 2070, Australia

11:30 AM **Sensors in Corrosion**
---**V. S. Agarwala**, Naval Air Systems Command, Research & Engineering Group, Building 2187, Suite 2373, 48110 Shaw Road, Patuxent River, MD 20670-2906

11:50 AM **Tracking Fabry-Perot Transmission Line Through Multiple Free Spectral Ranges**
---**J. A. Smith**, Advanced Engineering, Corning Incorporated, SP-AR-02-04, Corning, NY 14831

12:10 PM ***Lunch***

A Wireless Sensor Network of Permanently Installed Structural Integrity Monitors

---**Graham Benny**, Kenneth Steel, Alistair McNab, and Gordon Hayward, United Kingdom Research Centre for Non-Destructive Evaluation (UK RCNDE), Centre for Ultrasonic Engineering, University of Strathclyde, 204 George Street, Glasgow G1 1XW, Scotland, United Kingdom

---Structural integrity monitoring (SIM) involving a large numbers of distributed sensors is of increasing importance to a wide range of industries. Compact sensor packages combining ultrasonic transducers with local sensor and communications control functions and signal processing have been designed using modern miniaturization techniques. Autonomous wireless devices powered by on-board batteries can extract top-up energy derived from the sensor environment. Applications to date include erosion or corrosion monitors via ultrasonic thickness measurement devices, area mapping array sensors and time-of-flight diffraction (TOFD) technique transducers for defect monitoring. Formation or propagation of defects can also be monitored with passive acoustic emission (AE) sensors. The project concepts and early prototyping were presented at QNDE 2003. This paper highlights further progress towards a distributed wireless ultrasonic sensor network and presents results of TOFD and thickness measurement tests. Signal processing techniques including averaging, Finite Impulse Response (FIR) filtering and pulse compression have been employed to improve signal-to-noise ratio (SNR), to extend battery power and to address time resolution issues. Field trials in a hostile industrial environment with metallic obstructions in the form of pipework, ducting, stairs, beams and floors have been performed and methods of extracting environmental energy have been tested.

Guided Wave Tomography on an Aircraft Wing with Leave in Place Sensors

---**Huidong Gao**, Yijun Shi, and Joseph L. Rose, Department of Engineering Science and Mechanics, The Pennsylvania State University, State College, PA, 16802

---Structural health monitoring of aircraft components has attracted more and more attention these years. Frequent inspection is very important to prevent catastrophic failure of the aircraft. In our work, leave in place sensor and guided wave tomographic techniques are combined together in the health monitoring of an aircraft wing. In a sample problem, eight small PZT transducers are mounted on the surface of the wing. The diameter and thickness of the PZT transducers are 0.63mm and 0.254mm respectively. The small scale of the transducer makes it suitable to be fitted at many places of the aircraft. The transducers are arranged in a circle covering an area of a few rivet rows. Each of the transducer can be worked as both a sensor and an actuator. By taken the through transmission signal between each of the transducers, the whole area of within the circle are monitored. In our experiment, a simulated saw cut defect is produced beside one of the rivet holes. As the elongation of the defect size, several groups of signals are collected. With the technique of guided wave tomography, a pseudo image of the aircraft wing is reconstructed from the through transmission signals. With the occurrence of the defect and the procession of the defect size, differences are clearly depicted on the tomographic images. As a result, defects can be detected and located on the aircraft wing with the combined technology of leave in place sensor array and ultrasonic guided wave tomography.

Permanently Attached Single PZT Guided Wave Encoded Sensor for Flood Detection of Oil Rigs Cross Beams

---Rito Mijarez and **Patrick Gaydecki,** Department of Instrumentation and Analytical Science, UMIST, P.O. Box 88, Manchester M60 1QD, United Kingdom; Michael Burdekin, The Fatigue Monitoring Bureau, Macclesfield, Sk10 5LX, United Kingdom

---Structural flooded member detection of offshore oil platforms involves the detection of seawater in their normally hollow steel crossbeam members. NDT methods such as ultrasound have been used to inspect for the presence of water in these applications, often in conjunction with remote operating vehicles. Alternatively, a monolithic PZT guided wave sensor is now being developed which can be permanently attached to a sub-sea installation and that can be powered by the action of the seawater. Upon activation the transducer transmits encoded information to monitoring systems at deck level. This work presents preliminary results of a guided wave system composed of a waterproof transmitter based on a microcontroller, a signal booster, a single 21 kHz PZT transducer and a 5.5V Seawater Activated Battery (SAB) package. The receiver instrumentation package comprises a PZT transducer, an amplifier, a real-time digital signal processing system, a digital oscilloscope and a computer. Experiments were carried out using a jointed steel pipe structure, 10 m in length, 0.5m in diameter and 16 mm in thickness, completely immersed in seawater. The transmitter was attached to the inner wall of a spur pipe and configured to generate narrow bandwidth chirp signals to excite axi-symmetric modes. Results confirmed that although the attenuation was significant, the receiving system was capable of identifying the chirp transmissions by minimizing significantly the background noise levels.

Plate Waves Structural Health Monitoring of Composite Structures

---R. Jagannathan, B. Somashekar, **Krishnan Balasubramaniam**, and C.V. Krishnamurthy, Centre for Nondestructive Evaluation and Department of Mechanical Engineering, Indian Institute of Technology Madras, Chennai 600 036, India

---Layered composite plate-like structures are finding an increasing range of applications in the aerospace industry. Structural Health Monitoring (SHM) of such structures is seen as a paradigm that will embrace efficient non-destructive testing/evaluation techniques. The present study demonstrates two techniques that have the potential for the SHM of multi-layered composite structures. The first technique is based on multi-transmitter-multi-receiver (MTMR) technique with tomographic methods used for data reconstruction. In the MTMR, the possibility of SHM using algebraic reconstruction techniques (ART) for tomographic imaging with Lamb wave data measured in realistic materials is examined. Commercially available narrow bandwidth PZT crystals were used as sensors on multi-layered quasi-isotropic and cross-ply composite plates with and without defects. Defects (through holes and low velocity impact delaminations) were synthetic and have been chosen to simulate impact damage in composite plates. To achieve reasonable image quality, conventional cross-hole configuration is replaced by a new modified cross-hole configuration that also optimizes the number of sensors. The second technique is a single-transmitter-multi-receiver (STMR) technique that is more compact and uses reconstruction techniques that are analogus to synthetic aperture techniques. Here, the phase shifting is performed on the individual signals based on the guided wave dispersion relationships. The reconstruction algorithm uses summation of the phase shifted signals to image the location of defects, portions of the plate edges, and any reflectors from inherent structural features of the component.

An Intelligent Sensor System for Monitoring Fatigue Damage in Welded Steel Components

---**Bosco Fernandes** and Patrick Gaydecki, Department of Instrumentation and Analytical Science, UMIST, P.O. Box 88, Manchester M60 1QD, United Kingdom; Michael Burdekin, The Fatigue Monitoring Bureau, Macclesfield, SK10 5LX, United Kingdom

---This paper describes a sensor and data storage system that monitors fatigue damage in load-bearing steel components. The sensor is a thin steel sheet measuring 50  20 mm, within which is induced a pre-crack. It is attached to the component under test and follows its flexions. In service, the sensor begins to fatigue, thereby increasing the length of the pre-crack. Crack length is measured and recorded using a microcontroller. Electrically conductive tracks are laid on the sensor in a direction perpendicular to that of the crack. They are connected to the microcontroller via resistors in a potential divider arrangement. When the crack propagates past a track, it breaks its continuity, thereby changing the resistance ratio in the network and hence its output voltage. The crack length is represented by the analogue voltage recorded. The data are stored in memory and can be remotely downloaded from a distance of 30 m using Bluetooth™ technology, to a PC. The microcontroller is configured to operate in stop mode, waking up at a predetermined frequency to read the sensor. In this way, it consumes very little current and can operate over many years. The downloaded data can be analysed to predict the components useful life.

Self-Calibrating Ultrasonic Techniques for In-Situ Monitoring of Fatigue Crack Progression

---**Jennifer E. Michaels**, Thomas E. Michaels, Bao Mi, and Adam C. Cobb, School of Electrical and Computer Engineering, Georgia Institute of Technology, 777 Atlantic Dr., NW, Atlanta, GA 30332-0250

---Ultrasonic sensors permanently affixed to aluminum coupons are used to monitor progression of damage during fatigue testing with the long term goal of structural health monitoring for diagnostics and prognostics. Necessary for success are proper design of the ultrasonic testing methods, robust transducer mounting techniques, and real-time signal processing methods for determining the state of the structure. It is also highly desirable for the overall system to be self-calibrating with built-in diagnostics in order to detect and compensate for sensor failure or degradation. Self-calibrating ultrasonic techniques are applied for monitoring of cracks initiating and propagating from the inaccessible inner diameters of rivet holes where the transducers are mounted on the accessible specimen surface. Multi-scale ultrasonic methods are utilized that are suitable for detecting small defects in local regions as well as global detection of larger defects. Results are presented for aluminum coupons subjected to low cycle fatigue and demonstrate ultrasonic tracking of crack growth.

Visualization and Modeling of Short Wave Propagation by Using Genetic Algorithm and S-Transformation

---X. Wang, **I. N. Tansel**, P. Chen, and N. Reen, Florida International University, Miami, FL 33174

---Estimation of the time intervals between the propagating short waves and detection of change of their characteristics are very important in many structural health monitoring (SHM) applications and Non-Destructive Evaluation (NDE). Variation of the characteristics of the short waves can be visualized from the two-dimensional time-frequency map of S-transformations. Genetic algorithms (GA) are capable to estimate the parameters of the time domain models, which represent the delay, amplitude, and envelope characteristics of these waves. In this paper, complimentary use of the GA and S-transformation will be demonstrated. Characteristics of short waves (number, duration, frequency, amplitude, and envelope) will be determined by using the s-transformation, and the most appropriate time domain model will be designed. Once the model is determined, GA will be used to estimate the parameters of the selected model. Performance of the proposed procedure will be evaluated on the simulated data when short waves overlapped and significant background noise existed.---This work was performed at the Florida International University in cooperation with 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.

An Intelligent Sensing System for Detection and Evaluation of Particle Impact Damage

---**Andrew Scott**, Adam Batten, Graeme Edwards, Tony Farmer, Mark Hedley, Nigel Hoschke, Peter Isaacs, Mark Johnson, Chris Lewis, Alex Murdoch, Don Price, Mikhail Prokopenko, Philip Valencia, and Peter Wang, CSIRO Industrial Physics, P.O. Box 218, Lindfield, NSW, 2070, Australia

---Structures capable of self-assessment and repair require the development of appropriate strategies and technologies for processing NDE data, as well as the storage, communication and analysis of such data and the capability to make intelligent decisions. We shall report on a test-bed developed to investigate sensing technologies and strategies, and the algorithms for handling data and information. Such a system to detect and evaluate damage, and ultimately to initiate repair or remediation, needs to be able to operate effectively when damage has occurred to either the structure and/or the sensing system, and should also be capable of application to any sized structure without problems of saturation of communication pathways or overloading central controllers. The demonstrator we have built can determine the location and severity of fast particle impacts, and is aiming to be able to take autonomous actions to diagnose and repair damage. The sensing and processing are both robust and scalable. While some of the hardware and software developed so far are specific to the detection of impacts, much of the work has generic applications to structural health monitoring and management. These aspects as well as specifics regarding sensors, their placement, and the accuracy of impact location will be discussed.

Sensors in Corrosion

---**Vinold S. Agarwala**, Naval Air Systems Command, Research & Engineering Group, Building 2187, Suite 2373, 48110 Shaw Road, Patuxent River, MD 20670-2906

---Corrosion is the major factor responsible for driving the maintenance cost high and for premature equipment failures. Determining early signs of corrosion-assisted damage is essential for life prediction and prevention of major repairs and catastrophic occurrences. Sensors are the only means by which corrosion detection and monitoring is possible and should be made mandatory for critical equipment and structures. Sensors can predict when environmental conditions can be conducive to corrosion and when maintenance action should be mandated, could be cost effective and best in the interest of safety and reliability. Several forms of corrosion such as crevice and pitting corrosion, exfoliation of joints and edges, fatigue and stress cracking can be monitored. This presentation reviews what is currently available, the sensor types, what they can do to, and how they can be employed for diagnostic and prognostic analysis. Essentially, two classes of diagnostic tools have been discusses: one that monitors the corrosive condition or environment in which an equipment operates/performs, and the second that detects/ determine where an active corrosion or corrosion related damage has occurred. On-line inspection tools, leave-in-place damage detection and monitoring sensors cause the paradigm shift on scheduled maintenance and proactive remedial actions. Monitoring system “corrosion health” throughout their intended design life and controlling the cause and effect for aging is the viable solution to reducing total ownership cost. It has been noted than on an average over 35% of man-hour labor is spent in removing corrosion damage on naval aircraft. Knowing where is the problem early will save up to 30% total ownership cost.

Tracking Fabry-Perot Transmission Line Through Mulitple Free Spectral Ranges

---**James A. Smith**, Advanced Engineering, Corning Incorporated, SP-AR-02-04, Corning, NY 14831

---Corning Incorporated and its customers have a need for a measurement system to ensure the reliability of optical fiber and the validity of reliability models for a number of manufacturing processes. This measurement system will minimize degradation in fiber strength or reliability due to exposure of the fiber to excessive or improper tensile stresses. A proposed transducer based on fiber Bragg gratings (FBGs) has been designed to address this opportunity by dynamically measuring strain while the fiber is being processed. By using hybrid Bragg Fabry-Perot (BFP) transducers, strain measurements can be made from wavelength shifts in the transmitted line of the BFP. The BFP sensors will work well for low strains. For large strains, the BFP transmission line must be tracked through multiple free spectral ranges. For in-process applications, the tracking technique must be able to follow fast transient events that may span several free spectral ranges. A technique will be presented that will dynamically track the BFP transmission line when the sensor is under large strain. The successful implementation of this technique will allow for high strain in-process fiber measurements.

SESSION 20
UT PHASED ARRAYS
R. C. Addison, Chairperson
Parker Ballroom D/E

1:30 PM **Simulation of Phased Array Techniques and Modeling-Based Data Reconstruction**
---**J. Porré**, S. Mahaut, S. Chatillon, and P. Calmon, CEA/LIST, CEA Saclay, 91191 Gif-sur-Yvette, France

1:50 PM **An Evaluation of Phased Array Transducer Configurations Using Conventional and Finite Element Beam Simulation Models**
---A. Gachagan and **A. McNab**, Centre for Ultrasonic Engineering, University of Strathclyde, Glasgow, United Kingdom; D. Reilly, NDTSoft, Cumbernauld, United Kingdom; P. Reynolds, Weidlinger Associates, Los Altos, CA 94022

2:10 PM **Application of Tandem Techniques with Contact Monoelement or Phased Array Probes: Simulations and Experiments**
---S. Mahaut, **R. Raillon**, and E. Kerbrat, CEA/LIST, CEA Saclay, 91191 Gif-sur-Yvette, France; R. Spencer and M. Lozev, Edison Welding Institute, Columbus, OH 43218-2426

2:30 PM **Signal Processing of Ultrasonic Array Data**
---**C. Holmes**, B. W. Drinkwater, and P. D. Wilcox, Department of Mechanical Engineering, University of Bristol, United Kingdom

2:50 PM **Application of Piezocomposite Twin, Side by Side, Phased Array UT Probes for the Inspection of Stainless Steel**
---M. Delaide[1] and **P. Dumas**[2], [1]AVI International, Vilvoorde, Belgium, [2]Imasonic SA, Besancon, France

3:10 PM ***Coffee Break***

3:30 PM **Phased Array Inspection of Titanium Disk Forgings Targeting #1/2 FBH Sensitivity**
---**R. A. Roberts** and J. H. Friedl, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

3:50 PM **Algorithms for Ultrasonic Spacecraft Leak Location Using Structure Borne Noise**
---**S. D. Holland**, R. Roberts, M. Strei, and D. E. Chimenti, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

Simulation of Phased Array Techniques and Modeling-Based Data Reconstruction

---**J. Porré**, S. Mahaut, S. Chatillon, and P. Calmon, CEA/LIST, CEA Saclay, 91191 Gif-sur-Yvette, France

---Ultrasonic techniques based on phased arrays are increasingly applied in various industrial contexts. Such techniques include electronic commutation, sectorial scanning, adaptive beam forming, over canonical or complex profile specimen. These techniques rely on the application of delay and amplitude laws to all, or to groups of, elements of an array, to be optimized when complex structures are concerned (complex profile, non homogeneous and/or anisotropic materials). Once these techniques have been achieved, the interpretation of ultrasonic echoes arising from flaws in the specimen still has to be made, to locate and to size those defects. To achieve this, modeling-based phased arrays data reconstructions have been developed, accounting of the overall echoes received by each element of the array, and using the simulation tools developed at the French Atomic Energy Commission (CEA) for beam prediction and defect scattering. Such reconstructions allow to display the ultrasonic indications in the specimen coordinates. The application of these algorithms to canonical and complex structures containing artificial defects are presented, and compared to simulated data. The comparison of the reconstructed echoes with the actual positions of the detected defects show the efficiency of these methods.

An Evaluation of Phased Array Transducer Configurations Using Conventional and Finite Element Beam Simulation Models

---A. Gachagan and **A. McNab,** Centre for Ultrasonic Engineering, University of Strathclyde, Glasgow, United Kingdom; D. Reilly, NDTSoft, Cumbernauld, United Kingdom; P. Reynolds, Weidlinger Associates, Los Altos, CA

---This paper describes the comparison of a conventional point source model for beam simulation of NDE transducers with finite element (FE) modelling techniques. The models enable an evaluation of phased array representations operating into a variety of inspection materials and geometries. Representative inspection conditions are accommodated through planar, curved or irregular load surface profiles and furthermore, variations in the thickness of the couplant layer at the transducer/load interface can be incorporated. The FE models are used to predict pressure field distribution, wave propagation and interaction with defects. The point source beam simulation model has been developed as an individual customised add-on module for AutoCAD 2004 to provide an interactive environment within which NDE array configurations can be evaluated in 3D space. Good correlation in the predicted pressure field distribution from these two simulation approaches, for a number of different transducer configurations and focal laws on components of complex geometry, is demonstrated. Subsequently, the relative merits of each technique are discussed, with the AutoCAD approach providing a fast, accurate beam simulation. FE techniques are more computationally intensive and may be restricted to more complex inspection problems through which the NDE engineers overall interpretation of the fundamental mechanisms can be enhanced.

Application of Tandem Techniques with Contact Monoelement or Phased Array Probes: Simulations and Experiments
---S. Mahaut, **R. Raillon**, and E. Kerbrat, CEA/LIST, CEA Saclay, 91191 Gif-sur-Yvette, France; R. Spencer and M. Lozev, Edison Welding Institute, Columbus, OH

---Ultrasonic tandem inspection techniques are widely used to detect midwall defects, providing a way to assess them in specular reflection rather than diffraction, whereas a pulse-echo inspection with one probe can only be used for an optimal corner echo detection if the defect is emerging at backwall or frontwall. Conventionally, a pair of probes scans the specimen, one transducer at transmission, the other one for receiving echoes. The distance between both probes and their characteristics allow to master the inspection characteristics. An alternative application relies on the selection of different elements over an array, some at transmission, others at reception. In addition, with arbitrary applied delay laws, phased arrays provide a significantly more flexible tool for tandem inspections. The conception and application of such techniques, however, may become fairly complex, as multiple echoes may arise from different ultrasonic paths. Simulation tools have therefore been integrated into the Civa software developed at CEA, with support from EWI, allowing to predict the inspection performances of tandem techniques. Flaws signals may be computed, thus predicting the inspection performances. This paper presents some simulation and application examples carried out by EWI, for contact monolithic and phased arrays probes.

Signal Processing of Ultrasonic Array Data
---Caroline Holmes, Bruce W. Drinkwater, and Paul D. Wilcox, Department of Mechanical Engineering, University of Bristol, United Kingdom

---One of the most significant changes over recent years in many areas of NDE has been the move away from monolithic transducers and towards array devices. Arrays for eddy current inspection, ultrasonics and optical applications are now becoming increasingly commonplace. The existing processing for ultrasonic arrays for NDE is generally geared towards using the array to emulate a monolithic transducer. This is based on having independently controlled parallel transmission circuits that enable staggered firing of transmitter elements so that the physical wave front injected into a specimen can be steered or focussed. This is all done prior to the signals entering the specimen. This paper describes an alternative approach in which the complete raw data set is collected, containing the time domain signals from every transmitter-receiver pair. Linear post processing of this data set has enabled the conventional test techniques to be used and compared. In addition, an advanced processing algorithm has been developed which allows the array to focus at every point in the target, both in transmission and reception. The results from simulated point reflectors were used to assess the optimum performance of the array for a given application and these results were validated against experimental results from a manufactured reflector.

Application of Piezocomposite Twin, Side by Side, Phased Array UT probes for the Inspection of Stainless Steel

---M. Delaide[1] and **Ph. Dumas[2]**, [1]AVI International, Vilvoorde, Belgium, [2]Imasonic SA, Besancon, France

---Ultrasonic examination of austenitic stainless steel components and welds takes an increasing place during the fabrication and the ”in service inspection” of power and petrochemical plants, where cost reduction and severe safety rules impose to use innovative NDT methods with increased efficiency and flexibility. As a consequence, the UT probes to be used must allow to detect and size cracks in coarse-grain structure, with a high reliability level while the duration of the examinations must be drastically reduced. The combination of well-known TRL probes, based on twin side by side (emission / reception) crystals, with new technologies such as Phased array and piezocomposite allows for manufacturing new kind of transducers that improve both probes performances and inspection speed as requested. Single element crystals are replaced by matrix arrays, making it possible to deflect and to skew the beams, to change the inspection depth and, by way of consequence, to reduce the probe displacement to a minimum. Piezocomposite material improves the sensitivity and the cross coupling between elements thanks to its electro acoustical properties. This paper describes the designing, the manufacturing and the characterisation of several different probes. Application examples where these probes have been used will be presented.

Phased Array Inspection of Titanium Disk Forgings Targeting #1/2 FBH Sensitivity

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

---This work considers the ultrasonic inspection of titanium forgings for which inspection sensitivity is limited by microstructure-induced scattering noise. The scattering noise appears in two forms: 1) backscattered noise, due to randomly-occurring reflected signals generated by the inhomogeneous microstructure, and 2) forward scattered noise, in which the forward propagating incident pulse is randomly modulated in amplitude and phase by a longer-scale spatial inhomogeneity in wave velocity. It has been established that, when examining flat bottom hole (FBH) reflectors in titanium forgings, the observed signal-to-noise ratio can be improved by tightly focusing the ultrasonic field. Using this observation as an engineering principle, a zoned focused inspection was designed to yield adequate sensitivity to a #1/2 FBH (1/128 inch diameter) in designated forged materials. The design study established that an ultrasonic beam having an F6 focus in water (i.e. focal length/aperture diameter = 6) was sufficient to detect a #1/2 FBH in the forged materials of interest. Difficulties were encountered in implementing such a highly focused inspection using conventional focused ultrasonic transducers. Effort was therefore directed toward implementing the engineered inspection using phased array technology. A 110 element segmented annular array was designed to maintain an F6 focus to a depth of 3.25 inches in titanium. The zoned inspection was thereby carried out using discreet zoned focal laws. Results of these inspections will be presented demonstrating the attainment of the targeted #1/2 FBH sensitivity.---This work was supported by the Federal Aviation Administration Engine Titanium Consortium.

Algorithms for Ultrasonic Spacecraft Leak Location Using Structure Borne Noise

---**Stephen D. Holland**, Ron Roberts, Michael Strei, and D. E. Chimenti, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---We discuss the problem of locating air leaks in manned spacecraft. Pressure vessel leak detection is normally performed with microphones that detect airborne ultrasound generated by the leak turbulence. For spacecraft, this turbulence is generated outside the spacecraft and cannot be detected inside because the leak velocity is approximately the speed of sound. Instead, we monitor the cross-correlations of leak-generated guided ultrasonic waves in the plate-like spacecraft skin. In this presentation, we describe an algorithm for leak location with a minimal array of sensors. The algorithm utilizes a-priori knowledge of guided-mode dispersion to invert that dispersion and thereby identify possible location curves for the leak source. The intersection of curves from multiple correlations identifies a specific location for the leak source.---This material is based on work supported by NASA under award NAG-1-029-98.

SESSION 21

3D-POD

W. D. Rummel, Chairperson

Parker Ballroom B

1:30 PM **3-D POD Probability of Detection for Subsurface Defects**
---**W. D. Rummel**, D&W Enterprises, Ltd., 8776 W. Mountainview Lane, Littleton, CO 80125

1:50 PM **Summary of a Workshop on Computational NDE for Modeling POD**
---**G. A. Matzkanin** and H. T. Yolken, Nondestructive Testing Information Analysis Center (NTIAC), 415 Crystal Creek Drive, Austin, TX 78746

2:10 PM **Probability of Detection for Embedded Defects: Needs for Ultrasonic Inspection of Aerospace Turbine Engine Components**
---**D. A. Stubbs**, University of Dayton Research Institute, 300 College Park, Dayton, OH 45469-0120

2:30 PM **Design and Fabrication of Ultrasonic POD Test Specimens – Phase I**
---**J. L. Bartos**, Cincinnati Aerotech Consulting, 8325 Old Stable Road, Cincinnati, OH 45243; M. F. Gigliotti, General Electric Global Research Center, Schenectady, NY; A. Gunderson, University of Dayton Research Institute, Dayton, OH 45469-0120

3:10 PM ***Coffee Break***

3:30 PM **Uses of Physics-Based Models in the Determination of POD: Current Status**
---**R. B. Thompson**, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

3:50 PM **3-D POD Probability of Detection for Subsurface Defects (*Path Forward/Summary*)**
---**W. D. Rummel**, D&W Enterprises, Ltd., 8776 W. Mountainview Lane, Littleton, CO 80125

3-D POD Probability of Detection for Subsurface Defects

---**Ward D. Rummel**, D&W Enterprises, Ltd., 8776 W. Mountainview Lane, Littleton, CO 80125

---Probability of detection (POD) methods have provided a method of quantifying the detection capability of nondestructive evaluation (NDE) methods and have been used in a wide range of applications involving detection of both surface connected detects produced by fabrication processes and fatigue cracks that initiate and grow in service. Extending POD methods must to the characterization of NDE capabilities as applied to subsurface defects presented a number of significant challenges. The first challenge is in analyses and precise description of acceptance criteria. Criteria that has been successfully applied to volume anomalies in solid rocket motors includes specification of defect size, type, location, orientation, and nearest neighbor. For many applications, defect shape (geometric) must be added to this list. POD methodology for relating detection to signal size (amplitude) is well established. Unfortunately, detection of a small signal may relate to a large, but mal-oriented detect and some characterization is required to provide additional information on actual defect size. A 3-D, NDE procedure may therefore be viewed as an initial SURVEY mode in which detection is based on signal amplitudes. This has been a traditional approach in conventional , quality ultrasonic inspection as applied to new component fabrication. The remaining challenge is in a further CHARACTERIZATION mode, to related signal response from different “look angles” and to relate the additional information to an accept or reject decision. This paper proposes some approaches to CHARACTERIZATION and the challenge of meeting the more complex criteria for acceptance.

Summary of a Workshop on Computational NDE for Modeling POD

---**George A. Matzkanin** and H. Thomas Yolken, Nondestructive Testing Information Analysis Center (NTIAC), 415 Crystal Creek Drive, Austin, TX 78746

---A meeting was held in November 2003 in Austin, TX to discuss the status of modeling of Probability of Detection (POD) for NDE and the potential formation of a consortium to plan, financially support and carryout a cooperative research and development program to advance the technology base for modeling POD. The meeting was sponsored by the Air Force, the FAA and NASA and was attended by 25 invited participants from the government, academia and private industry. The meeting provided a forum for very active discussion among participants who voiced a number of comments during discussion of relevant technical issues. These technical issues included the influence of input parameters on the sensitivity of models, the need for NDE engineering tools based on physics based models, the importance of calibration, the need to define limiting measurements to provide needed information, the importance of POD transfer capability, and the cost savings driver for doing POD modeling. Other issues tackled included roadblocks for a consortium to accomplish the desired technical goals and potential solutions to those roadblocks. After discussion about the structure and organization of a potential consortium it was decided by the group to form a Working Group as an interim step to establish what could be done now and to serve as a basis for longer-term activities. The working Group would formulate ideas for the consortium and agree on the basic goals to save costs. This presentation will summarize the output of the POD meeting and provide information on the conclusions and recommendations reached.

Probability of Detection for Embedded Defects: Needs for Ultrasonic Inspection of Aerospace Turbine Engine Components
---**David A. Stubbs**, University of Dayton Research Institute, 300 College Park, Dayton, OH 45469-0120

---In recent years requirements have been created, by the FAA, U.S. Air Force, and engine manufacturers, for the ultrasonic inspection of selected in-service engine components. Typically, inspection sensitivities are developed in terms of calibrating to or detecting artificial embedded defects such as flat bottom holes (FBHs) or side drilled holes (SDHs). These defects are used because they are relatively easy to make, but they impose constraints on attempts to thoroughly evaluate the integrity of inspections. Also, FBHs and SDHs are not very similar to any real embedded defects found in engine alloys. A need exists for new artificial embedded defects that produce a range of reflectivities, are producible in different sizes, allow interrogation from different angles, are reproducible and relatively inexpensive to make, can be made in large quantities, and can be placed in realistic engine component features. This presentation will examine the reasons for these artificial defect requirements and make recommendations for specimens that would allow quantitative assessment of the probability of detection for automated ultrasonic inspections of engine components. Needs also exist for adaptation of statistical POD analysis methods, such as those currently being used for eddy current inspections, to the unique characteristics of ultrasonic inspections and data. This presentation will examine POD analysis needs and make recommendations for the application of current POD methodologies to embedded defect detection.

Design and Fabrication of Ultrasonic POD Test Specimens – Phase I
---**Jon L. Bartos**, Cincinnati Aerotech Consulting, 8325 Old Stable Road, Cincinnati, OH 45243; Michael F. Gigliotti, General Electric Global Research Center, Schenectady, NY; Alan Gunderson, University of Dayton Research Institute, Dayton, OH

---The United States Air Force (USAF) has initiated an effort to develop a new ultrasonic inspection system for use on in-service rotating parts under the Turbine Engine Sustainment Initiative (TESI). A supporting program to develop a quantitative analytical method and test specimens for evaluating the relative Probability of Detection (POD) capability of the ultrasonic system complements this effort, is being led by the University of Dayton Research Institute (UDRI). The primary topic of this paper is the design and fabrication of the POD test specimens. The primary objective of this first phase of the TESI program was to design, prepare, and evaluate POD test samples containing several candidate defect reflector compositions and sizes. The evaluation consisted of physical and ultrasonic characterization of the candidate defects, ultrasonic and metallographic characterization of the test samples, and documentation of the manufacturing processes used to prepare the samples.

Uses of Physics-Based Models in the Determination of POD: Current Status

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

---Motivated by the desire to reduce the time and costs and to improve the accuracy of POD studies, there is an increasing interest in incorporating information from physics-based models of flaw response. This paper will concentrate on the case of internal defects. As compared to surface-breaking fatigue cracks, internal defects, generally inclusions or voids, have a 3-dimensional shape and are hard to simulate in simply fabricated reference samples. Hence, empirical studies pose many problems. This paper will summarize experiences in the development of Model-Assisted POD predictions. After an introduction to some of the fundamental issues, an approach for Model-Assisted POD determination will be presented, supported by data obtained in applications to the ultrasonic inspection of aircraft engine components and welds in pipelines. Attention will be paid to the interplay of information provided by the physics-based models and empirical measurements. This interplay is intimately related to the relative importance of the fundamental physics of the problem, governing the strengths of signals under ideal conditions, and variabilities that might be encountered in the field. Of particular importance for internal defects are the effects of flaw morphology and orientation, information that can significantly affect signal strength. Examples will be given regarding how models can be used to understand and quantify these effects and to reduce their impact on flaw detectability.

SESSION 22
COMPOSITE APPLICATIONS
D. K. Hsu, Chairperson
Parker Ballroom A

1:30 PM **Percolative Conductivity and Impedance Spectroscopy of SWNT Polymer Composites**
---**D. S. McLachlan**[1], C. Chiteme[1], C. Park[2], K. E. Wise[2], Z. Ounaies[3], S. E. Lowther[4], P. Lillehei[4], E. J. Siochi[4], and J. S. Harrison[4], [1]School of Physics, University of the Witwatersrand, Johannesburg, South Africa, [2]National Institute of Aerospace (NIA), [3]Virginia Commonwealth University, [4]Advanced Materials & Processing Branch, NASA Langley Research Center, Hampton, VA 23681-2199

1:50 PM **Signal Processing Variables for Optimization of Flaw Detection in Composites Using Ultrasonic Guided Wave Scanning**
---**D. J. Roth**, MS 6-1, NASA Glenn Research Center, 21000 Brookpark Road, Brookpark, OH 44135; L. M. Cosgriff and R. E. Martin, Cleveland State University; 2100 Brookpark Road, Brookpark, OH 44135; L. Teemer, Florida A&M University

2:10 PM **Thermal Imaging Characterization of Material Properties for Ceramic Matrix Composites**
---**J. Sun**, ET/212, Argonne National Laboratory, 9700 South Cass Avenue, Argonne, IL 60439

2:30 PM **FT-IR Photoacoustic Spectroscopy Applied to the Curing and Aging of Composites**
---**R. W. Jones**, A. J. Wagner, and J. F. McClelland, Ames Laboratory, Iowa State University, 109 Spedding Hall, Ames, IA 50011; J. J. Sweterlitsch, Department of Chemical Engineering, Iowa State University; D. K. Hsu, Center for NDE, Iowa State University, Ames, IA 50011; D. L. Polis, Swales Aerospace, NASA/GSFC, Greenbelt, MD 20771-0001; M. F. Sovinski, NASA/GSFC, Greenbelt, MD 20771

2:50 PM **Applications of the Zero-Group-Velocity Lamb Mode for Air-Coupled Ultrasonic Imaging**
---**S. D. Holland**, V. L. Evan, and D. E. Chimenti, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

3:10 PM ***Coffee Break***

3:30 PM **Experience with Air-Coupled Ultrasonic Inspection of Aerospace Composites**
----**D. K. Hsu**, J. J. Peters, D. J. Barnard, V. Kommareddy[1], and V. Dayal, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

3:50 PM **Application of Stress Waves to Bond Inspection**
---R. H. Bossi, K. Housen, and C. Walters, Boeing Phantom Works, P. O. Box 3999, MC 2T-50, Seattle, WA 98124

Percolative Conductivity and Impedance Spectroscopy of SWNT Polymer Composites
---David S. McLachlan[1], Cosmas Chiteme[1], Cheol Park[2], Kristopher E. Wise[2], Zoubeida Ounaies[3], Sharon E. Lowther[4], Peter Lillehei[4], Emilie J. Siochi[4], and Joycelyn S. Harrison[4], [1]School of Physics, University of the Witwatersrand, Johannesburg, South Africa, [2]National Institute of Aerospace (NIA), [3]Virginia Commonwealth University, [4]Advanced Materials & Processing Branch, NASA Langley Research Center, Hampton, VA 23681-2199

---An understanding of the electric and dielectric properties of Carbon Nanotube-polymer composites is important if one is to exploit the electrical properties of Carbon Nanotubes and to use them as sensors. Finding correlations between the electrical and mechanical properties would also be valuable in QNDE. The results of measurements of the DC and AC conductivity (10^-2 to 10^7 hertz) of single wall carbon nanotubes (SWNT) in polyimide are reported, for volume concentration of SWNTs from 0 to 5%. The results are analyzed using the Three standard percolation equations and a two exponent Single percolation equation. Both analyses involve five parameters, the conductivity of the SWNTs and the polyimide, the critical volume fraction φ_c or percolation threshold of the SWNTs and two exponents s and t. The exponent s characterizes the system below φ_c and t above. Where possible the results are are presented as impedance spectroscopy plots. The values of all five parameters are reasonably consistent with previous experiments on Carbon Nanotubes and the theory and results from other percolation studies. However, as the SWNTs still exist as bundles in these composites, an understanding of a φ_c value of 0.05% is not straightforward.

Signal Processing Variables for Optimization of Flaw Detection in Composites Using Ultrasonic Guided Wave Scanning
---**Don J. Roth**, MS 6-1, NASA Glenn Research Center, 21000 Brookpark Rd., Brookpark, OH 44135; Laura M. Cosgriff and Richard E. Martin, Cleveland State University; 2100 Brookpark Rd., Brookpark, OH 44135; LeTarrie Teemer, Florida A&M University

---This study analyzes the effect of signal processing variables on the ability of the ultrasonic guided wave scan method at NASA Glenn Research Center to distinguish various flaw conditions in ceramic matrix composites samples. In the ultrasonic guided wave scan method, several time- and frequency-domain parameters are calculated from the ultrasonic guided wave signal at each scan location to form images. The parameters include power spectral density, centroid mean time, total energy (zeroth moment), centroid frequency, and ultrasonic decay rate. A number of signal processing variables are available to the user when calculating these parameters. These signal processing variables include 1) the time portion of the time-domain waveform processed, 2) integration type for the properties requiring integrations, 3) bounded versus unbounded integrations, 4) power spectral density window type, 5) and the number of time segments chosen if using the short-time fourier transform to calculate ultrasonic decay rate. Flaw conditions examined included delamination, cracking, and density variation.

Thermal Imaging Characterization of Material Properties for Ceramic Matrix Composites
---**Jiangang Sun**, ET/212, Argonne National Laboratory, 9700 South Cass Avenue, Argonne, IL 60439

---Ceramic matrix composites (CMCs) are being developed for a variety of high-temperature applications, including advanced heat engines for military and commercial applications. Because of the critical functions and the high costs of making CMC components, microstructural variations (such as porosity or micro-cracks) and defects (such as delaminations) within these materials must be detected and characterized. To advance nondestructive evaluation (NDE) of CMCs, we have developed a flash thermal imaging system at Argonne National Laboratory. The system can be operated in through-thickness or one-sided setup to obtain two-dimensional NDE image data of the tested CMC sample. Thermal diffusivity is the primary physical property determined by thermal imaging, and its value is related to the material microstructure and the presence of defects. The two-dimensional NDE data allow for direct characterization of material microstructural variation and determination of the size, severity, and, from one-sided setup, the depth of delaminations within the CMC sample. NDE results for CMCs and their correlation with material mechanical property will be presented and discussed.

FT-IR Photoacoustic Spectroscopy Applied to the Curing and Aging of Composites
---**Roger W. Jones**, Anthony J. Wagner, and John F. McClelland, Ames Laboratory, Iowa State University, 109 Spedding Hall, Ames, IA, 50011; Jeffrey J. Sweterlitsch, Department of Chemical Engineering, Iowa State University, Ames, IA, 50011; David K. Hsu, Center for NDE, Iowa State University, Ames, IA, 50011; Daniel L. Polis, Swales Aerospace, NASA/GSFC, Greenbelt, MD; M. F. Sovinski, NASA/GSFC, Greenbelt, MD 20771

---Carbon-fiber composites are widely used where strength-to-weight ratios are critical, so their strength must not be compromised. Inadequate cure and deterioration from aging can result in significant shortfalls in mechanical performance. FT-IR photoacoustic spectroscopy (PAS) can be used to measure chemical changes related to cure and aging, but the measurement probes only a few micrometers into the material. This probe depth is too shallow to directly characterize the material bulk, which defines the mechanical properties of the matrix. Nevertheless, the near-surface chemical changes that PAS can probe may be predictive of bulk chemistry changes and could therefore be used to predict, using partial-least-squares (PLS) chemometrics, the mechanical properties within the bulk. Two systems to which we have recently applied FT-IR PAS are determining cure levels in carbon-cyanate ester composites and loss of strength in carbon-epoxy composites from accelerated aging by heat treatment. For example, in one study of a set of aged carbon-epoxy composites having interlaminar shear strengths spread over a 55 MPa range, PLS modeling of FTIR-PAS spectra achieved a standard error of cross validation of 1.6 MPa.

Applications of the Zero-Group-Velocity Lamb Mode for Air-Coupled Ultrasonic Imaging

---**Stephen D. Holland**, Victoria L. Evan, and D. E. Chimenti, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---Airborne ultrasound couples particularly well into plates at the zero-group-velocity point of the first order symmetric (S1) Lamb mode. We discuss applications of this mode to ultrasonic imaging of plate-like structures. The sensitivity and high Q of this mode makes it ideal for imaging. We present images from a wide variety of materials and samples, including composites and honeycomb structures. Transmission at the zero-group-velocity frequency is shown to be particularly sensitive to nearby flaws and discontinuities, and is therefore suitable for wide-area scanning for cracks or manufacturing flaws.---This material is based on work supported by NASA under award NAG-1-029-98.

Experience with Air-Coupled Ultrasonic Inspection of Aerospace Composites

---**D. K. Hsu**, J. J. Peters, D. J. Barnard, V. Kommareddy[1], and V. Dayal, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---This paper reports our experience of applying air-coupled ultrasound to the inspection of aerospace composite structures. The project consists of quantitative measurement and understanding of air-coupled ultrasonics in the laboratory and an effort to develop and test a fieldable scanning system. The laboratory study involves transducer characterization, insertion loss measurement, and imaging of flaws in solid laminates and honeycomb sandwiches. The fieldable system, having no motorized scanner, produces images by manual scan using a magnetic position tracker. The manual scan is made more efficient by making the resolution (pixel size) changeable during the scan. The system has been tested on aircraft in maintenance hangars.---This work was supported in part by FAA under contract #DTFA03-98-00008, delivery order IA047, technical monitor Paul Swindell, and in part by NSF I/U CRC for NDE at Iowa State University.

Application of Stress Waves to Bond Inspection

---**Richard H. Bossi**, Kevin Housen, and Craig Walters, Boeing Phantom Works, P. O. Box 3999, MC 2T-50, Seattle, WA 98124

---The use of controlled, localized stress waves in materials and bonded joints offers new opportunities for the characterization of structures. Bonded joints in particular benefit from this application because there is no nondestructive method to monitor bond strength. Previously full-scale proof testing of bonded structure has been the only sure method of detecting “kissing” or weak bonds. High-intensity stress waves have now been shown to provide a method for localized testing of bond strength. Stress waves of sufficient intensity to evaluate bonding can be generated by electron beam, mechanical impact or laser pulse. Of these methods the laser pulse method has been found to provide the most reliable and controlled method for stress wave generation. The current approach for the application of stress waves is the use of a high peak power, short pulse laser system and surface velocity monitoring system. Modeling of the method has shown that the laser beam shape results in controlled, very localized testing of internal strength. A compact high peak power laser system and beam delivery method has been designed for factory implementation. To date numerous tests have shown the method to be sensitive to weak bonds created by poor adhesive mixing, improper surface preparation or contamination.

SESSION 23
NDE FOR WELDS, PROPERTIES, AND TECHNIQUES
D. Olson, Chairperson
Parker Ballroom C

1:30 PM **Utilization of Non-Destructive Thermoelectric Power Measurements for Determination of Interstitial Nitrogen Content in Nitrogen-Strengthened Austenitic Stainless Steel Weldments**
---A. Lasseigne, **D. Olson**, V. Kaydanov, Department of Metallurgical and Materials Engineering, Colorado School of Mines, Golden, CO 80401; T. Boellinghaus, Federal Institute of Materials Research and Testing, Berlin, Germany

1:50 PM **Ultrasonic Evaluation of Weld Strength for Aluminum Ultrasonic Spot Welds**
---**B. Ghaffari**, E. T. Hetrick, and G. Mozurkewich, Ford Motor Company, Research and Advanced Engineering, MD 3083/SRL, P. O. Box 2053, Dearborn, MI 48121-2053

2:10 PM **Finite Element Analysis for the Verification of Post Weld Heat Treatment of Cr-Mo Welds**
---**W. Cheng**, M. Shiwa, and I. Komura, NDE Center, Japan Power Engineering and Inspection Corporation, Kanagawa 230-0044, Japan; Y. Gotoh, Department of Electrical and Electronic Engineering, Kurume National College of Technology, Fukuoka 830-8555, Japan; N. Takahashi, Department of Electrical and Electronic Engineering, Okayama University, Okayama 700-8530, Japan

2:30 PM **Inspection of Resistance Spot Welds Using a Portable Ultrasonic Phased-Array System**
---**F. Reverdy**, Lawrence Berkeley National Laboratory, One Cyclotron Road, MS 46A-1123, Berkeley, CA 94720

2:50 PM **Simulation of NDE Methods for Weld Inspection**
---**R. N. Yancey**, M. Lozev, and E. Todorov, EWI, 1250 Arthur E. Adams Dr., Columbus, OH 43221

3:10 PM ***Coffee Break***

Utilization of Non-Destructuve Thermoelectric Power Measurements for Determination of Interstitial Nitrogen Content in Nitrogen-Strengthened Austenitic Stainless Steel Weldments

---Angelique Lasseigne, **David Olson**, Victor Kaydanov, Department of Metallurgical and Materials Engineering, Colorado School of Mines, Golden, CO 80401; Thomas Boellinghaus, Federal Institute of Materials Research and Testing, Berlin, Germany

---Through the application of solid state physics concepts, a new non-destructive surface contact probe utilizing the thermoelectric power, known as the Seebeck effect, has been developed to conveniently assess and quantitatively map soluble nitrogen content in nitrogen strengthened austenitic stainless steel weldments. The thermoelectric power coefficient has been measured on plasma welds on a nitrogen-strengthened austenitic Alloy 1.4565, which has been interstitially strengthened for enhancement in mechanical properties and corrosion resistance. The thermoelectric power coefficient is capable of the nitrogen content assessment because as the nitrogen enters interstitial positions in the metal matrix it induces lattice distortion or lattice strain. Nitrogen forces the nearest neighbor atoms to shift apart and the resulting lattice strain causes a change in the electronic d-band overlap, thus altering the electronic effective mass. Changes in the effective mass due to nitrogen variations are detectable through utilization of the thermoelectric power coefficient. For Alloy 1.4565, a linear correlation exists for the thermoelectric power coefficient as a function of the weldment interstitial nitrogen concentration allowing utilization of a new non-destructive tool for interstitial nitrogen assessment of austenitic stainless steel weldments.

Ultrasonic Evaluation of Weld Strength for Aluminum Ultrasonic Spot Welds

---**Bita Ghaffari**, Elizabeth T. Hetrick, and George Mozurkewich, Ford Motor Company, Research and Advanced Engineering, MD 3083/SRL, P.O. Box 2053, Dearborn, Michigan 48121-2053

---Ultrasonic spot welding is a novel and promising joining technique for automotive body construction applications. The goal of this work is to determine the feasibility of using an ultrasonic, non-destructive technique for post-process evaluation of aluminum ultrasonic spot welds. For various welding configurations and weld strengths specimen surfaces were flattened, and a focused, 15-MHz, immersion transducer was utilized to obtain C-scans of the weld area. At each point, the A-scan of the reflected ultrasound pulse was fit to a template to obtain amplitudes of the echoes originating from various specimen surfaces. Weldments were subsequently tested destructively, in lap shear using a tensile testing machine, to determine the weld strength. C-scans of the amplitude of the interfacial echo were analyzed to obtain a single parameter related to the weld integrity. The most obvious choice, the weld contact area, displayed a relatively good correlation with weld strength, obtaining an $R2=0.84$ for fitting all samples to a saturating exponential. Though promising, the correlation indicates that the ultrasonic contact area is not the sole predictor of weld quality. Other characteristics, such as the weld shape, might also play a large role in determining weld integrity.

Finite Element Analysis for the Verification of Post Weld Heat Treatment of Cr-Mo Welds

---**Weiying Cheng**, Mitsuharu Shiwa, and Ichiro Komura, NDE Center, Japan Power Engineering and Inspection Corporation, Kanagawa 230-0044, Japan; Yuji Gotoh, Department of Electrical and Electronic Engineering, Kurume National College of Technology, Fukuoka 830-8555, Japan; Norio Takahashi, Department of Electrical and Electronic Engineering, Okayama University, Okayama 700-8530, Japan

---Post weld heat treatment (PWHT) is required for weld of Cr-Mo steel components in high temperature pressure vessels and pipes, in order to temper the weldment and reduce the residual welding stresses. The uniformity of PWHT is of significant importance to the soundness of repair weld. The PWHT temperature is generally measured by thermopiles set up on the surface of welding parts and base metal when the treatment is implemented. This measurement is affected by the PWHT method and the way the thermopiles are installed. The administration of PWHT procedure is of great interest to quality control of weldment. An AC magnetic induction method was developed to verify the local PWHT of Cr-Mo steel in thermal power plants after the PWHT. This method is based on the fact that the magnetic properties, e.g., the permeability, of Cr-Mo steel are sensitive to thermo history. The variation of magnetic property of specimens with different thermo histories can be detected non-destructively using an AC magnetic induction probe. On the other hand, PWHT can be verified from the analysis of inductive signals. This helps to improve the PWHT procedure and justify the installation of thermopiles. The objective of this study is to include in a 3-D finite element simulation to the PWHT verification process. The hysteresis effect, which has usually been ignored in magnetic modelling, is incorporated into the finite element simulation. The material under study is assumed to have isotropic magnetic property and the hysteresis loop is presented point by point. Simulations taking into account of hysteresis and not are presented. Comparison is also made between signals from simulation and measurement. The 3-D finite element analysis helps the understanding of hysteresis effects on induction signals and finding the correlation between magnetic properties and PWHT temperatures.

Inspection of Resistance Spot Welds Using a Portable Ultrasonic Phased-Array System

---**Frederic Reverdy**, Lawrence Berkeley National Laboratory, One Cyclotron Road, MS 46A-1123, Berkeley, CA 94720

---The most common methods for monitoring spot-weld integrity in manufacturing operations are pry checks and physical teardown. During teardown, weld quality is inferred from the size of the weld button that remains when the joint is peeled open. Destructive testing has several drawbacks including high costs associated with scrapped material, ergonomic injuries, and the time lag between the onset and identification of problems. Results obtained using an ultrasonic phased array with a 32-element 10-MHz probe were presented last year. At that time, weld quality was estimated based on a single B-scan. Although these results were considered to be more diagnostic than measurements obtained with a single-crystal transducer, they did not allow dimensional analysis of the weld, or identification of misshapen welds or defects located outside of the line scan. During the past year, a 64-element 17-MHz probe with a natural focus was used in conjunction with mechanical scanning to obtain C-scan images of welds. A housing for the probe has been designed that makes it possible to inspect spot welds without having to immerse the sample. Comparisons between peeled samples and C-scan images will be presented to demonstrate the validity of the method.

Simulation of NDE Methods for Weld Inspection

---**Robert N. Yancey**, Mark Lozev, and Evgueni Todorov, EWI, 1250 Arthur E. Adams Dr., Columbus, OH 43221

---Computer simulation modeling has become mainstream in many industries. Finite element analysis (FEA) and computational fluid dynamics (CFD) are used extensively to develop and validate designs of components and systems. Computer simulation modeling of nondestructive Inspection (NDI) processes is a relatively new technology but the benefits of the technology are already being realized. Simulation methods include analytical formulations as well as finite element analysis. This paper will present some case studies of how simulation modeling is used to develop inspection procedures and inspection instrument designs for weld inspections. Benefits include reduced time to develop inspection processes, optimized inspection methods, ability to visualize beam-defect interactions which lends insight to the physics behind the process, and quick comparisons between different inspection techniques. Examples covering a range of NDI techniques will be presented. Future needs and directions will also be covered.

SPECIAL EVENING SESSION

J. Malas, Chairperson
Parker Ballroom A

8:00 PM Requirements for Structural Health Monitoring/Prognosis

The high costs of maintenance of aging military assets, including a significant inspection component, are causing an examination of alternate ways to sense the state of a structure to assure its integrity. Included are such new strategies as Structural Health Monitoring and Prognosis. Although these techniques are different from traditional NDE, they share the common goal of requiring nondestructive sensing of material condition. In this discussion session, guest speakers will discuss the measurement requirements presented by these new scenarios. It is hoped that this information, and the ensuing discussion, will stimulate new measurement concepts that will be key to the implementation of these scenarios.

SESSION 24
THERMAL TECHNIQUES
X. Han, Chairperson
Parker Ballroom D/E

8:30 AM **Coating Thickness and Thermal Conductivity Evaluation Using Flash IR Imaging**
---**H. I. Ringermacher**, GE Global Research Center, P. O. Box 8, Schenectady, NY 12301; E. R. Rozier, GE Energy, 1 River Road, Schenectady, NY 12345

8:50 AM **Flash Duration Effect in One-Sided Thermal Imaging**
---**J. Sun**, ET/212, Argonne National Laboratory, 9700 South Cass Avenue, Argonne, IL 60439

9:10 AM **Characterizing the Effects of Sonic IR Variables on Turbine Disk Inspection Using a Design of Experiments Approach**
---**D. J. Mayton** and C. Alvarez, SAIC, 16701 West Bernardo Drive, San Diego, CA 92127; F. W. Spencer, Sandia National Laboratories, P. O. Box 5800, MS 0829, Albuquerque, NM 87185-0829

9:30 AM **Study the Effect of Geometry in Sonic IR Imaging**
---**X. Han**, W. Li, and Z. Zeng, Electrical and Computer Engineering, Wayne State University, Detroit, MI 48202; L. Favro and G. Newaz, Institute of Manufacturing Research, Wayne State University, Detroit, MI 48202; R. L. Thomas, College of Science, Wayne State University, Detroit, MI 48202

9:50 AM **Developing Sonic IR Imaging NDE for Aircraft Structures**
---**X. Han**, S. Islam, J. Lu, W. Li, Z. Zeng, and N. Kashyap, Electrical and Computer Engineering, Wayne State University, Detroit, MI 48202; L. D. Favro and G. M. Newaz, Institute of Manufacturing Research, Wayne State University, Detroit, MI 48202; R. L. Thomas, College of Science, Wayne State University, Detroit, MI 48202

10:10 PM ***Coffee Break***

10:30 PM **Derivative Contrast in Thermographic NDT**
---**S. M. Shepard**, Y. Hou, and J. R. Lhota, Thermal Wave Imaging, Inc., 845 Livernois, Ferndale, MI 48220

10:50 PM **Improved Thermographic Damage Detection with Principle Component Analysis**
---**W. P. Winfree**, K. E. Cramer, and J. N. Zalameda, NASA Langley Research Center, MS 231, Hampton, VA 23681; A. R. Roberts, Swales Aerospace, K. L. Hodges, Lockheed Martin

11:10 PM **Acoustic Thermography: Vibrational Modes of Cracks and the Mechanism of Heat Generation**
---**M. Rothenfusser** and C. Homma, Corporate Technology, Siemens AG, Munich 81730, Germany

11:30 PM **Vibro Acoustic Modulation NDE Technique. Part 1: Theoretical Study**
---**P. Duffour**, P. Cawley, and M. Morbidini, RCNDE, Department of Mechanical Engineering, Imperial College, London, United Kingdom

11:50 PM **Vibro Acoustic Modulation NDE Technique. Part II: Experimental Study**
---**M. Morbidini**, P. Duffour, and P. Cawley, RCNDE, Department of Mechanical Engineering, Imperial College, London, United Kingdom

12:10 PM **Vibro-Thermography Crack Tip Temperature Measurements**
---**D. L. Simon**, General Motors Corporation, Detroit, MI 48207

12:30 PM ***Lunch***

Coating Thickness and Thermal Conductivity Evaluation Using Flash IR Imaging

---**H. I. Ringermacher**, GE Global Research Center, P. O. Box 8, Schenectady, NY 12301; E. R. Rozier, GE Energy, 1 River Road, Schenectady, NY 12345

---We will describe a transient IR approach to obtaining absolute simultaneous measurements of coating thickness and thermal conductivity based on the thermal response of a multi-layer system to an impulse function. This method is applicable to any insulative coating on a conductive substrate. Recent development of "flash quenching" capabilities allow for true rectangular impulse functions, permitting the possibility of measuring very thin coatings accurately.

Flash Duration Effect in One-Sided Thermal Imaging

---**Jiangang Sun**, ET/212, Argonne National Laboratory, 9700 South Cass Avenue, Argonne, IL 60439

---One-sided thermal imaging has been widely used as a nondestructive evaluation technique for characterizing structural components and detecting defects. Most thermal imaging systems use photographic flash lamps to provide uniform and nearly-instantaneous radiant heating on the surface of a test sample. The radiant intensity from these flash lamps typically exhibits a short rise time (<0.5 ms) but a long exponential-decay time of several milliseconds. Although the flash duration is considered short, it affects the early-time temperature response and may reduce the accuracy for determining material properties such as thermal diffusivity or defect depth. In this study, we developed a theoretical formulation in which the effect of finite flash duration on one-sided thermal imaging can be analyzed for typical photographic flash lamps. Both theoretical and experimental results will be presented and discussed.

Characterizing the Effects of Sonic IR Variables on Turbine Disk Inspection Using a Design of Experiments Approach

---**Donna J. Mayton** and Carlos Alvarez, SAIC, 16701 West Bernardo Drive, San Diego, CA 92127; Floyd W. Spencer, Sandia National Laboratories, P. O. Box 5800, MS 0829, Albuquerque, NM 87185-0829

---Sonic IR has shown potential as a viable nondestructive inspection technique, but many questions remain as to how to optimize the technique for detectability and reliability. There are many adjustable variables that influence the performance of this technique and it is not known how, or if, these variables interact with each other. In this program, sponsored by the Air Force Research Laboratory, we are taking a Design of Experiments (DoE) approach to the issue. Small samples with known fatigue cracks were tested and reported on previously. In our current work, we placed fatigue cracks in the non-symmetrical anti-rotation features of scrapped F100-PW-220 1st-stage high pressure turbine disks and conducted controlled experiments measuring peak crack response. This paper will discuss the design of this test matrix for the turbine disks, the experimental setup, test results, and conclusions.

Study the Effect of Geometry in Sonic IR Imaging

---Xiaoyan Han, Wei Li, and Zhi Zeng, Electrical and Computer Engineering, Wayne State University, Detroit, MI 48202; Lawrence Favro and Golam Newaz, Institute of Manufacturing Research, Wayne State University, Detroit, MI 48202; Robert Thomas, College of Science, Wayne State University, Detroit, MI 48202

---Sonic IR imaging NDE technique employs a short ultrasonic pulse, typically a fraction of a second, to excite the defects in materials while an infrared camera images the time evolution of the heating effect to identify the defective areas. In our work, laser vibrometers monitor the vibrational behavior of the sample. We have learned that geometry plays an important role in Sonic IR Imaging. For example, the presence of large cracks and the transducer tip position, both affect vibration patterns and the sonic heating. In this paper, we present some results of our study on these geometrical effects in Sonic IR Imaging.

Developing Sonic IR Imaging NDE for Aircraft Structures

---**Xiaoyan Han**, Sawar Islam, Jianping Lu, Wei Li, Zhi Zeng, and Nagarag Kashyap, Electrical and Computer Engineering, Wayne State University, Detroit, MI 48202; L. D. Favro and G. M. Newaz, Institute of Manufacturing Research, Wayne State University, Detroit, MI 48202; R. L. Thomas, College of Science, Wayne State University, Detroit, MI 48202

---We will describe the recent development of Sonic IR Imaging (SIR) NDE for aircraft structures. In the Sonic IR imaging NDE technique, a short ultrasonic pulse is applied to the aircraft/aircraft structures to excite the defects to heat up, while an infrared camera images the time evolution of the heating effect to identify the defective areas in the target. Widespread Fatigue damage (WFD) in aircraft is a critical problem to safety. In this paper, we'll show our study on WFD specimens and on B737, B727 structures, as well as composite structures. Progress on studying fundamental issues related to SIR will also be addressed.

Derivative Contrast in Thermographic NDT

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

---Early efforts to perform quantitative measurement using flash thermography were based almost entirely on the use of contrast data, in which the time history of a defect free reference pixel was subtracted from the time history of all other pixels in the field of view. Although a self-referenced contrast method was subsequently introduced, the analysis of the raw temperature data has proved to be effective only in cases where significant contrast exists, i.e. where the feature is evident in the raw thermal image. Recently, the Thermographic Signal Reconstruction (TSR) method has demonstrated the capability to detect defects that cannot be found using normal contrast or image processing approaches. The net result of the TSR process is a noise-reduced history of the time derivatives of each pixel. Although extremely sensitive, the derivative time histories may be difficult to interpret. However, application of the self-referenced method for contrast analysis to the TSR derivative data yields an extremely sensitive means for detecting and measuring the depth of true subsurface defects. The resulting derivative contrast curves are particularly useful for unassisted detection of subsurface defects, as they segment the image data based on both spatial and temporal characteristics of each pixel.

Improved Thermographic Damage Detection with Principle Component Analysis

---**William P. Winfree**, K. Elliott Cramer, and Joseph N. Zalameda, NASA Langley Research Center, MS 231, Hampton, VA 23681;Allison R. Roberts, Swales Aerospace, Kenneth L. Hodges, Lockheed Martin

---Thermographic detection of flaws in materials and structures is maturing into a viable technique for rapid inspection of critical hardware. As this technique has matured, there is an increasing need to examine complex configurations where the thermal response is not simply defined. This paper examines the application of principle component analysis (PCA) to thermographic data to enable the rapid detection of anomalous responses in the thermographic response without any prior knowledge of the structure. A small set of eigenvectors, calculated from the thermal response of the structure, is used to accurately represent the thermal response of the data. The representation reduces all the thermographic data into as few as five images that accurately represent the meaningful thermographic information. The improved signal to noise in the representations enables the rapid identification of anomalous regions in a structure. For samples with known flaws, this technique is particularly beneficial for rapidly determining if the thermographic technique is sensitive to the flaw. Results are presented on several different materials and structures with both manufacturing and in-service flaws.

Acoustic Thermography: Vibrational Modes of Cracks and the Mechanism of Heat Generation

---**Max Rothenfusser** and Christian Homma, Corporate Technology, Siemens AG, Munich 81730, Germany

---Ultrasound induced thermography is already on its way to be utilized in industrial inspection systems and to become a common nondestructive technique for flaw detection. From a technical point of view the principles of acoustic thermography are easy to understand. The induced vibration causes defects like cracks to heat up. This temperature rise can be visualized by means of an infrared camera. However, the physics of the heat generation mechanism seems to be complex and lacks a quantitative description. Which kind of acoustic modes cause the frictional heating of both crack faces and what is the efficiency? What is the dependency on the ultrasound frequency? Is there a specific influence of the enhanced local stress at the crack tip? Which role plays the geometry of the crack? There are many open questions which are important to be understood in order to be able to assess the indications in the infrared images. Recent investigations with laser vibrometers deliver a first insight into this complex matter. Comparative experiments with other NDE methods on the same test sample also help to understand what acoustic thermography indicates. Simple models describing different types of the movement of the crack faces will be discussed.

Vibro Acoustic Modulation NDE Technique. Part 1: Theoretical Study

---Phillippe Duffour, Peter Cawley, and Marco Morbidini, RCNDE, Department of Mechanical Engineering, Imperial College London, United Kingdom

---The vibro-modulation technique is a potential non-destructive testing method which involves monitoring the amplitude modulation of an ultrasonic vibration field transmitted through a cracked specimen undergoing an additional low frequency structural vibration (typically one of the first structural modes). If the specimen is undamaged and appropriately supported, the two vibration fields do not interact. In this paper, a model is presented which accounts for the modulation in the presence of a crack. It is assumed that the low frequency structural vibration slowly opens and closes the crack. This periodically modifies the dynamic characteristics of the system thereby modulating the amplitude of the ultrasound transmitted through a cracked specimen. Two simulation techniques are used to support this idea. First using a receptance analysis, the cracked beam is conceptually divided into three subsystems: two identical beams on both sides of a very short beam of smaller cross section, intended to represent the crack. The results show that the degree of modulation of the ultrasound by the low frequency vibration is strongly dependent on the particular ultrasound frequency chosen, as well as the damping in the specimen. These conclusions were confirmed by a finite element model, the geometry of which follows closely that of the specimens used for the experimental investigation presented in the second part of this paper.

Vibro Acoustic Modulation NDE Technique. Part 2: Experimental Study

---Marco Morbidini, Philippe Duffour, and Peter Cawley, RCNDE, Department of Mechanical Engineering, Imperial College London, United Kingdom

---The Vibro Acoustic Modulation NDE technique has the potential for the quick and reliable detection of cracks in structures when low frequency structural vibrations are excited in them. The test consists in monitoring the modulation in amplitude of an interrogating ultrasonic signal, caused by the opening and closing of a crack under the imposed structural vibration. The ultrasound amplitude modulation is observed in the frequency domain and the size of the resultant sidebands is compared to the amplitude of the ultrasound carrier frequency. The crack detection capability of the technique is investigated over a broad range of the ultrasonic frequencies and for different materials with different damping coefficients. The generation of low frequency modes of the samples is carried out using either harmonic excitation applied by a shaker or by tapping. For both excitation methods the effect of different strain levels on the sideband activity is analyzed. Throughout the study the implementation of practical and reliable supports for testing of the specimens is considered. Furthermore results from tests on a real industrial component are presented together with a discussion on the applicability of the test to in-situ conditions.

Vibro-Thermography Crack Tip Temperature Measurements

---**Daniel L. Simon**, General Motors Corporation, Detroit, MI 48207

---The physics of vibro-thermography are under investigation because of its' many unknowns brought to attention by groups interested in industrial implementation of this nondestructive evaluation (NDE) technique. After several years of exploring applications of vibro-thermography, many questions still need to be answered for a more complete understanding of these phenomena. One question that is always asked has to do with the peak temperatures being generated within a crack when vibro-thermography is used to locate the crack in a metal fabricated part. An experiment will be described using high-speed radiometric thermography and a variable slit apparatus to replicate the same geometry as a crack. Once these questions are answered, it is hoped that vibro-thermography will join the ranks of other well-understood, widely applied NDE techniques such as ultrasonics, magnetic particles, eddy currents, and radiography.

SESSION 25

INVERSION, RECONSTRUCTION, AND CLASSIFICATION II

J. Turner, Chairperson
Parker Ballroom A

8:30 AM **Residual Crack Depth Estimation in Plates Via Frequency Gradient Measurement of EC Impedance**
---**N. Nakagawa** and B.P.C. Rao, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

8:50 AM **Reconstruction of Flaw Profiles Using Neural Networks and Multi-Frequency Eddy Current System**
---**T. Chady** and M. Caryk, Faculty of Electrical Engineering, Technical University of Szczecin, Szczecin, Poland

9:10 AM **Improving Ultrasonic C-Scan Resolution Using the Hilbert-Huang Transform**
---**G. G. Leisk**, E. S. Miller, and D. J. Murphy, Tufts Mechanical Engineering

9:30 AM **Quantitative Evaluation of Local Young's Modulus of Small-Scale Solids by Isolated Langasite Oscillator: Resonant-Ultrasound Microscopy**
---**H. Ogi**, J. Tian, T. Tada, and M. Hirao, Graduate School of Engineering Science, Osaka University, Machikaneyama 1-3, Toyonaka, Osaka 560-8531, Japan

9:50 AM **Analytical Approach to Simulation of Magnetic Particle Inspection of Defects with Various Shapes and Sizes**
---**Y. Melikhov**[1], S.-J. Lee[1], D. C. Jiles[1], M. Garton[2], R. Lopez[2], and L. Brasche[2], Center for Aviation Systems Reliability, Iowa State University, [1]2581 Metals Development, [2]Center for NDE, 1915 Scholl Road, Ames, IA 50011

10:10 AM ***Coffee Break***

10:30 AM **Application of Memory-Saved Time Domain BIE Method for Visualization of Scattered Wave Fields**
---**K. Nakahata**, Department of Civil and Environmental Engineering, Ehime University, Matsuyama, Ehime, Japan; S. Hirose, Department of Mechanical and Environmental Informatics, Tokyo Institute of Technology, Meguro, Tokyo, Japan

10:50 AM **Multi-Sensor NDE Data Intregration and Visualization for Gas Transmission Pipelines**
---J. Oagaro, S. Papson, J. Bram, P. J. Kulick, R. Polikar, J. Chen, J. Schmalzel, and **S. Mandayam**, College of Engineering, Rowan University, Glassboro, NJ 08028

11:10 AM **Detection and Sizing of Cracks in Structural Components of a Nuclear Power Plant by ECT**
---**Z. Chen** and K. Miya, International Institute of Universality, Imon Ikenohata Bldg. 7F, 2-7-17 Ikenohata, Taito-ku, Tokyo, 110-0008, Japan

11:30 AM **Lamb Waves Converted and Diffracted by an Artificial Bonding Defect of Two Composite Plates**
---H. Duflo, B. Morvan, and J.-L. Izbicki, Laboratoire d'Acoustique Ultrasonore et d'Electronique, UMR CNRS 6068, Place Robert Schuman, 76600 Le Havre, France (Presenter: **D. Leduc**)

12:10 PM ***Lunch***

Residual Crack Depth Estimation in Plates Via Frequency Gradient Measurement of EC Impedance

---**N. Nakagawa** and B.P.C. Rao, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---This paper reports on experimental results of frequency-dependent eddy current measurements that may imply a novel EC sizing methodology. A few years ago, one of the authors reported on modulated eddy current drive and phase-sensitive detection for advanced EC data acquisition. The modulated EC method was introduced to measure frequency dependence of the impedance in the vicinity of the drive frequency. In its simplest form, the modulated EC method measures both impedance Z and its frequency derivative dZ/df simultaneously. The report also pointed out that the log-derivative dlnZ/dlnf was a new measurement quantity which might provide useful information for defect sizing. Here, as a specific demonstration, we examined the residual crack depth determination problem in plate geometry. We prepared an SS316 plate specimen with EDM notches of various depths, and performed the simultaneous Z and dZ/df measurements from the back side of the plate. The log-derivative dlnZ/dlnf is measured as a function of the frequency f. It is shown that, when plotted as a function of skin depths, the log-derivative curves show characteristic transition from one gradient to another, where the skin-depth value at the inflection point shows a good correlation with the known residual depth. We will present the experimental data, as well as qualitative understanding of how the measured quantity correlates with the power-law behaviors of impedance in frequencies.---This work was supported by the NSF Industry/University Cooperative Research program.

Reconstruction of Flaw Profiles Using Neural Networks and Multi-Frequency Eddy Current System

---**Tomasz Chady** and Marcin Caryk, Faculty of Electrical Engineering, Technical University of Szczecin, Szczecin, Poland

---The objective of this paper is to identify profiles of flaws in conducting plates. To solve this problem, application of a multi-frequency eddy current system (MFES) and artificial neural networks is proposed. A basic idea of the MFES system is to use a complex signal containing a big number of harmonic components as a test signal. It enables precise flaw characterization. Dynamic feed-forward neural networks with various architectures are investigated. Extended experiments with all neural models are carried out in order to select the most promising configuration. Comparison of results achieved from single and multi-frequency models is also carried out. Data utilized for the experiments were obtained from the numerical analysis of the mathematical model of the transducer and measurements performed on the Inconel plates with EDM flaws having different size and shape. Results of the experiments will be presented in the full version of the paper.

Improving Ultrasonic C-Scan Resolution using the Hilbert-Huang Transform

---**Gary G. Leisk**, Elliot S. Miller, and Daniel J. Murphy, Tufts University, Mechanical Engineering, 204 Anderson Hall, Medford, MA 02155

---It is an on-going challenge in ultrasonic Nondestructive Testing (NDT) to provide high-resolution images of internal defects in materials. Certain classes of materials, such as composite materials, are especially troublesome to deal with, due to their severe anisotropy and high ultrasonic attenuation. However, given the presence of significant volumes of such materials in modern load-bearing applications, it is critical that safe performance be assured through detection, sizing, and mapping of incipient internal damage. Many algorithms and ultrasonic testing techniques are available for reconstructing defect geometry from NDT data with varying degrees of success. This research explores the usage of a modified Hilbert transform algorithm, known as the Hilbert-Huang Transform (HHT), in providing improved resolution of pulse-echo ultrasonic C-scan maps of flat-bottomed holes in monolithic aluminum samples. HHT provides clear echo indications through calculation of an ultrasonic waveform's instantaneous frequency, and correlation with the transducer's nominal frequency. While preliminary results are favorable for mapping defects in monolithic materials, there are clear implications for improved mapping in more difficult material classes, such as composites.

Quantitative Evaluation of Local Young's Modulus of Small-Scale Solids by Isolated Langasite Oscillator: Resonant-Ultrasound Microscopy

---**Hirotsugu Ogi**, Jiayong Tian, Toyokazu Tada, and Masahiko Hirao, Graduate School of Engineering Science, Osaka University, Machikaneyama 1-3, Toyonaka, Osaka 560-8531 Japan

---We present the resonant-ultrasound-microscopy method for mapping a material's elastic constant in a localized surface region. It detects the effective Young modulus through a resonance frequency of a free vibration of the rectangular parallelepiped langasite crystal contacting the specimen at an antinode point. Langasite is a piezoelectric material showing the low sensitivity of its elastic constants to temperature and high piezoelectric coefficients. The vibration of the probe is excited and detected with a surrounding solenoid coil. This noncontacting acoustic coupling isolates the probe vibration and measures the resonance frequency with an accuracy better than one part in 100,000. This microscopic method is applied to composite materials to determine Young-modulus distribution on individual components.

Analytical Approach to Simulation of Magnetic Particle Inspection of Defects with Various Shapes and Sizes

---**Yevgen Melikhov**[1], Seong-Jae Lee[1], David C. Jiles[1], Mike Garton[2], Rick Lopez[2], and Lisa Brasche[2], Center for Aviation Systems Reliability, Iowa State University, [1]2581 Metals Development, [2]Center for NDE, 1915 Scholl Road, Ames, IA 50011

---Magnetic particle inspection (MPI) method is based on agglomeration of magnetic particles in the vicinity of at-surface or near-surface defect in magnetic components due to magnetic flux leakage (MFL). Reliable theory, modeling and computer simulations of MPI can identify factors that affect its characteristics, helping to reduce the inspection design cost and time and to improve the analysis of experimental MPI data. This work was devoted to study the influence of various defects on results of MPI. Test materials for an MPI simulation were assumed to have isotropic constant or nonlinear permeability. In order to generate MFL signals from different at-surface and sub-surface cracks of various shapes and sizes, we used both analytical approach and numerical approach based on the finite element method (FEM). Varying the shape, dimensions and type of a defect, the magnetic field gradient and the magnetic force on magnetic particles were computed. The amount of the retained magnetic particles due to the defect was estimated. The simulated results can be used to assist in understanding of the results of experimental MPI.---This material is based upon work supported by the Federal Aviation Administration under Contract #DTFA03-98-D-00008, Delivery Order #IA051 and performed at ISU Center for NDE as part of the Center for Aviation Systems Reliability program.

Application of Memory-Saved Time Domain BIE Method for Visualization of Scattered Wave Fields

---Kazuyuki Nakahata, Dept. of Civil and Environmental Engineering, Ehime University, Matsuyama, Ehime, Japan: Sohichi Hirose, Dept. of Mechanical and Environmental Informatics, Tokyo Institute of Technology, Meguro, Tokyo, Japan

---A time domain boundary integral equation (BIE) method is applied to the visualization of scattered wave fields around inclusions. The interface between a matrix and an inclusion often shows nonlinear mechanical properties due to the separation-contact interaction. Since the nonlinearities in the scattering problem studied here are involved only in the boundary condition, we can use an ordinary time-domain BIE method to solve this nonlinear problem. However the time domain BIE method needs considerable computational memory capacity because of a step-by-step time marching calculation. In other words, we have to perform an iterative calculation using all fundamental solutions in the past time to converge the solution at the present time for the nonlinear problem. To save the memory size we introduce an interpolation technique into the calculation of fundamental solutions. For numerical examples, near-field visualization and far-field waveforms of scattered waves from inclusions are shown in the conference.

Multi-Sensor NDE Data Integration and Visualization for Gas Transmission Pipelines

---Joseph Oagaro, Scott Papson, Justin Bram, Philip J. Kulick, Robi Polikar, John Chen, John Schmalzel, and **Shreekanth Mandayam,** College of Engineering, Rowan University, Glassboro, NJ 08028

---The in-line inspection of gas transmission pipelines generates vast amounts of data. When multiple sensor modalities (for example, magnetic, ultrasonic, thermal, acoustic) are used to inspect the same length of pipe, the challenge of data integration becomes formidable. This paper explores the use of multi-sensor data fusion algorithms for the combination of homogeneous and heterogeneous NDE data sets. The multi-sensor data is fused to predict the size and shape of anomalous indications. Models that are based on human stereoscopic vision are used to design a data fusion process in order to extract defect related information that is redundant and complementary among different sets of sensors. The result is displayed in an immersive, interactive, and navigable virtual reality (VR) environment. The VR platform allows the simultaneous visualization of raw multidimensional NDE data, defect characterization results, pipeline network components and the surrounding topography. It is anticipated that this technique for data integration and advanced visualization allows the user to make more informed remediation decisions.---This work is supported by the National Energy Technology Laboratory, US Department of Energy and the National Science Foundation.

Detection and Sizing of Cracks in Structural Components of a Nuclear Power Plant by ECT

---**Zhenmao Chen** and Kenzo Miya, International Institute of Universality, Imon Ikenohata Bldg.7F, 2-7-17 Ikenohata, Taito-ku, Tokyo, 110-0008, Japan

---In this paper, studies on the inspection of the core internals and the Principle Loop Recirculation (PLR) tubes of a Nuclear Power Plant (NPP) with Eddy Current Testing (ECT) are introduced. The typical structural components of the core internals where ECT may show its advantage are the welding joints in a CRD housing tube, a shroud plate, and a penetration zone of Reactor Pressure Vessel (RPV). In the first part of the paper, the basic information of the ECT technique currently applied in these components or those still under development is described. As examples, experimental results of some typical ECT probes for weld testpieces of SUS304 austenitic stainless steel or INCONEL high Ni steel are presented. The experimental results reveals that a defect is possibly to be detected by ECT though welding noise occurs. In the second half, some validation results for crack sizing with ECT technique are given. Crack sizes such as the length and the depth have been predicted from the measured ECT signal in an acceptable accuracy even for cracks located in a welding part. It is also found that the crack sizes can also be reconstructed properly for practical SCC in a SG tube or a secondary coolant tube.

Lamb Waves Converted and Diffracted by an Artificial Bonding Defect of Two Composite Plates

---Hugues Duflo, Bruno Morvan, and Jean-Louis Izbicki, Laboratoire d'Acoustique Ultrasonore et d'Electronique, UMR CNRS 6068, Place Robert Schuman, 76600 Le Havre, France (Presenter: **Damien Leduc**)

---This work is devoted to defects characterization in the bonding of two carbon epoxy composite plates. The artificial defect is first detecting by a c-scan performed by two air-coupling transducers. The damage zone is well determined by the ultrasonic transmission throw the structure. It has been well recognized that guided Lamb waves techniques can offer a very sensitive mean for a large area determination. The Lamb waves (able to propagate in the structure) are generated by a piezo-composite transducer placed before the defect. Their diffraction and conversion are studied along the propagation direction by a laser interferometer detecting the normal vibrations of the plate. The same laser is also used to measure the diffracted waves on the defect by storing the scattered signals on a circle centered on the damage zone. With an adapted signal processing (temporal and frequency filtering) the waves generated by a pulse methods are separated and their diffraction are obtained on polar diagrams. The Lamb waves scattering by different defects are then compared.

SESSION 26

NDE DESIGN, PROCESS CONTROL, AND LIFE PREDICTION

J. Harris, Chairperson

Parker Ballroom C

8:30 AM **Strategy and Software Framework for Integration of QNDE and Product Life Management Design**
---**E. A. Medina** and M. Altynova, Austral Engineering and Software, Inc., P. O. Box 340646, Dayton, OH 45434; J. C. Aldrin, Computational Tools, Gurnee, IL; J. Knopp and C. Kropas-Hughes, NDE Branch, Materials and Manufacturing Directorate, U.S. Air Force Research Laboratory, Wright-Patterson AFB, OH 45449

8:50 AM **In-Process Measurement of Particle Size for Explosive Slurries**
---**W. N. Cobb**, University of Denver Research Institute, 2050 E. Lliff Avenue, Denver, CO 80208

9:10 AM **Measurement of the Viscosity-Density Product Using a Quartz Wedge**
---**M. S. Greenwood**, J. D. Adamson, and L. J. Bond, NDE Measurement Systems, Pacific Northwest National Laboratory, Battelle Blvd., Mailstop K5-26, Richland, WA 99352

9:30 AM **Ultrasonic Characterization of Solid-Liquid Suspensions**
---**P. D. Panetta**, B. Tucker, and S. Ahmed, Pacific Northwest National Laboratory, 903 Battelle Boulevard, P. O. Box 999, MSIN K5-26, Richland, WA 99352

9:50 AM **Observing Effects of Particle Size for a Slurry Using Ultrasonic Diffraction Grating Spectroscopy**
---**M. S. Greenwood** and L. J. Bond, NDE Measurement Systems, Pacific Northwest National Laboratory, P. O. Box 999, Mailstop K5-26, Richland, WA 99352; A. Brodsky and L. Burgess, Center for Process Analytical Chemistry, University of Washington, Seattle, WA 98195

10:10 AM ***Coffee Break***

10:30 AM **Laser Ultrasonic Measurement of Elastic Properties of Moving Paper**
---**P. L. Ridgway** and R. E. Russo, Lawrence Berkeley National Laboratory, Berkeley, CA 94720; E. F. Lafond and T. G. Jackson, Institute of Paper Science and Technology at Georgia Tech

10:50 AM **Application of Laser AE Technique to Monitoring of Sintering in Structural Ceramics**
---**S. Nishinoiri** and M. Enoki, Department of Engineering, Graduate School of Engineering, The University of Tokyo, Hongo 7-3-1, Bunkyo-ku, Tokyo, Japan

11:10 AM **Characterization of Magnetron Sputtered Coatings by Pulsed Eddy Current Techniques**
---**C. P. Mulligan**, Benet Laboratories, US Army, AMSRD-AAR-AEW-T (B), Watervliet Arsenal, NY 12189; C. Lee and Y. Danon, Department of Mechanical, Aerospace and Nuclear Engineering, Rensselaer Polytechnic Institute, Troy, NY 12180

11:30 AM **Quality Control of the Continuous Casting Process Using Electromagnetic Transducers (EMAT) Sensors**
---**I. S. Kim**, C. E. Park, J. S. Son, and B. A. Chin, Department of Mechanical Engineering, Mokpo National University, 61, Dorim-ri-Chunhke-myun, Muan-gun, Chonnam, 534-729, Korea

11:50 AM **Machine Condition and Remaining Service Life Prediction**
---**L. Burstein** and L. Segal, Quality Assurance and Reliability Department, Technion – Israel Institute of Technology, Technion City, Haifa, Israel

12:10 PM ***Lunch***

Strategy and Software Framework for Integration of QNDE and Product Life Management Design

---**Enrique A. Medina** and Marina Altynova, Austral Engineering and Software, Inc., P. O. Box 340646, Dayton, OH 45434; John C. Aldrin, Computational Tools, Gurnee, IL; Jeremy Knopp and Claudia Kropas-Hughes, NDE Branch, Materials and Manufacturing Directorate, U.S. Air Force Research Laboratory, Wright-Patterson AFB, OH

---We present a strategy and software framework for integrating various NDI design and product life management tools into a design platform enabling analysis of tradeoffs among NDI decisions and product life cycle outcomes such as reliability and cost. The strategy uses object-oriented building blocks for integrating (1) probabilistic models of flaw distribution and growth, probability of detection, and complex inspection and repair strategies, (2) NDI design tools, and (3) optimization algorithms, into a software system for NDI prototyping, product life cycle design, and optimization. This will allow rapid evaluation and optimization of alternative component life management strategies while considering multiple design, inspection, maintenance, damage tolerance, life-extension, and costs as design variables, objectives and constraints. A prototype software system is under development, and preliminary case studies have demonstrated its value. Current work focuses on modeling complex series of inspections and repairs often found in the field, enabling integration of NDI simulation tools, and allowing use of real inspection data to populate probabilistic life models. The integration software is expected to improve reliability and reduce development costs for NDI procedures and integrated vehicle health monitoring systems by optimizing the design of these tools while limiting the use of expensive empirical studies.

In-Process Measurement of Particle Size for Explosive Slurries

---**Wes N. Cobb**, University of Denver Research Institute, 2050 E. Lliff Avenue, Denver, CO 80208

---Many of today's energetic materials are produced by a wet slurry process. Explosive particles are coated with polymer binders and allowed to agglomerate until the required size is achieved. This process results in less sensitive explosives that help protect the soldier. Unfortunately, the final particle size is critical to the safety of the product and can not be monitored using existing instruments. Lack of particle size control during agglomeration results in poor product yields. This talk presents new experimental results for ultrasonic sensing of particle size in stirred mixing vessels. The primary advantage of ultrasound is that the sensors can be made non-invasive by shielding them inside a steel probe. This probe is placed inside the mixing vessel and the particle size is measured continually during agglomeration. The ultrasonic spectroscopy technique is described and data is presented for inert stimulants of the explosive materials. In addition, a novel probe design is described that reduces problems caused by large amounts of air bubbles in the turbulent mixture.

Measurement of the Viscosity-Density Product Using a Quartz Wedge

---**Margaret S. Greenwood**, Justus D. Adamson, and Leonard J. Bond, NDE Measurement Systems, Pacific Northwest National Laboratory, Battelle Blvd., Mailstop K5-26, Richland, WA 99352

---The objective is to develop an on-line computer-controlled sensor to measure the product of viscosity and density for a liquid or slurry in real time. This is accomplished by analyzing the multiple reflections of an ultrasonic shear horizontal (SH) wave within a quartz wedge. The low attenuation of ultrasound results in 22 echoes as the ultrasound is reflected from the two sides (inclined at a 70° angle) and the quartz-liquid interface at the base of the wedge. The 7.5 MHz SH transducer is mounted on one side and the opposite side is in air. The measurement is self-calibrating because it is not affected by changes in the pulser voltage. Data were obtained for sugar water (SW) solutions ranging from 15% to 60% by weight. The viscosity values are in good agreement with the handbook values at 20 C. For 20% SW the sensor value is 2.02 mPa-s compared to a handbook value of 1.94 mPa-s and for 60% SW 39.3 mPa-s compared to 42.7 mPa-s. The sensor can be deployed in a pipeline as part of the pipeline wall or immersed in a tank.

Ultrasonic Characterization of Solid-Liquid Suspensions

---**P. D. Panetta**, B. Tucker, and S. Ahmed, Pacific Northwest National Lab, 903 Battelle Blvd., P. O. Box 999, Richland, WA 99352

---Rapid, on-line, non-invasive measurements of the particle size and concentration of moderate to highly concentrated slurries is required for the efficient process measurement and control for many processes. High concentrations are often found in government applications such as waste remediation for the Department of Energy sites and in and industrial applications such as chemical and pharmaceutical manufacturing. However, existing methods to determine the particle size based on ultrasonic attenuation can become inaccurate for non-dilute suspensions due to the complex interactions of ultrasonic waves with the constituents of the slurries and the particle-particle interactions. Further complications arise because of the necessity for careful transducer alignment for attenuation measurements. We are developing two measurements that help overcome these difficulties, the ultrasonic backscattering and measurements of the diffuse field properties. The backscattering measurement is attractive because viscous, thermal, and inertial effects have small contributions to backscattering. Furthermore, the backscattering theories are simpler than attenuation theories and lend themselves to more stable inversion processes. In addition, the measurements of backscattering and diffuse fields do not require long travel distances and can be performed with a single transducer thus eliminating alignment problems. We also present ultrasonic attenuation and backscattering measurements on solid-liquid suspensions and emulsions at concentrations up to 55 wt% with particle sizes ranging from 0.160 um - 800 um. Where the attenuation of the propagating ultrasonic signal is caused by energy loss due to scattering and absorption mechanisms, a measure of the energy loss can also be determined from the backscattering and the diffuse field properties. Results which elucidate the interrelationship between these energy loss mechanisms are reported. Experimental measurements will be compared with theoretical predictions.---This work was supported by the Department of Energy, Environmental Management Science Program. Pacific Northwest National Laboratory is operated for the U.S. Department of Energy by Battelle under Contract DE-AC06-76RLO18310.

Observing Effects of Particle Size for a Slurry Using Ultrasonic Diffraction Grating Spectroscopy

---**Margaret S. Greenwood** and Leonard J. Bond, NDE Measurement Systems, Pacific Northwest National Laboratory, P. O. Box 999, Mailstop K5-26, Richland, WA 99352; Anatol Brodsky and Lloyd Burgess, Center for Process Analytical Chemistry, University of Washington, Seattle, WA

---The objective is to characterize the slurry in contact with the stainless steel (SS) grating, formed by machining triangular grooves, 240 microns apart, on the flat surface of a half-cylinder. Ultrasound from a send transducer travels through the SS and strikes the back of the grating where it is reflected to a receive transducer. A peak in this signal is used to determine properties of the slurry. The frequency at which the peak occurs is used to determine the velocity of sound in the slurry, as has been reported. The peak height for a slurry is reduced due to scattering from the particles, which is dependent upon particle size. Experimental data will be presented for polystyrene spheres in water, ranging in size from 16 microns to 275 microns, which will demonstrate the effect of particle size. Additional experiments are underway and this data will also be presented.

Laser Ultrasonic Measurement of Elastic Properties of Moving Paper

---**Paul L. Ridgway** and Richard E. Russo, Lawrence Berkeley National Laboratory, Berkeley, CA 94720; Emmanuel F. Lafond and Ted G. Jackson, Institute of Paper Science and Technology at Georgia Tech

---A laser-based ultrasonic sensor for non-contact measurement of the elastic properties of paper was demonstrated on a a pilot web handler at paper speeds to 25.4 m/s. Measurements of flexural rigidity and out-of-plane shear rigidity were determined by fitting of the frequency dependence of the phase velocity of Ao mode Lamb waves to a model equation. Ultrasonic waves were generated in the paper with a pulsed Nd:YAG laser and detected with a Mach-Zehnder interferometer coupled with a scanning mirror/timing system to compensate for paper motion. For paper grades with basis weights of 39 to 100 g/m2, on-line measurements agreed with off-line laboratory measurements. Effects of web tension and moisture were quantified. A fully automated prototype of the sensor has been developed for use in paper manufacturing and is ready for demonstrations on full scale paper machines during commercial operation. An estimate of the economic value of the sensor will be presented.

Application of Laser AE Technique to Monitoring of Sintering in Structural Ceramics

---**Satoshi Nishinoiri** and Manabu Enoki, Department of Engineering, Graduate School of Engineering, The University of Tokyo, Hongo 7-3-1, Bunkyo-ku, Tokyo, Japan

---Conventional acoustic emission (AE) method has a limit of measurement at elevated temperature because of the use of piezoelectric element. We have investigated the method to detect AE signal using laser interferometer which can detect an elastic wave at a surface of materials, and it has been demonstrated that it is a very powerful tool for non-contact AE measurement. Cracking in sintering of structural ceramics is a serious problem for fabrication. Thermal stress due to temperature distribution or difference in shrinkage rate in sample causes cracking. Crack initiation is strongly affected by shape, density and particle size of green compact and sintering pattern. It is important to investigate when cracks occur for optimization of sintering condition. In this study, we tried to monitor the sintering process of ceramic by noncontact AE technique. A green compact of alumina was heated in electrical furnace and AE signals generated during sintering were detected using heterodyne interferometer. Probe beam was irradiated to the surface of sample through small opening of the furnace. AE signal during sintering was successfully detected, and AE events were mainly generated in cooling step. This result gave a criterion for cracking during sintering.

Characterization of Magnetron Sputtered Coatings by Pulsed Eddy Current Techniques

---**Christopher P. Mulligan,** Benet Laboratories, US Army, AMSRD-AAR-AEW-T (B), Watervliet Arsenal, NY 12189; Changqing Lee and Yaron Danon, Department of Mechanical, Aerospace and Nuclear Engineering, Rensselaer Polytechnic Institute, Troy, NY 12180

---A method that uses induced eddy current for characterization of thick magnetron sputtered coatings on steel is presented in this paper. The objectives of this work are to develop a system for rapid quantitative nondestructive inspection of coatings as well as to determine the correlation between the deposition conditions and eddy current measured resistivity of coatings. This technology is to be initially applied to thick bore coatings on large caliber gun barrels. A two-probe differential system having higher sensitivity and less noise than a one-probe system with 2-D scanning ability was developed. A computer program that controls an XY table and performs fast data acquisition was written. Niobium coatings ranging in thickness from 15 to 60 microns were deposited via planar magnetron deposition for characterization. The coating purity level was varied by introducing controlled leaks into the vacuum system measured by a residual gas analyzer and the coating density was regulated by varying sputtering pressure. The relationship between both coating density and impurity level to eddy current measured resistivity of the deposited niobium coatings is examined. 2-D resistivity and thickness maps of the niobium coated samples were constructed and are given in the paper.

Quality Control of the Continuous Casting Process Using Electromagnetic Transducers (EMAT) Sensors

---**I. S. Kim**, C. E. Park, J. S. Son, and B. A. Chin, Department of Mechanical Engineering, Mokpo National University, 61, Dorim-ri, Chunhke-myun, Muan-gun, Chonnam, 534-729, Korea

---In a steel industry, a lot of skilled techniques and operations are required to enhance high-quality products, safe operation and efficiency of equipment. Molten steel in aligned ladles in steelworks is transferred to be poured into a mold through tundish for the continuous casting process. As various sensors and control units are connected to lower frame of tundish and mould, continuous casting processes are automatically in operation. In a continuous casting process, a solidification point has a major effect on quality of products. However, a solidification point has been predicted based on merely limited consequences from computer simulation. An early stage of study using EMAT was progressed on routes to mostly detect defects in addition to fundamental study on ultrasonic duplex of each mode. An EMAT (Electro Magnetic Acoustic Transducer) has been designed and fabricated with elongated spiral coil with permanent magnetic core. The 75*75mm and 75*10mm simulators with 2, 4, 8, 16, 32 mm hole have been produced and demonstrated that the location of the final solidification point during continuous casting process can be monitored using frequency from 0.6 MHz to 1.0 MHz. The measured ultrasonic waves are shown to provide a useful opportunity to provide a useful opportunity to predict the casting speed necessary to correctly locate the liquid core in order to maximize the benefits of soft reduction or the productivity of the machine.

Machine Condition and Remaining Service Life Prediction

---**L. Burstein** and L. Segal, Quality Assurance and Reliability Department, Technion – Israel Institute of Technology, Technion City, Haifa, Israel

---Machine condition (MC) and remaining service life (RSL) were studied on the basis of a new method using the thermal diagnostics parameter (TDP). The rates of temperature change at the starting stage were chosen as criterion. As the measurements show, the point where the temperatures characterize the machine condition in the best way, is the one at which second derivative of the T(t) dependence is zero. The applied method for determining the MC and RSL is based on the well-known fact of heat emission changes during operation of the machine. With the TDP - time line constructed for two identical, normally-operated (reference) machines known, the condition of tested machine and its RSL are to be predicted. The TDP - time line was analyzed and its behavior discussed. The ascending straight line characterizes machines with a predominate number of couplings whose heat emission increases with service time - gears, bearings etc. The descending straight line characterizes machines in which decrease of heat emission predominates - vehicle brakes, piston rings/piston assemblies etc. The line with the extremum characterizes for the machine with mechanisms the time behavior of whose heat emission is opposite, such as automotive automatic gear. Constructing the TDP - time graph on the basis of the temperature measurements for the reference machines, we can conclude about the MC of the tested machine. The experiments were carried out on reliably operated SAWA reduction gears of portal container cranes and on brake assemblies of T-150K tractors. These machines have different TDP-time lines - ascending in the first case, descending in the second. Two special Mathcad 11 programs were developed, and the TDP and the RSL were obtained for tested objects. The developed method and computer programs can be recommended as a compact diagnostic tool for a wide range of mechanisms.

SESSION 27

NEW TECHNIQUES AND APPLICATIONS

M. Gorman, Chairperson
Parker Ballroom B

8:30 AM **Natural Focusing Inspection for Pipes by Frequency Tuning**
---**L. Zhang**, J. L. Rose, and B. J. Gavigan, The Pennsylvania State University, Department of Engineering Science and Mechanics, 212 Earth and Engineering Science Building, University Park, PA 16802

8:50 AM **Non-Contact Ultrasonic Characterization of Defects Using EMATs**
---**R. S. Edwards**, S. Dixon, and X. Jian, Department of Physics, University of Warwick, Coventry, United Kingdom

9:10 AM **Comparison of Damage and Ultrasonic Signals, Induced by Laser at Different Wavelengths, for Al and Alumina Samples**
---**Y. Perchenok**, G. Hurvitz, and A. Azoulay, Department of Electro-Optics, Soreq NRC, Yavne 81800, Israel

9:30 AM **NDE Characterization of Residual Stress on Shrink-fit Specimens of Ti-6Al-4V**
---S. Sathish and M. P. Blodgett, Metals, Ceramics and NDE Division, Air Force Research Laboratory, Wright Patterson Air Force Base, Dayton, OH 45469-0127; **R. W. Martin**, R. T. Ko, and R. Reibel, Structural Integrity Division, University of Dayton Research Institute, 300 College Park, Dayton, OH 45469-0127

9:50 AM **Development of New Surface Crack Inspection Technique Using Electronic Speckle Pattern Interferometry**
---**A. Baba**, M. Nakamura, and T. Matsui, Power & Industrial Systems R & D Laboratory, Hitachi, Ltd., Japan

10:10 AM ***Coffee Break***

10:30 AM **Ultrasonic Estimation of Mechanical Properties of Pulmonary Artery Wall Under Normotensive and Hypertensive Conditions**
---**K. R. Waters**, National Institute of Standards and Technology, Materials Reliability Division, Mail Stop 853.00, 325 Broadway, Boulder, CO 80305-3328; O. M. Mukdadi, The Children's Hospital, University of Colorado Health Sciences Center, Denver, CO 80305

10:50 AM **Acoustic Emission – A Precision Indicator of Phase Transition in Soft PZT Ceramics Under an Applied Electric Field**
---**S. P. Mallikarjun Rao** and K. Prabakar, Acoustic Emission Laboratory, Physics Department, University College of Science, Osmania University, Hyderabad – 500 007, India

11:10 AM **Combining X-Ray, Eddy Current, and Electric Field Measurement Techniques for Automating Particle Fuel Characterization**
---**R. Hockey**, R. Mathews, and L. Bond, Pacific Northwest National Laboratory, P. O. Box 999, MS K5-26, Richland, WA 99352; J. Gray, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

11:30 AM **Ultrasonographic Periodontal Probing Based on the Dynamic Wavelet Fingerprint**
---**M. K. Hinders** and J. Hou, College of William and Mary, Department of Applied Science, Williamsburg, VA 23187-8795

11:50 AM **Critical Timing Issues in Flash Thermography**
---**S. M. Shepard** and J. R. Lhota, Thermal Wave Imaging, Inc., Ferndale, MI 48220

12:10 PM ***Lunch***

Natural Focusing Inspection for Pipes by Frequency Tuning

---**Li Zhang**, Joseph L. Rose, and Brian J. Gavigan, The Pennsylvania State University, Department of Engineering Science and Mechanics, 212 Earth and Engineering Science Building, University Park, PA 16802

---The energy of ultrasonic guided waves may be focused in pipes by utilizing a partially loaded excitation. This focusing technique is called 'natural focusing', which can be used to improve a defect's sensitivity to ultrasonic guided waves. However, it is possible that there are few natural focal points within the inspection range at a particular frequency. Consequently, some defects could be missed. The location of natural focal points changes with frequency. This phenomenon was theoretically predicted and experimentally confirmed. In this paper, the natural focusing inspection technique is investigated. Although very limited circumferential length might be covered by a naturally focused profile at a single excitation frequency, the entire cross sectional area of the pipe can be inspected when a range of frequencies is employed. Hence, the natural focusing inspection technique can sufficiently inspect the entire pipe with frequency tuning.

Non-Contact Ultrasonic Characterization of Defects Using EMATs

---Rachel S. Edwards, Steve Dixon, and Xiaoming Jian, Department of Physics, University of Warwick, Coventry, United Kingdom

---We have developed a non-contact ultrasonic technique for detecting and gauging the depth of surface and subsurface defects in metals. A low-frequency broadband Rayleigh-wave pulse is generated and detected by two electro-magnetic acoustic transducers (EMATs) held at a standoff of up to 5 mm, with laser generation and detection also possible. This technique has applications for online testing such as rail track inspection, where faster speeds than with conventional contact ultrasonic techniques should be possible. A reduction in signal amplitude is observed when the EMATs are on opposite sides of a defect, where the defect lies within 3 cm of the surface. By measuring the frequency content of the received pulse we are able to calculate its depth, and by scanning the EMATs give an estimate of its spread. An enhancement of the signal when the receive EMAT approaches a defect from the same side as the generator is observed, and is due to constructive interference between the direct signal and that reflected back from the defect. This is observed even when measuring defects of depth shorter than the Rayleigh wavelength, as a fraction of the incident wave will still be reflected; by studying the magnitude of the enhancement it may be possible to gauge the depth of very shallow cracks.

Comparison of Damage and Ultrasonic Signals, Induced by Laser at Different Wavelengths, for Al and Alumina Samples
---**Yaaqov Perchenok**, Gilad Hurvitz, and Amnon Azoulay, Department of Electro-Optics, Soreq NRC, Yavne 81800, Israel

---A Q-switch Nd:YAG laser was focused at a narrow line on Al and Alumina samples to induce ultrasonic waves. The stimulated surface acoustic wave was measured by a Fabry-Perot interferometer, while the depth of the damage created in the sample was quantified by a profilometer. Similar samples of Al and Alumina were used to measure ultrasonic signals at different laser powers and wavelengths. A profilometer was then used to quantify and measure damage depths that exceeded the ~1ìm sample roughness. Generally speaking, a good correlation between the ultrasonic signal and the damage depth was observed in both Al and Alumina samples. In addition, the ultrasonic signals were significantly larger in the Al sample at similar damage depth. In the Al sample, no wavelength dependence was observed and ultrasonic signals were detected at low incident laser power. In contrary, in the Alumina sample, only laser power exceeding a wavelength-dependent threshold created both damage and ultrasonic signal. The threshold level increased together with incident laser wavelength.

NDE Characterization of Residual Stress on Shrink-fit Specimens of Ti-6Al-4V
---Shamachary Sathish and Mark P. Blodgett, Metals, Ceramics and NDE Division, Air Force Research Laboratory, Wright Patterson Air Force Base, Dayton, OH 45469-0127; **Richard W. Martin**, Ray T. Ko, and Richard Reibel, Structural Integrity Division, University of Dayton Research Institute, 300 College Park, Dayton, OH 45469-0127

---Residual stress is induced in many turbine engine components by surface modification techniques, which create a stress gradient very near the surface. The goal of this project is to develop a “calibration reference” for residual stress measurements using different nondestructive evaluation (NDE) techniques. X-ray diffraction (XRD), focused acoustic beam and eddy current measurements are performed on shrink-fit Ti-6Al-4V specimens in order to measure the residual stress variations. The radial and hoop stress measurements using X-ray diffraction are used to interpret the images obtained with focused acoustic beam and eddy current techniques. Rayleigh surface wave phase measurements with a three-element focused acoustic transducer are also compared with X-ray diffraction results. When completed, these specimens should provide a reliable and reproducible reference level of residual stress that may be used to calibrate NDE residual stress measurements.---Research sponsored by, and performed on-site at the NDE Branch, AFRL/Material and Manufacturing Directorate, Wright-Patterson Air Force Base, Ohio under Contract # F33615-03-C-5219.

Development of New Surface Crack Inspection Technique Using Electronic Speckle Pattern Interferometry

---**A. Baba**, M. Nakamura, and T. Matsui, Power & Industrial Systems R & D Laboratory, Hitachi, Ltd. Japan

---A new inspection technique to detect surface cracks is investigated using electronic laser speckle pattern interferometry (ESPI); it allows a wide region to be inspected all at once. In this method, an elastic wave is generated on the object surface, and its propagation causes fluctuation around any surface crack due to reflection or diffraction. Then, fluctuation around the crack is measured as surface displacement by ESPI. The present authors verified the basic principle for surface crack detection using a steel ball hitting a surface to generate an elastic wave. The detectability of the surface crack and the sizing of crack length are confirmed using an EDM (electrical discharge machined) notch. In this study, the present authors verified the elastic wave generation method that is applicable for actual inspection system using a multilayer piezoelectric actuator and a pulsed laser. The elastic wave was generated by these two methods and the detectability of the surface crack was confirmed using an EDM notch respectively. Moreover, the reflected wave from a fatigue crack (in stainless steel plate) was detected by ESPI in case when an elastic wave that was generated by a pulse laser.

Ultrasonic Estimation of Mechanical Properties of Pulmonary Artery Wall Under Normotensive and Hypertensive Conditions

---**Kendall R. Waters**, National Institute of Standards and Technology, Materials Reliability Division, Mail Stop 853.00, 325 Broadway, Boulder, CO 80305-3328; Osama M. Mukdadi, The Children's Hospital, University of Colorado Health Sciences Center, Denver, CO 80305

---Secondary pediatric pulmonary hypertension is a disease that could benefit from improved ultrasonic diagnostic techniques because no single test permits a complete evaluation. Improved understanding of the effects of tissue remodeling due to hypertension on mechanical properties of the pulmonary artery wall could lead to earlier detection. The pulmonary artery wall is composed of 3 tunics (intima, media, adventitia) with elastic properties provided primarily by the media. The media is generally modeled as having orthotropic symmetry and, consequently, 9 independent elastic stiffness coefficients. The Long-Evans rat model has been identified as potentially useful for the study of pulmonary hypertension because it can be genetically modified to give the rat a greater propensity for developing hypertension. Ultrasound measurement techniques are used to evaluate the mechanical properties of pulmonary artery walls from normotensive and hypertensive rat models. We perform high-frequency in vitro ultrasound measurements (16 MHz to 100 MHz) on fresh and fixed pulmonary artery walls excised from control and hypoxic rat models. Estimates of the elastic stiffness coefficients are determined from measurements of the speed of sound, and are compared between groups. Preliminary results indicate that hypertension leads to up to a 30% increase in stiffening of the pulmonary artery wall.

Acoustic Emission – A precision Indicator of Phase Transition in Soft PZT Ceramics Under an Applied Electric Field

---**S. P. Mallikarjun Rao** and K. Prabakar, Acoustic Emission Laboratory, Physics Department, University College of Science, Osmania University, Hyderabad – 500 007, India

---An in-situ method for precisely determining the phase transition (PT) temperature under an applied electric field, in some soft PZT ceramics, using Acoustic Emission (AE) is detailed. High frequency (HF) AE signals due to domain fall-backs were observed during thermal depoling (while the temperature was increasing from about 50^{O}C to 150^{O}C). And mostly by about 250^{O}C the samples were found to be fully depoled. Also, no AE signal was observed at PT during the temperature-increase phase due to the structural change from ferroelectric tetragonal to paraelectric Cubic. This absence was attributed to the depoled nature of the sample with net polarization vector (Ps) of grains pointing in random directions. An application of threshold electric field from about 250^{O}C, yielded HF AE signals due to domain alignments, whose rapidity and amplitude increased as the PT approached and at PT, the AE signals abruptly stopped. These were attributed to the domain alignments in the direction of the field and a co-operative effect of similarly oriented Ps grains going through a structural change from tetragonal to cubic. In the temperature decrease cycle and with field being present, a sudden onset of HF domain alignment AE signals indicated the PT. However this sudden on-set was preceded by a low frequency AE signal indicative of micro-cracking in the sample due to excessive stresses involved during PT (now a structural change from cubic to tetragonal). Results of variation of PT temperature for some soft PZT ceramics with variation in the applied electric field are presented.

Combining X-Ray, Eddy Current, and Electric Field Measurement Techniques for Automating Particle Fuel Characterization

---**R. Hockey**, R. Mathews, and L. Bond, Pacific Northwest National Laboratory, P. O. Box 999, MS K5-26, Richland, WA 99352; J. Gray, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---In a multidisciplinary research effort to enable the production and safe use of sub-millimeter sized coated particle fuels designed for next generation nuclear reactors, the integration of multiple NDE techniques is showing positive results for in-process and on-line quality and process control of TRISO coated fuel particle production. Currently, economically feasible means for reliably inspecting the billions of particles necessary to fuel a single reactor are nonexistent. This paper focuses on a thematic blend of X-ray, eddy current, and electric field methods (a subset of the many different methods being evaluated by this project) to help resolve this essential inspection problem. High-resolution micro-focus radiographs and CT images are providing a library of X-ray characterized surrogate fuel particles intentionally coated to span the predominate range of parameters expected to influence fuel performance. Eddy current and electric field measurements--responding to the electrical and volumetric properties of the surrogate fuel kernel, and chemical vapor deposited layers of porous carbon, SiC, and pyrolytic carbon--of the X-ray characterized particle library are shown to correlate with dimensional properties and hold promise for eventually providing the high-speed quality and process control technology necessary to satisfy the fuel requirements for Generation IV reactor designs.---This work is being supported by the DOE-NERI Program and involves a research team lead by the Pacific Northwest National Laboratory, with collaborators at General Atomics, Iowa State University and Oak Ridge National Laboratory.

Ultrasonographic Periodontal Probing Based on the Dynamic Wavelet Fingerprint

---**Mark K. Hinders** and Jidong Hou, College of William and Mary, Department of Applied Science, Williamsburg, VA 23187-8795

---Manual pocket depth probing has been widely used as a retrospective diagnosis method in periodontics. However, numerous studies have questioned its ability to accurately measure the anatomic pocket depth. In this talk, an ultrasonic periodontal probing method is described, which involves using a hollow water-filled probe to focus a narrow beam of ultrasound energy into and out of the periodontal pocket, followed by automatic processing of pulse-echo signals to obtain the periodontal pocket depth. The signal processing algorithm consists of three steps: peak detection/characterization, peak classification and peak identification. A dynamic wavelet fingerprint (DWFP) technique was first applied to detect suspected scatterers in the A-scan signal and generate a two-dimensional black and white pattern to characterize the local transient signal corresponding to each scatterer. These DWFP patterns were then classified by a two-dimensional FFT procedure and mapped to an inclination index curve. The location of the pocket bottom was identified as the third broad peak in the inclination index curve. The algorithm was tested on full mouth probing data from two sequential visits of 14 patients. Its performance was evaluated by comparing ultrasonic probing results with that of full-mouth manual probing at the same sites, which was taken as the 'gold standard'.

Critical Timing Issues in Flash Thermography

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

---The conventional strategy for flash thermography has been to apply a pulse of light with full width half maximum duration on the order of 2-3 milliseconds to surface of a solid sample. In current practice, only the flash amplitude is typically adjusted, in order to minimize saturation of the detector array. However, closer examination of the process indicates that more precise interrogation of subsurface structure obtains if the timing parameters of the excitation pulse are carefully controlled. In particular, limiting the pulse duration and the offset between the initiation of the pulse and the camera integration period significantly increases the correlation between modeled and experimental results during the early post-flash frames. Once precise a relationship between pulse timing and camera integration has been established, additional performance enhancement can be achieved by mathematically compensating for the interval between the pulse and acquisition, which is often desirable for optimum performance.

SESSION 28 - POSTERS

LASER ULTRASOUND, GUIDED WAVES, CHARACTERIZATION AND CLASSIFICATION, SENSORS AND PROBES, NEW APPLICATIONS, NEW TECHNIQUES, INSTRUMENTS AND SYSTEMS, COMPOSITE MATERIALS, INFRASTRUCTURE, DESIGN MANUFACTURING, AND RELIABILITY

Green Center

1:30 PM

Laser Ultrasound

Simulation of Ultrasonic Waveform Excited by Laser Source by Using Finite Element Method
---J. He, G. Chen, **X. R. Zhang**, and J. C. Chen, State Key Laboratory of Modern Acoustics and Institute of Acoustics, Nanjing University, 210093 Nanjing, China; M. Zhou, College of Material Science and Engineering, Jiangsu University, 212013, Zhengjiang, China

Defects Detection on Silicon Nitride Balls by Laser-Ultrasonics
---M. Lemarie, M. Duquennoy, **F. Jenot**, M. Ouaftouh, and M. Ourak, IEMN, Département OAE (UMR CNRS 8520), Université de Valenciennes et du Hainaut Cambrésis, 59313 Valenciennes Cedex 9, France

Guided Waves

Analysis of Ultrasonic Guided Wave Dispersion in Pipes Using 3-D FEM and 2-D FFT
---J.-S. Park, H.-J. Yu, **S.-J. Song**, and Y. H. Kim, Sungkyunkwant University, School of Mechanical Engineering, 300 Chonchon-dong, Jangan-gu, Suwon, Kyounggi-do, 440-746; Jangan-gu, Suwon, Kyounggido, Korea; Y.-M. Cheong and H.-K. Jung, Korea Atomic Energy Research Institute, Daejon, Korea

Generation of the Ultrasonic Guided Waves in a Steamless Stainless Steel Pipe Using an Array Transducer
---**S.-J. Song**, Y. H. Kim, J.-S. Park, and J.-S. Heo, School of Mechanical Engineering, Sungkyunkwan University, 300 Chonchon-dong, Jangan-gu, Suwon, Kyounggi-do, 440-746, Korea; J.-H. Kim and H.-S. Eom, Korea Atomic Energy Research Institute, Daejon, Korea; K.-H. Im, Woosuk University, Department of Automotive Engineering, Wanju-Kun, Chonbuk, Korea

Theoretical Aspects of Laser-Generated Guided Waves in Bonded Plates by Expansion of the Two-Layer Normal Mode Method
---J. Du and J. Cheng, State Key Laboratory of Modern Acoustics, Nanjing University, No. 22 Hankou Road, Nanjing 210093, China; M. Li, Institute of Acoustics, Chinese Science Academy, Beijing 100080, P. R. China (Presenter: **F. Zhang**)

Characterization and Classification

Modeling and Simulation of the Effects of AC and DC Excitation Currents on Magnetic Particles Inspection Using an Extended 3D Finite Element Model
---**S.-J. Lee**, Y. Melikhov, D. C. Jiles, M. Garton, R. Lopez, and L. Brasche, Iowa State University, Center for Aviation Systems Reliability, Ames, IA 50011

Evaluation of Adhesive Bonded Properties by Using Wavelet Transform and Neural Networks from Laser-Generated Ultrasonic Guided Wave
---L. Cui, J. Yang, and J. Cheng, State Key Laboratory of Modern Acoustics, Nanjing University, Nanjing 210093, P. R. China; M. Li, Institute of Acoustics, Chinese Science Academy, Beijing 100080, P. R. China (Presenter: **F. Zhang**)

System and Method for Ultrasonic Image Reconstruction Using Mode-Converted Rayleigh Wave Technique
---**D.-M. Suh**, Raynar/Kunjang College, HTVC 5114, Kaist, Yusong, Daejon, Korea; J.-J. Sung, Sae-An Engineering Company, Korea; J.-G. Chung, Chonbuk National University, Chonju, Korea

On the Problem of the NDE of Concentrated Slurries
---M. Mather, **R. E. Challis**, A. K. Holmes, and A. Kalashnikov, UNDE Laboratory, School of Electrical and Electronic Engineering, University of Nottingham, United Kingdom

Sensors and Probes

Detection of Laser Excited Lamb-Wave Using Air-Coupled Transducer and Wave Mode Identification Using Wavelet Transform
---**H. K. Ann**, N. G. Kwag, and C. M. Lee, Sae-An Engineering Corporation, #910 ByukSan Digital Vally, 481-10, Gasan-dong, KeumChun-Gu, Seoul, Korea; H. M. Kim and K. Y. Jhang, Graduate School of Hanyang University, Seoul, Korea

Modeling and Analysis of the Membrane-Behavior in Capacitive Micromachined Ultrasonic Transducer
---S. S. Lee, **K.-B. Kim**, and B. Ahn, Center for Environment & Safety Measurement, Korea Research Institute of Standards and Science, Daejeon, Korea

Choice of the Distance Between the Pole-Pieces of the Electromagnet Yoke in a Magnetic Method of Material Testing
---M. Komorowski, S. Gratkowski, and **T. Chady**, Faculty of Electrical Engineering, Technical University of Szczecin, Szczecin, Poland

An Interrogating Electric Field Simulation for Probes with Short Coplanar Electrodes
---**Y. Bulbik**[1,2] and I. Chernykh[2], [1]UNESCO Chair "New Materials and Technologies" at Krasnoyarsk State Technical University, Krasnoyarsk, Russia; [2]Siberian Aerospace University, Krasnoyarsk, Russia

Eddy Current and Magnetic Testing of Magnetic Material by Uniform Eddy Current Probe
---**H. Hoshikawa**, K. Koyama, and S. Mitsuhashi, Nihon University, Izumicho Narashino Chiba 275-8575, Japan

Mode Extraction and Defect Detection Using a Multi-Channel Array with Magnetostrictive Transducer and Mode Extraction
---**M. Murase**, T. Hayashi, M. Nagao, and Y. Okuda, Faculty of Engineering, Nagoya Institute of Technology, Nagoya, Aichi, Japan

New Applications

Thermoelastic Generation of Resonant Ultrasonic Waves by a Pulsed Laser
---K. E. Claytor, J. A. Tencate, and **T. N. Claytor**, Los Alamos National Laboratory, MS C914, Los Alamos, NM 87544

Analysis of Dispersion Characteristics of Circumferential Guided Waves and Detection of Feeder Cracking in Pressurized Heavy Water Reactor
---Y.-M. Cheong, S.-S. Kim, D.-H. Lee, and **H. K. Jung**, Division Nuclear Materials Technology, Korea Atomic Energy Research Institute, Yusong P. O. Box 105, Daejon, 305-600, Korea

Applications of the Helmholtz Coil for Eddy Current Testing of Ferromagnetic Materials
---**J. Sung**, K. Jang, and S. Ku, Research and Development Center, Sae-an Engineering Corporation, Seoul, Korea; D. Suh, Kunjang College, Kunsan, Korea; M. Lee, Raynar Corporation, Daejeon, Korea

Remote Field Eddy Current Signal Modeling for the Gap Measurement of Neighboring Tubes
---**H. K. Jung**, D. H. Lee, and Y. S. Lee, Nuclear Robot Laboratory, Korea Atomic Energy Research Institute, Yusong P. O. Box 105, Daejon, 305-600, Korea

Advanced Ultrasonic Simulations in Complex Geometries
---**M. Garton**, T. Gray, L. W. Schmerr, Jr., H.-J. Kim, and R. Huang, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

New Techniques, Instruments, and Systems

Damage Detection in Plate Structures Using Laser Vibrometry and Sparse Ultrasonic Transducer Arrays
---**T. E. Michaels**, J. E. Michaels, and B. Mi, School of Electrical and Computer Eng., Georgia Institute of Technology, 777 Atlantic Dr., NW, Atlanta, GA 30332-0250; M. Ruzzene and S. M. Jeong, School of Aero. Eng. Georgia Institute of Technology, Atlanta, GA 30332-0250

Using Ultrasound for Non-Invasive Slurry Characterization
---J. A. Bamberger and **M. S. Greenwood**, Battelle Pacific Northwest National Laboratory, Richland, WA 99352

Air-Coupled Ultrasound Images of Spot Welds Having Sub-Wavelength Resolution
---T. J. Potter, **B. Ghaffari**, and G. Mozurkewich, Ford Motor Company, Research and Advanced Engineering, MD 3083/SRL, P. O. Box 2053, Dearborn, MI 48121-2053

Lift-Off Point of Intercept (LOI) Behavior
---**J. H. V. Lefebvre**, Defense Research and Development Canada, Ottawa, Ontario, Canada; J. M. S. Dubois, Royal Military College of Canada, Kingston, Ontario, Canada

Resonant Transmission of Air-Coupled Ultrasound Through Metallic Inserts in Honeycomb Sandwich
---**J. J. Peters**, V. Dayal, D. J. Barnard, and D. K. Hsu, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

Acoustic Leak Location in Spacescraft Structures Using Dispersed Multimode Signals
---**R. A. Roberts**, S. D. Holland, M. Strei, J. Song, and D. E. Chimenti, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

Towards a Generic Manual Scanner for Nondestructive Inspection
---**D. J. Barnard**, J. J. Peters, and D. K. Hsu, Iowa State University, Center for NDE, Ames, IA 50011

New NDT Equipment Concepts
---**V. Mengeling**, D. Simonet, and S. Rolet, EADS Corporate Research Centre, 12 rue Pasteur, BP76, F-92152 SURESNES Cedex, France

Composite Materials

Subsurface Defect Detection in FRP Composites Using Infrared Thermography
---U. B. Halabe, A. Vasudevan, H. V. S. GangaRao, West Virginia University, Department of Civil and Environmental Engineering, Constructed Facilities Center, Morgantown, WV 26506-6109; P. Klinkhachorn and **G. M. Lonkar**, Lane Dept. of Computer Science and Electrical Eng., West Virginia University, Morgantown, WV 26506-6103

Infrastructure

Evaluation of a Fiber Optic Strain Measurement System for Monitoring FRP Bridge Decks
---P. Klinkhachorn and **G. M. Lonkar**, Lane Dept. of Computer Science and Electrical Eng., West Virginia University, Morgantown, WV 26506-6109; U. B. Halabe and H. V. GanagaRao, Dept. Civil and Environmental Eng., West Virginia University, Morgantown, WV 26506-6103

Ultrasonic Study on Modulus of Elasticity and Nonlinearity Parameter (B/A) in Norway Spruce as a Function of Year Ring
---T. Koponen, **E. O. Haeggström**, T. Karppinen, and R. Serimaa, University of Helsinki, Department of Physical Sciences, Gustav Hällströms gata 2, FIN-00014, Finland; P. Saranpää Finnish Forest Research Institute, Vantaa Research Centre, P. O. Box 18 FIN-01301, Finland

Study on Attenuation and Nonlinearity in ThermoWood Using Ultrasound
---**E. O. Haeggström**, University of Helsinki, Department of Physical Sciences, Gustav Hällströms gata 2, FIN-00014, Finland

Design Manufacturing and Reliability

Contribution of Modelling Tools to Aeronautic NDT
---**V. Mengeling**, O. Petillon, and H. Voillaume, EADS Corporate Research Centre, 12 rue Pasteur, BP76, F-92152 Suresnes Cedex, France

NDE Procedure Validation and Use in NDE System Calibration for NDE Applications
---**Ward D. Rummel**, D&W Enterprises, Ltd., 8776 W. Mountainview Lane, Littleton, CO 80125

On-Line, Real-Time NDE and Quality Assessment in the Precision Small Lot Manufacturing Environment
---V. R. Dave, **D. A. Hartman**, M. J. Cola, W. H. King, Los Alamos National Laboratory, Nuclear Materials Technology, NMT-10: Manufacturing Process Science and Technology, P. O. Box 1663, MS E506, Los Alamos, NM 87545

Monitoring of Detection Probability in QNDE Devices for Storage Tanks
---**Y. H. Michlin**, Quality Assurance and Reliability, Technion – Israel Institute of Technology, Technion City, Haifa 32000

Observing Effects of Particle Size for a Slurry Using Ultrasonic Diffraction Grating Spectroscopy
---**M. S. Greenwood** and L. J. Bond, Pacific Northwest National Laboratory, Richland, WA 99352; A. Brodsky and L. Burgess, University of WA, Seattle, WA

3:10 PM ***Coffee Break***

Simulation of Ultrasonic Waveform Excited by Laser Source by Using Finite Element Method

---J. He, G. Chen, **X. R. Zhang**, and J. C. Chen, State Key Lab. of Modern Acoustics and Institute of Acoustics, Nanjing University, 210093 Nanjing, China; M. Zhou, College of Material Science and Engineering, Jiangsu University, 212013, Zhengjiang, China

---We calculate the waveforms of laser-generated ultrasound for the sample Stain-less Steel and Aluminum by using the finite element model. According to thermoelastic theory, considering the temperature dependence of the thermophysical parameters of the material the transient temperature field can be precisely calculated by using the finite element method; then, laser-generated bulk generated at different distance from the excited source and for different duration of laser source are calculated. The calculation results show that to select the size of mesh of the finite element model is a key step for get good result, the finite element method is efficient not for the sample suffer pure fore load but also for the thermo-structural couple research field. The results obtained and discussions will present in this article.

Defects Detection on Silicon Nitride Balls by Laser-Ultrasonics

---M. Lemaire, M. Duquennoy, **F. Jenot**, M. Ouaftouh, and M. Ourak, IEMN, Département OAE (UMR CNRS 8520), Université de Valenciennes et du Hainaut Cambrésis, 59313 Valenciennes Cedex 9, France

---In this work, we study the generation and the detection of surface waves on silicon nitride balls a few millimeters in diameter. The excitation of these waves is carried out thanks to a pulsed laser YAG and their detection is achieved with a laser interferometric probe. The whole of the device requires neither coupling nor direct contact with the balls. These waves are then used for the analyze of defects close to the surface of the balls. Several measurements are carried out on samples presenting various defects. Correlation attempts are also carried out between some ultrasonic parameters and some characteristics of defects.

Analysis of Ultrasonic Guided Wave Dispersion in Pipes Using 3-D FEM and 2-D FFT

---Joon-Soo Park, Hyung-Ju Yu, **Sung-Jin Song**, and Young H. Kim, Sungkyunkwant University, School of Mechanical Engineering, 300 Chonchon-dong, Jangan-gu, Suwon, Kyounggi-do, 440-746; Jangan-gu, Suwon, Kyounggi-do, Korea; Yong-Moo Cheong and Hyun-Kyu Jung, Korea Atomic Energy Research Institute, Daejon, Korea

---Ultrasonic guided waves have been widely used for the nondestructive evaluation of pipes. The dispersion characteristics should be understood for the reliable applications of the guided waves, and those in straight pipes can be obtained by Gazis' solution. In the present study, the dispersion curves of the bent cylindrical pipe as well as straight pipe were obtained by using the finite element modeling and 2-dimensional Fourier transform. The transient response of the bent pipe were calculated by using commercial finite element program, and the displacements were obtained as a function of spatial position and time, u(x,t). Then 2-dimensional FFT of u(x,t) offers U(k,w), the relation between wave number and angular frequency, so that the phase velocity and group velocity can be calculate. The modes of the guided waves were also identified using time-frequency analysis obtained by wavelet transform.

Generation of the Ultrasonic Guided Waves in a Seamless Stainless Steel Pipe Using an Array Transducer

---**Sung-Jin Song**, Young H. Kim, Joon-Soo Park, and Jin-Soo Heo, School of Mechanical Engineering, Sungkyunkwan University, 300 Chonchon-dong, Jangan-gu, Suwon, Kyounggi-do, 440-746, Korea; Jae-Hee Kim and Heung-Sup Eom, Korea Atomic Energy Research Institute, Daejon, Korea; Kwang-Hee Im, Woosuk University, Department of Automotive Engineering, Wanju-Kun, Chonbuk, Korea

---Ultrasonic guided waves have been widely employed for the long range inspection of structures such as plate, rod and cylindrical tube. In ultrasonic guided waves, however, there are numerous modes with different wave velocities, so that the generation and detection of the appropriate wave mode of the guided wave is one of key techniques in the application of guided waves. The most common way to generate guided waves is oblique incidence of ultrasound. Array transducers, such as comb transducer and interdigital transducer, have been used to generate guided waves for the flexible tuning pf the particular wave. Recently, a new method to generate and receive phase-tuned signals, called synthetic phase tuning (SPT) was reported. In the present work, SPT using an array transducer was apply to generate ultrasonic guided waves in a seamless stainless steel pipe. For this purpose, 8-channel ultrasonic pulser/receiver and their controller which enables sequential activation of each channels with given time delay were developed. 8 transducers were fabricated in order to generate guided waves by using SPT. The results of tuned generation and reception of guided waves will be shown.

Theoretical Aspects of Laser-Generated Guided Waves in Bonded Plates by Expansion of the Two-Layer Normal Mode Method

---Jun Du and Jianchun Cheng, State Key Laboratory of Modern Acoustics, Nanjing University, No. 22 Hankou Road, Nanjing 210093, China; Mingxuan Li, Institute of Acoustics, Chinese Science Academy, Beijing 100080, P. R. China (Presenter: **F. Zhang**)

---The two-layer normal mode expansion (NME) method is developed to analyze the laser-generated elastic guided wave in bonded plates accounting for the adhesive bond layer in terms of a weak interface with the spring model. The dispersion of the cylindrically symmetric guided wave modes and transient responses of the laser-generated guided wave in two-layer bonded plates are analyzed numerically for different cohesive situations characterized by the stiffness coefficients, such as the rigid, the weak and the slip interfaces. We found that there exists a physically impossible mode, which has a group velocity approaching infinity at low frequency, and a systematic study of the parameter space of stiffness coefficients shows the spring model for modeling the adhesive bond interface results in this defect.

Modeling and Simulation of the Effects of AC and DC Excitation Currents on Magnetic Particles Inspection Using an Extended 3D Finite Element Model

---**Seong-Jae Lee**, Yevgen Melikhov, David C. Jiles, Mike Garton, Rick Lopez, and Lisa Brasche, Iowa State University, Center for Aviation Systems Reliability, Ames, IA 50011

---Magnetic particle inspection (MPI) technique is used for detecting surface or sub-surface defects in aerospace structures and components. When inspecting magnetic materials, either DC or AC current is used to induce magnetic flux leakage (MFL) fields around defects. The MFL fields attract magnetic particles to the defects and enables visualization of the defects. Although it is generally agreed that DC excitation current should be used for detection of subsurface defects due to the absence of skin depth effect, there are still questions on which type and waveform of excitation current would be best suited for MPI testing and how much amperage should be applied to identify an arbitrary shaped defect. To aid optimizing conditions for MPI, we extended a 3D finite element model by including algorithms for AC current excitations and applied the extended model to study the variation of magnetic flux density around a defect having different widths and depths under DC and AC currents. The amplitude of the output signals and other simulation results around the defect region as the applied current and frequency increase will be presented and discussed in detail.---This research was supported by the Federal Aviation Administration under Contract #DTFA03-98-D-00008, Delivery Order #IA051 and performed at Iowa State University's Center for NDE as part of the Center for Aviation Systems Reliability program.

Evaluation of Adhesive Bonded Properties by Using Wavelet Transform and Neural Networks from Laser-Generated Ultrasonic Guided Wave

---Lianjun Cui, Jing Yang, and Jianchun Cheng, State Key Laboratory of Modern Acoustics, Nanjing University, Nanjing 210093, P.R. China; Mingxuan Li, Institute of Acoustics, Chinese Science Academy, Beijing 100080, P. R. China (Presenter: **F. Zhang**)

---A method based on a combination of wavelet transform (WT) and artificial neural networks (ANN) is presented to evaluate the adhesive bonded properties in two-layer composite plates from transient laser-generated ultrasonic guided waveforms. The waveforms obtained by numerical simulations are taken as the sample database of ANN for training and learning, and the WT is used to extract the eigenvectors from the wave signals to simplify the structure of the ANN. The results show that it is available to classify three kinds of interfaces, as the rigid, the weak and the slip interfaces of the adhesive layer, from the transient waveforms. As to the weak interface situation, a more detailed quantitative work proves the effectiveness of the inversion of stiffness coefficients from the transient waveforms. This method provides a new promising way for the characterization of the cohesive quality in bonded plates by laser-generated guided wave detection.

System and Method for Ultrasonic Image Reconstruction Using Mode-Converted Rayleigh Wave Technique

---**Dong-Man Suh**, Raynar/Kunjang College, HTVC 5114, Kaist, Yusong, Daejon, Korea; Je-Jung Sung, Sae-An Eng. Co., Korea; Jin-Gyun Chung, Chonbuk Nat. Univ., Chonju, Korea

---In conventional ultrasonic imaging methods, the specular reflections are usually used for image reconstruction. However, these techniques are not efficient in some cases due to multiple specular reflections, and mode-converted acoustic waves.In this paper, The Rayleigh wave technique for ultrasonic characterization of defect is presented, where Rayleigh waves traveling along the surface of strong scatterers in the materials are used for the reconstruction of inclusions with pitch-catch method. In particular, this study describes a method of defect detection and sizing by the Rayleigh wave in the circularly arrayed pitch-catch method. When a beam is directed to the crack, reflections, refractions and diffractions are generated from the crack. If the crack surface is smooth, both the specular echo and the Rayleigh wave are clearly detected since the time-delay between the two waves is relatively large. This large time-delay is due to the fact that the Rayleigh wave in the surface of the crack is slower than the incident wave. For ultrasonic detection by the Rayleigh wave in the pitch-catch method by angular observation, circularly arrayed-receiving transducers are used. In this method, a single transmitter is located in the center and the arrayed receivers are circularly arranged for the detection of the Rayleigh signal from the crack surface. The impulse response of the inclusion by pitch/catch was obtained by deconvolution. In this deconvolution the signal of the single transmitter by pulse/echo and the output signal by pitch/catch was used for calculation. To show the validity of the proposed method, test specimens with various kinds of artificial reflectors, void-like defects, flat-bottom holes were used. This study also shows it is feasible to accurately predict the defect shape by the Rayleigh wave.

On the Problem of the NDE of Concentrated Slurries

---Melissa Mather, **Richard E. Challis**, Andrew K. Holmes, and Alexander Kalashnikov, UNDE Laboratory, School of Electrical and Electronic Engineering, University of Nottingham, United Kingdom

---Concentrated suspensions of high density particles in liquids (slurries) are found in manufacturing processes in many industrial sectors, including minerals, dyestuffs, pigments and abrasives. The dimensional scale of the particles is generally of the order 100 nm to 1000 nm, but may extend beyond this range. There is an ongoing need to monitor the dispersed particle size distribution (PSD) as it changes either due to diminution procedures such as milling or due to flocculation/aggregation. The frequency dependence of ultrasonic compression wave attenuation is sensitive to PSD and so could provide a non-invasive method for its estimation. The technique requires a mathematical model which relates PSD to measured attenuation. However, most available models work well for dilute suspensions (up top 5% v/v, say) but are not appropriate for concentrated systems. This paper considers a number of hydrodynamic approaches to acoustic wave propagation in slurries with a view to identifying a suitable model. A unified mathematical format is developed in which different formulations for viscosity in a concentrated field of particles can be compared. The focus of this comparison is what is meant by the *local viscosity* which affects individual particles as they oscillate to and fro in response to the exciting acoustic field. The theoretical models will be compared with only limited experimental results, as the investigation is ongoing.

Detection of Laser Excited Lamb-Wave Using Air-Coupled Transducer and Wave Mode Identification Using Wavelet Transform

---**H. K. Ann**, N. G. Kwag, and C. M. Lee, Sae-An Engineering Corporation, #910 ByukSan Digital Vally, 481-10, Gasan-dong, KeumChun-Gu, Seoul, Korea; H. M. Kim and K. Y. Jhang, Graduate School of Hanyang University, Seoul, Korea

---Ultrasonic nondestructive testing used widely to detect mechanical defects like as crack because ultrasonic have profitable advantage of the sensitivity and economy. But, most conventional ultrasonic techniques use the contact transducer with PZT (piezo-electric transducer). With like this cause, the hour of inspection is caught plentifully at wide area of site. It is difficult to automate and apply at field. Thus, the developments of more efficient technique are demanded. In this study, the laser source with arrayed linear slits generated Lamb-wave that has a wavelength, and an air-coupled transducer received it. Modes of leaky Lamb-wave at plate had different oblique angles in air. By changing oblique angle of an air-coupled transducer, a selected mode was received. Also, the received signal was processed by wavelet transform for the analysis in domain of time-frequency. We compared the theoretical dispersion curve and the spectroscopy by wavelet transform.

Modeling and Analysis of the Membrane-Behavior in Capacitive Micromachined Ultrasonic Transducer

---Seung Seok Lee, **Ki-Bok Kim**, and Bongyoung Ahn, Center for Environment & Safety Measurement, Korea Research Institute of Standards and Science, Daejeon, Korea

---In this study, theoretical analysis and finite element analysis of the behavior of membrane (such as resonance frequency, membrane deflection, collapse deflection and collapse voltage) in the capacitive micromachined ultrasonic transducer (cMUT) were performed. The design parameters of the cMUT were estimated and are the dimension and thickness of membrane, thickness of sacrificial layer, thickness and size of electrode, size of active element and so on. The resonance frequency of the membrane increased as the thickness of the membrane increased but decreased as the diameter of the membrane increased. The deflection of the membrane increased as d-c bias voltage increased. The collapse voltage of the membrane was predicted.

Choice of the Distance Between the Pole-Pieces of the Electromagnet Yoke in a Magnetic Method of Material Testing

---M. Komorowski, S. Gratkowski, and **T. Chady,** Faculty of Electrical Engineering, Technical University of Szczecin, Szczecin, Poland

---Magnetic methods of testing are widely used for the detection of surface and sub-surface anomalies in ferromagnetic materials. With magnetic methods of testing, a magnetic field is induced inside the object being tested and any resulting changes of magnetic flux in the region of interest are observed. Magnetic fields can be excited either by a permanent magnet or by an electromagnet with either AC or DC. DC methods provide greater sensitivities for detecting sub-surface defects. In this paper we consider the magnetic field excitation using an electromagnet yoke, operated by DC and with adjustable distance between the pole-pieces of the yoke. The sensitivity of detection for any portion of a component being tested varies with the distance between the pole pieces and, hence, the choice of the distance is of great importance. Simplified theoretical analysis as well as results of measurements for steel plates are given.

An Interrogating Electric Field Simulation for Probes with Short Coplanar Electrodes

---**Ya. Bulbik**[1,2] and I. Chernykh[2], [1]UNESCO Chair "New Materials and Technologies" at Krasnoyarsk State Technical University, Krasnoyarsk, Russia; [2]Siberian Aerospace University, Krasnoyarsk, Russia

---One of the problems at the layered composite structures manufacturing is to evaluate their surface and subsurface physical parameters on-line. Unilateral access to the surface and its curvature motivate to use a simple probe with three short coplanar electrodes under enhanced pulse-excited potentials. Electric charge simulation method has been used to model both transient and quasi-steady interrogating fields. A voltage pulse is applied to the central high-potential and external zero-potential electrodes contacting with the composite surface. Sensory electrodes are located symmetrically in respect to the central electrode with some gaps above the curvilinear surface under test. To reduce some changes of injection from the high-potential electrode it is made with a piezoelectric interface layer. Besides, the high-potential electrodes length is slightly less than the sensory one. These features taken into account allow to optimize the probe electrode system. The probe arrangement and some experimental results are described.

Eddy Current and Magnetic Testing of Magnetic Material by Uniform Eddy Current Probe

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

---The authors have studied about eddy current and magnetic testing of surface flaws on magnetic material by uniform eddy current probe. The probe consists of a large exciting tangential coil and a small detecting pancake coil and comprises only air-cored coils. The probe picks up flaws perpendicular to the exciting coil winding based on eddy current testing and those parallel to based on magnetic flux leakage testing. The signal from the probe is lift-off noise free and self-nulling in principle. The directions of the flaws can be distinguished based on the signal phase because the phase by eddy current testing is distinctly different from that by magnetic flux leakage testing. Making a comparison of relative sensitivity between the eddy current testing and the magnetic flux leakage testing, the former has higher sensitivity at higher test frequency and the latter at lower frequency. Uniform eddy current probe generates magnetic flux without a hefty exciting magnetic core and turns magnetic flux leakage testing to a manual testing just like eddy current testing. The experimental results have shown that the flaw signals by uniform eddy current probe decays much less by its lift-off from test material than those by a conventional pancake coil probe. Thus uniform eddy current probe can be promising for surface flaw testing of magnetic material through anticorrosion painting.

Mode Extraction and Defect Detection Using a Multi-Channel Array with Magnetostrictive Transducer and Mode Extraction
---**Morimasa Murase**, Takahiro Hayashi, Masahiro Nagao, and Yuichiro Okuda, Faculty of Engineering, Nagoya Institute of Technology, Nagoya, Aichi, Japan

---Recently, guided wave NDE for a pipe has attracted considerable attention. The contact techniques widely used for guided wave NDE is very sensitive to contact condition between transducers and specimen. If a multi-channel array is required, therefore, the contact techniques do not provide sufficient accuracy in detected signals. The non-contact technique with magnetostrictive sensors, developed by H. Kwun et. al., enables us to measure signals with higher accuracy, though it requires to attach a nickel plate to a pipe first. This study presents that mode extraction and defect detection using a multi-channel array with magnetostrictive transducers. Guided waves are excited and detected with magnetostrictive sensors. In order to detect multi-modes guided waves and extract them, we use transducer array with many transducers in the circumferential direction. The signals detected in the multi transducers are processed in data analyzing system developed by Lab view. The mode extraction technique gives the results that crack locations in both longitudinal and circumferential directions are detected.

Thermoelastic Generation of Resonant Ultrasonic Waves by a Pulsed Laser
---Kevin E. Claytor, James A. Tencate, and **Thomas N. Claytor**, Los Alamos National Laboratory, MS C914, Los Alamos, NM 87544

---A small unfocussed Q switched laser was used to excite resonances in aluminum targets using the thermoelastic effect. It was found that, contrary to expectations, excitation of modes by the thermoelastic effect in aluminum was only a factor of 2-3 times less efficient than ablation near the ablation threshold. Both piezoelectric and a laser interferometer were used to detect the resonances. Due to the differing mechanisms for acoustic wave generation, different resonances were excited in rods for each method. A simple explanation is proposed for the fact that the ratio of the thermoacoustially generated signal to the ablative signal is much greater that that observed at high frequencies (>5 MHz). The signal levels are sufficient that a relatively low power high repetition rate Q switched laser may also be able to generate detectable resonances in materials. The laser technique is similar to conventional ARS (Acoustic Resonance Spectroscopy) however the non contact nature of the method leads to possible applications that would not be feasible with standard contact transducers.

Analysis of Dispersion Characteristics of Circumferential Guided Waves and Detection of Feeder Cracking in Pressurized Heavy Water Reactor

---Yong-Moo Cheong, Sang-Soo Kim, Dong-Hoon Lee, and Hyun-Kyu Jung, Division Nuclear Materials Technology, Korea Atomic Energy Research Institute, Yusong P. O. Box 105, Daejon, 305-600, Korea

---A circumferential guided wave method was developed to detect the axial crack on the bent feeder pipe. Dispersion curves of circumferential guided waves were calculated as a function of curvature of the pipe. In the case of thin plate, i. e. infinite curvature, as the frequency increases, the S0 and A0 become to be coincided and eventually Rayleigh wave mode. In the case of the pipe, however, as the curvature increases, the lowest modes do not coincide even in the high frequencies. Based on the analysis, a rocking technique using angle beam transducer was applied to detect axial defect in the bent region of PHWR feeder pipe. After review of the experimental data on the artificial notches, the vibration modes of each signal were identified. It was found that the notches with the depth of 10% of wall thickness be detected with the method.

Applications of the Helmholtz Coil for Eddy Current Testing of Ferromagnetic Materials

---**Jejoong Sung**, Kwanseop Jang, and Sangmo Ku, Research and Development Center, Sae-an Engineering Corporation, Seoul, Korea; Dongman Suh, Kunjang College, Kunsan, Korea; Minho Lee, Raynar Corporation, Daejeon, Korea

---The Helmholtz coil was applied to inspection of ferromagnetic materials. Generally, the eddy current signals from the ferromagneic materia can be distorted easily due to irregularity of magnetic permeability, The irregularity must be minimized to obtain the signal of good quality. Magnetic saturation is one of the best effective methods which suppress the irregularity of magnetic field in inspection area. In this paper, the Helmholtz coil was used to saturate the insepction area magnetically. This coil has a number of favorable characteristics such as generation of uniform magnetic field, low cost, accessibility, easy to design, etc. The design and operation of eddy current testing probe including the Helmholtz coil are presented. Characterization of coil operating parameters was presented to measure variance of impedance in comparison of signal to noise (SNR) performance between the Helmholtz coil probe and the conventional probe, analysis of magnetic field homogeneity. Results were presented to demonstrate the SNR advantage of the Helmholtz probe for eddy current testing of ferromagnetic materials. The experimental results not only demonstrated the irregularity of magnetic field in ferromagnetic material was significantly decreased but also confirmed a capability of detection flaws.

Remote Field Eddy Current Signal Modeling for the Gap Measurement of Neighboring Tubes

---**Hyun Kyu Jung**, Dong Hoon Lee, and Yoon Sang Lee, Nuclear Robot Lab., Korea Atomic Energy Research Institute, Yusong P.O. Box 105, Daejon, 305-600 Korea

---The fuel channels in the Canadian Deuterium Uranium (CANDU) reactor consist of the coaxial pressure tube (PT) and calandria tube (CT). Liquid injection nozzle (LIN) is cross aligned with the fuel channel to control the reactor by injecting poison. For the safe operation, the gap between LIN and CT should be maintained in order to prevent a contact of neighboring tubes. Under the condition of inserting the RFEC probe into the coaxial tubes and of crossing a LIN above or under the CT, the modeling of a LIN signal was needed to check the possibility of gap measurement. VIC-3D S/W which covers the axi-symmetric 3D configuration was hardly applied to get a LIN signal. This problem was solved by assuming a LIN as the flaw which can be described as the complete 3D object. This simulated LIN signal was verified by performing the laboratory experiment. The gap between LIN and CT can be correlated with the amplitude of LIN signals in the voltage plane. Typical noises in the fuel channel were the relative constriction, the change in the pressure tube diameter (fill-factor), thickness variation, and so on. These noise signals were simulated by using the modeling and were analyzed by considering their dependency on the phase angle and amplitude of the voltage plane in order to separate the gap signal from them. It could be concluded that the voltage plane analysis of the simulated RFEC signals were effective for obtaining the gap measurement of neighboring tube.

Advanced Ultrasonic Simulations in Complex Geometries

---**M. Garton**, T. Gray, Les Schmerr, Hak-Joon Kim, and R. Huang, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---This poster will show the integration of numerical beam models and flaw models with an interface to CAD that can be used to simulate ultrasonic inspections. Time domain waveforms will be calculated based on reflections from complex shapes. Maps of quantitative scan sensitivity and coverage will be shown.---This material is based upon work supported by the Federal Aviation Administration under Contract #DTFA03-98-D-00008, Delivery Order #IA014 and performed at Iowa State University's Center for NDE as part of the Center for Aviation Systems Reliability program. This material is based on work supported by NASA under award NAG-1-029-98. This work was supported by the NSF Industry/University Cooperative Research program.

Damage Detection in Plate Structures Using Laser Vibrometry and Sparse Ultrasonic Transducer Arrays

---**Thomas E. Michaels**, Jennifer E. Michaels, and Bao Mi, School of Electrical and Computer Engineering, Georgia Institute of Technology, 777 Atlantic Dr., NW, Atlanta, GA 30332-0250; Massimo Ruzzene and Sang M. Jeong, School of Aerospace Engineering, Georgia Institute of Technology, Atlanta, GA 30332-0250

---The structural health of an aluminum plate is monitored via a spatially sparse array of piezoelectric transducers combined with a Laser Doppler Vibrometer (LDV). The LDV detects the out-of-plane displacement or velocity components of a vibrating surface by means of the Doppler effect. A scanning device provides velocity patterns over large surfaces in a timely manner, and gives the unique opportunity of capturing and visualizing the propagation of transient ultrasonic waves. The measurements produce animated displacement maps which clearly highlight the interactions of the propagating waves with discontinuities in the plate. The accuracy and sensitivity of the LDV measurements are assessed through direct comparison with the signals detected by the transducer array. The performance of both methods is assessed and results correlated with the goal of jointly applying the two techniques with the objective of combining their advantages. Sparse transducer arrays can in fact be employed in a "usage monitoring" framework and are generally capable of detecting very small damage. The LDV-based technique directly provides precise location information together with a detailed representation of the propagating waves. The LDV can therefore be proposed for confirmation and localization of damage detected with the transducer array. Also, the analysis of LDV waveforms may be utilized in support of the optimal positioning of transducers on the structure to be monitored.

Using Ultrasound for Non-Invasive Slurry Characterization

---Judith Ann Bamberger and **Margaret S. Greenwood,** Battelle Pacific Northwest National Laboratory, Richland, WA 99352

---Ultrasonic sensors developed and deployed to characterize physical properties of radioactive waste slurries provide a unique robust method for non-invasively characterizing multiphase pipe flows. Transducers mounted in spool pieces, or for large tanks and vessels mounted on the wall or suspended in the fluid, can be used to measure fluid or slurry density, solids concentration, rheology, viscosity, detect changes in particle size or crystal growth and detect interfaces, such as those between air and oil and oil and water. Ultrasound transducers can be mounted into a spool piece or simply strapped to the outside of the piping and the waves penetrate metal and plastic pipes and vessels, without the need for invasive sensors or pipe penetrations. With a multi-transducer configuration, sensors can both send and receive signal pulses through the piping and the flowing material and extract ultrasonic time-of-flight information, make amplitude measurements and give back-scatter or signal reflection data. This information is combined with a temperature measurement to provide real-time measurement of various fluid-slurry system physical properties.

Air-Coupled Ultrasound Images of Spot Welds Having Sub-Wavelength Resolution
---Timothy J. Potter, **Bita Ghaffari**, and George Mozurkewich, Ford Motor Company, Research and Advanced Engineering, MD 3083/SRL, P.O. Box 2053, Dearborn, MI 48121-2053

---Air-coupled ultrasound at 1 MHz was utilized to image resistance spot welds joining mild steel sheets. The transmission geometry used two axially-aligned transducers, each focused on the adjacent surface of the specimens. Because of the enormous impedance mismatch between air and steel, the transmitted signal was exceedingly weak, requiring several hours to collect a C-scan of the weld. The air-coupled images resembled the weld shapes as determined by an independent, higher-frequency, water-coupled reflection technique. However, surface roughness and surface topography from weld electrode indentation introduced artifacts and uncertainties that interfered with straightforward interpretation of the air-coupled images. Nevertheless, the smearing of the images was substantially less than the 5.9-mm wavelength in steel, with the steepness of the transition between welded and un-welded areas indicating a transverse spatial resolution around 0.8 mm. We suggest that this sub-wavelength resolution is possible because the air-coupled experimental technique is similar to near-field imaging.

Lift-Off Point of Intercept (LOI) Behavior
---**J. H. Vivier Lefebvre**, Defense Research and Development Canada, Ottawa, Ontario, Canada; J. M. Stéphane Dubois, Royal Military College of Canada, Kingston, Ontario, Canada

---In Pulsed Eddy Current it was previously shown that there is a point where probe responses are independent of the lift-off distance for a given material condition. It was effectively used previously to detect corrosion, cracks and map first and second layer defects independently of lift-off variations. In this paper, the behavior of the LOI was investigated experimentally under a wide variety of conditions. The results show that the LOI points follow a unique curve for a given probe. The results also lead to a method of selecting a probe, based on its electrical properties, for a given pulsed eddy current inspection and evaluation.

Resonant Transmission of Air-Coupled Ultrasound Through Metallic Inserts in Honeycomb Sandwich

---**J. J. Peters**, V. Dayal, D. J. Barnard, and D. K. Hsu, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---Metallic inserts are embedded into composite honeycomb sandwiches as hard points for mechanical connection. Air-coupled ultrasound can be used for detecting disbond between insert and facesheet. It was discovered in such inspection that surprisingly large amplitude could be transmitted through thick metallic inserts (e.g., 3/4" thick, 1.5" diameter titanium), whereas a thin plate of the same metal can only transmit a much weaker signal. This paper reports an experimental and analytic study of the geometrical effects of inserts. Modal analysis of cylindrical inserts was made using finite element ANSYS codes. The transmission efficiency of air-coupled ultrasound correlated well with the vibration modes of the cylinder, i.e., axial versus torsional. An understanding of the resonant transmission through metallic inserts is important for the inspection of such structures with narrow-band or broadband air-coupled ultrasonic systems.---This work was supported in part by NSF I/U CRC for NDE at Iowa State University and in part by NASA under award No. NAG-1-02098.

Acoustic Leak Location in Spacecraft Structures Using Dispersed Multimode Signals

---**R. Roberts**, S. Holland, M. Strei, J. Song, and D. E. Chimenti, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---Progress in the development of a method using leak-generated structure-borne noise to locate small air leaks in long-duration spacecraft, such as the International Space Station (ISS), is presented and demonstrated. Space debris and micrometeorites can penetrate the ISS pressure container, causing loss of air. Stopping a small leak is relatively simple, once its location is known. Because rack-mounted equipment and insulation mask the leak location, and because a leak into space vacuum produces almost no airborne ultrasonic noise in the spacecraft interior, a structure-borne noise solution is necessary. Source location using time of flight information contained in structure-borne noise signals is complicated by the multi-mode dispersive propagation characteristics of thin plate structures. Correlation-based triangulation methods do not perform well, because the underlying assumption that signals at two separate locations are time shifted replicas of one another is violated in the case of multi-mode dispersive propagation. This work is exploring the generalization of correlation-based source location to compensate for the effects of multi-mode dispersion. Array measurements are being tested which determine the propagation characteristics of the structure and isolate individual modes of propagation, while simultaneously determining source location. Experiments are examining several leak sizes in plates of different thickness. Noise signals are measured at remote locations using pinducer probes spatially scanned over receiver, acquisition grids. Results demonstrating the underlying data analysis will be presented.---This material is based on work supported by NASA under award NAG-1-029-98.

Towards a Generic Manual Scanner for Nondestructive Inspection

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

---NDE imaging modalities are gradually gaining acceptance in airline maintenance hangars operations. Even so, the high cost and complexity of single modality units precludes airlines from wide use of current commercial systems. With low cost commercial encoding apparatus available for manual scanning and hand held inspection instruments available with data ports or alarm outputs, a low cost generic manual scanning instrument should be realizable. Software controlling the generic scanner should allow selectable encoding methods and data inputs from the instruments the inspectors currently have on hand. The software should also allow inspection setups to be downloaded to the instrument, eliminating the need for (and possibility of errors from) inspectors manually setting up the instrument. Data displays should allow selection of amplitude, time-of-flight or thickness, impedance magnitude or angle, or simple go-no go images based on alarm or threshold settings, and images should be recorded as common format image files (*.bmp, *.jpg, etc.) or delimited text files for manipulation/post processing in common programs such as MS Excel. This report summarizes recent efforts at a generic manual scanning system. Other features of the software such as resolution changes on-the-fly and other encoding schemes are discussed.---This material is based upon work supported by the Federal Aviation Administration under Contract #DTFA03-98-D00008, Delivery Order No. IA047 and performed at Iowa State University's Center for NDE as part of the Center for Aviation Systems Reliability program. The technical monitor is Paul Swindell.

New NDT Equipment Concepts

---**Vanessa Mengeling**, Didier Simonet, and Sébastien Rolet, EADS Corporate Research Centre, 12 rue Pasteur, BP76, F-92152 SURESNES Cedex, France

---The European project called by the acronym "INDeT" brings together major European aircraft manufacturers and Information Technologies (IT) developers for 3 years (Start : June 2002). This project contributes to improve inspection conditions, reliability and costs reduction by implementing IT tools in NDT maintenance activities. Main objectives concern : - Replacement of paper documentation by a digital support: implemented on a NDT platform, developed multimedia procedures should be more clearly illustrated, interactive, in whom the information should be easy and fast to consult and modify. Change of information transfer : through accessible web servers, NDT inspector can get the exact amount of information he needs : updated procedure, automatic settings, expert advices. Such technologies enable a world-wide online support from maintenance organizations. Evolution of NDT environment : Already based on PC and specific NDT board , this situation is ideal for implemented new features in NDT systems. Therefore a compact system including the multimedia procedure is developed on a PC tablet. Relevant data (notes, images, settings) could also be stored during the inspection. This possibility appears of great interest for the life cycle monitoring and NDT data management during the whole life of an operating aircraft.

Subsurface Defect Detection in FRP Composites Using Infrared Thermography

---Udaya B. Halabe, Archana Vasudevan, Hota V. S. GangaRao, West Virginia University, Department of Civil and Environmental Engineering, Constructed Facilities Center, Morgantown, WV 26506-6109; Powsiri Klinkhachorn and **Gajanan Lonkar**, Lane Department of Computer Science and Electrical Engineering, Constructed Facilities Center, West Virginia University, Morgantown, WV 26506-6103

---This paper demonstrates the use of digital infrared thermography to detect subsurface defects such as debonds and delaminations in Fiber Reinforced Polymer (FRP) bridge decks. Simulated sub-surface debonds and delaminations were inserted between the wearing surface and the underlying FRP deck specimens. The infrared thermography technique was used to detect these embedded subsurface defects. The use of various heating and cooling methods was explored. The effect of distance on the detectability of debonds and delaminations were also considered. Surface temperature-time curves were established for different sizes of subsurface defects. The results show that infrared thermography can be a useful tool for defect detection in composite bridge decks. Therefore, the technique can be used for several applications such as quality control during pultrusion of new decks (in factories), during field construction, and field inspection of in-service decks.

Evaluation of a Fiber Optic Strain Measurement System for Monitoring FRP Bridge Decks

---Powsiri Klinkhachorn and **Gajanan M. Lonkar**, Lane Department of Computer Science and Electrical Engineering, West Virginia University, Morgantown, WV 26506-6109; Udaya B. Halabe and Hota V. GanagaRao, Department of Civil and Environmental Engineering, West Virginia University, Morgantown, WV 26506-6103

---The use of Fiber Optic Sensors (FOS) for structural monitoring applications has attained popularity among researchers and practitioners recently. This is due to its advantages e.g., immunity to electromagnetic interference, small size, environmental ruggedness, multiplexing capability etc., over strain gauges. In this paper we discuss a continuous structural monitoring technique using surface mounted/embedded fiber optic strain sensors to measure the strain in FRP bridge decks. Extrinsic Fabry-Perot strain sensors (EFPI) were selected as they offer a good compromise between accuracy and cost considerations. These strain sensors, along with a strain gauge, were surface mounted on FRP bridge decks. The decks were then tested for a performance comparison of both the sensors. The first test deals with monitoring their performance under simulated aging conditions. In this test, an FRP bridge with plan dimensions of 5.5ft x 2ft was used. The specimen was then placed in an environmental chamber that goes through a temperature cycle simulating freeze thaw weather conditions. Readings from both the sensors were recorded at regular intervals. In another test, a FRP bridge deck with plan dimensions of 2.2ft x 1ft was used. This specimen has been placed in a pH3 solution to simulate acidic environmental aging. The results show that the strain gauge sensor and the EFPI Fiber Optic sensor, are still in working condition. The EFPI fiber optic sensor detects minute and sudden changes in strain more effectively. Placement in the environmental chamber did not affect the EFPI sensor's performance and is an indication of its applicability to field structural monitoring for lengthy periods of time. Embedding the sensor in the structure increases the longevity of the Fiber Optic Sensor.

Ultrasonic Study on Modulus of Elasticity and Nonlinearity Parameter (B/A) in Norway Spruce as a Function of Year Ring

---Tiina Koponen, **Edward O. Hæggström**, Timo Karppinen, and Ritva Serimaa, Univ. Helsinki, Dept. Physical Sciences, Gustav Hällströms gata 2, FIN-00014, Finland; Pekka Saranpää
Finnish Forest Research Institute, Vantaa Research Centre, P.O. Box 18 FIN-01301, Finland

---Information how cellular stucture and growth rate affects modulus of elasticity (MOE) as a function of year-ring number in Norway spruce, Picea abies [L.] Karst., (NS) or on impact of rapid growth of NS on its MOE is scarce. We studied elastic properties of NS ultrasonically (2.35MHz). MOE and the ultrasonic nonlinearity parameter (B/A) was determined in longitudinal, radial and tangential direction as a function of distance from the pith using 1mm thick dry-coupled samples. Tangentially cut samples contained only earlywood while radially and longitudinally cut samples contained earlywood and latewood. Longitudinal MOE (MOElong) for NS grown at medium fertility site increased with pith-distance from 6±1 to 8.5±1 GPa. This parameter correlated with the samples' mean microfibril angle (MFA). The radial and tangential MOE was constant, 1±0.15 and 0.35±0.036 GPa. For a rapidly grown clone (6mm average growth ring width, GRW), containing mostly juvenile wood, grown at high fertility site MOElong was smaller than that in normally grown (2mm GRW) wood. No difference in MOEradial or MOEtang existed between specimen grown at the two sites. The MOElong difference is explained by rapidly-grown trees' larger MFA. Our MOE data agreed with published modeling predictions. The B/A parameter mirrored the MOE trend.

Study on Attenuation and Nonlinearity in ThermoWood Using Ultrasound

---**Edward O. Haeggström**, University of Helsinki, Department of Physical Sciences, Gustav Hällströms gata 2, FIN-00014, Finland

---Thermal treatment refines wood by improving its life-time and dimensional stability. Heating temperature, heating time and sample treatment influence the strength/stiffness and elasticity of thermally modified wood (TMW). By knowing the relationship between treatment and wood strength, thermal modification that maximizes the TMW strength can be carried out. This knowledge is used to develop methods for quality control and classification which reduce quality spread in TMW products thus increasing their value. Therefore we determined ultrasonically the attenuation and nonlinear response of dry defect-free TMW samples of Finnish pine, Pinus Sylvestris, as a function of treatment temperature (60-240ºC, 3 hours in protective water steam). An airborne ultrasonic confocal microscope was used that emitted 532kHz narrowband bursts and featured 68 dB geometrical gain, 7mm depth and 0.8mm lateral resolution. Linear and nonlinear (265-532kHz) transmission mesurements were performed on radially and tangentially cut samples (3x25x100mm, 450-600kg/m3, in 20±2.5% Rh, 22±0.5ºC). Macroscopic, open as well as closed, thermally induced cracks were distinguishable as was the different attenuation of early and late wood. The attenuation and second harmonic showed a linear dependence on treatment temperature (0.34±0.03 dB/cmºC, R2=0.84 and 0.38±0.04 dB/cmºC, R2=0.83). The B/A-graph exhibited a small "transformation-like" peak at 180ºC.

Contribution of Modelling Tools to Aeronautic NDT

---Vanessa Mengeling, Odile Petillon, and Hubert Voillaume, EADS Corporate Research Centre, 12 rue Pasteur, BP76, F-92152 Suresnes Cedex, France

---The development cycle of new aeronautical products has been significantly reduced during last years due to the increasing use of concurrent engineering tools. A wide range of simulation tools has been developed in order to better understand and control the NDT parameters for ultrasonic, radiography or eddy currents. Though these tools are not yet the most appropriate for aeronautic structures, it already becomes evident that they can provide help through different axes like earlier integration of NDT in the development cycle, better NDT information towards the design and stress office or the process, and support for NDT operators' training. The evaluation and adaptation of NDT simulation tools has been investigated for several years at EADS Corporate Research Centre and has covered till now a number of applications. General simulation objectives, the modelling contribution to NDT domain and the deployment of NDT simulation tools in the aeronautical domain are discussed and illustrated on applications.

NDE Procedure Validation and Use in NDE System Calibration for NDE Applications

---**Ward D. Rummel**, D&W Enterprises, Ltd., 8776 W. Mountainview Lane, Littleton, CO 80125

---This summary outlines some of the issues and tasks that a focuses on improvement of nondestructive inspection (NDE) calibration procedures and hence improvement of NDE reliability. The output is a standardized protocol for validation of instrumented NDE procedures and supporting data for implementation. Assessment of the capabilities of an NDE procedure by the probability of detection (POD) method is recognized as an essential element in reliable NDE applications. NDE reliability is characterized by: a) Capability - POD assessment, b) Reproducibility – Calibration, and c) Repeatability - Rigid Process Control. The role of "calibration" is to address and provide assurance of reproducibility of an applied NDE procedure. Unfortunately, widely applied NDE practices use a single reference/set-up artifact (notch, slot, hole, crack etc.) as the basis for NDE system "calibration". A single point "calibration" is partially reproducible for applications where the rejection level is identical to the "calibration" level, but is not reproducible at other reject levels. Requirements for assessment and implementation of quantitative NDE are met by probability of detection (POD) assessment. The basis for the Berens POD model is the establishment of a relationship (log/log or log /linear) between crack (artifact) size and NDE response (output). In order to reproduce a POD curve, it is necessary to reproduce the artifact size/response relationship used for POD analysis. If a single artifact is used, the A-HAT vs A response relationship may vary significantly with resulting variance in there POD output. Three or more point "calibration" are necessary to validate NDE procedures and in subsequent application of a procedure to provide confidence in detection at a reproducible POD level.

On-Line, Real-Time NDE and Quality Assessment in the Precision Small Lot Manufacturing Environment

---Vivek R. Dave, **Daniel A. Hartman**, Mark J. Cola, William H. King, Los Alamos National Laboratory, Nuclear Materials Technology, NMT-10: Manufacturing Process Science & Technology, P. O. Box 1663, MS E506, Los Alamos, NM 87545

---Small Precision Lot manufacturing is common in defense, aerospace, and other performance-critical, mission-critical, or highly man-rated manufacturing environments. Small lot statistical process control (SPC) methods have been developed, but they have several shortcomings: they apply to lot sizes of 25 or greater, they cannot provide fault classification, and the extrapolation from subscale manufacturing development to the full scale part is problematic. This current work presents a method that utilizes real-time, on-line data streams, uses feature extraction to identify key process attributes, and applies heuristics-based classification and pattern identification schemes to correlate in-process data to quality attributes. In this manner, exhaustive inspection and destructive evaluation need only be carried out in the manufacturing development phase, and since the current method infers quality through direct interrogation of process physics as opposed to inspection of part attributes, the lessons learned on subscale coupons are more readily transferable to full scale parts. Specific examples are shown for machining, welding, and heat treatment operations. Advantages and limitations of this on-line NDE approach are discussed, but it is generally shown that the method is useful in inferring quality and classifying fault conditions, thereby automating root cause analysis in the event of process faults.

Monitoring of Detection Probability in QNDE Devices for Storage Tanks

---**Yefim H. Michlin**, Quality Assurance and Reliability, Technion – Israel Institute of Technology, Technion City, Haifa 32000

---Tightness-testing devices (TTD's) for underground storage tanks have to be monitored for their accuracy during exploitation. The indices of this accuracy are the probability of detection (POD) of a specified leakage rate, and that of a false alarm (PFA). Periodic testing of the TTD's is economically prohibitive. A monitoring procedure has been recommended and adopted in Israel, whereby the tank testers e-mail brief data reports (a single line of an Excel table for each tank or connecting pipe) to the Ministry of the Environment. The basic purpose of this procedure - periodic verification that the above indices comply with the US EPA requirements, adopted in Israel. Moreover, it permits setting a range of application of the TTD's. The paper presents information on the POD monitoring methods used in Israel (whose effectiveness has been demonstrated in practice). Also presented are data on the distributions of the leakage measurement results and of fuel temperatures - and on the rates of change of the latter in the course of the measurements, in terms of their effect on accuracy. Other factors affecting the latter are also discussed. These data are of interest for the developers and users of this equipment.

Observing Effects of Particle Size for a Slurry using Ultrasonic Diffraction Grating Spectroscopy

---M. S. Greenwood and L. J. Bond, Pacific Northwest National Laboratory, Richland, WA 99352; A. Brodsky and L. Burgess, University of Washington, Seattle, WA

---The objective is to characterize the slurry in contact with the stainless steel (SS) grating, formed by machining triangular grooves, 240 microns apart, on the flat surface of a half-cylinder. Ultrasound from a send transducer travels through the SS and strikes the back of the grating where it is reflected to a receive transducer. A peak in this signal is used to determine properties of the slurry. The frequency at which the peak occurs is used to determine the velocity of sound in the slurry, as has been reported [QNDE 22B, 1637 (2002) and *Ultrasonics* 42, 531(2004)]. The peak height for a slurry is reduced due to scattering from the particles, which is dependent upon particle size. Experimental data will be presented for polystyrene spheres in water, ranging in size from 16 microns to 275 microns, which will demonstrate the effect of particle size. Additional experiments are underway and this data will also be presented.

SESSION 29

LAYERED MATERIALS AND INTERFACES

C. Pecorari, Chairperson
Parker Ballroom B

3:30 PM **Ultrasonic Inspection of Thin Multilayers**
---**M. K. Hinders**, Department of Applied Science, College of William & Mary, Williamsburg, VA 23187-8795; J. Hou and J. C. P. McKeon, Sonix, Inc., 8700 Morrissette Drive, Springfield, VA 22152

3:50 PM **Elastic Constants of Co/Pt Nano-Multilayers by Resonance Ultrasound Spectroscopy**
---**N. Nakamura**, H. Ogi, and M. Hirao, Graduate School of Engineering Science, Osaka University, Machikaneyamacho 1-3, Toyonaka, Osaka 560-8531, Japan

4:10 PM **Application of SAFT to Layered, Anisotropic Media**
---C. Engstrand and **R. Kline**, San Diego Center for Materials Research, San Diego State University, San Diego, CA 92182

4:30 PM **Characterization of Interfacial Properties of Solids in Elasto-Plastic Contact by an Ultrasonic Method**
---A. Baltazar, J.-Y. Kim, and **S. I. Rokhlin**, The Ohio State University, Nondestructive Evaluation Program, Edison Joining Technology Center, 1248 Arthur E. Adams Drive, Columbus, OH 43221

Ultrasonic Inspection of Thin Multilayers

---**Mark K. Hinders,** Department of Applied Science, College of William & Mary, Williamsburg, VA 23187-8795; Jidong Hou and James C.P. McKeon, Sonix, Inc., 8700 Morrissette Drive, Springfield, VA 22152

---Multilayer structures play important roles in many engineering applications such as aerospace, automotive and microelectronics. The quality and reliability of these structures are strongly dependent on the integrity of the interfaces between different layers. Because ultrasonic waves are reflected or scattered by discontinuities in acoustic impedance, they are very sensitive to defects such as cracks and delaminations at the interfaces of multilayers. However, with the rapid development of materials packaging technology, the thickness of these layers has been reduced significantly. In microelectronic devices, for example, it is no longer unusual to see packages with four to six dies stacked together with each die only 50 microns thick. Such extremely thin multilayer structures are becoming a serious challenge to current ultrasonic inspection techniques. On one hand, it is necessary to use much higher frequencies to achieve high resolution; on the other hand, there is a limit to the highest frequency that can be used for a particular application. In this talk, a pattern-based auto-detection technique is presented in which we generate simplified and intuitive two-dimensional time-scale patterns (the dynamic wavelet fingerprint, or DWFP) to characterize local signals. It is expected that a true echo will have a distinctive time-scale pattern that can be differentiated from that of noise and interference. Because of its two-dimensional nature, a pattern is more intuitively recognized and less sensitive to noise. Furthermore, as a knowledge-based approach, the algorithm can be customized for specific application and its performance can be improved by learning.

Elastic Constants of Co/Pt Nano-Multilayers by Resonance Ultrasound Spectroscopy

---**Nobutomo Nakamura**, Hirotsugu Ogi, and Masahiko Hirao, Graduate School of Engineering Science, Osaka University, Machikaneyamacho 1-3, Toyonaka, Odaka 560-8531, Japan

---Easy magnetization direction of a ferromagnetic thin film sandwiched between noble-metal thin films changes from parallel to the film plane into perpendicular to the film plane as the thickness of the ferromagnetic layer becomes thinner. This property is called perpendicular magnetic anisotropy (PMA), and attracting many researchers because such a multiplayer can be a candidate for extremely high-density-magnetic-recording media. PMA arises when the energy of the system takes a minimum with the perpendicular magnetic direction. The energy of the system consists mainly of magnetocrystalline-anisotropy energy, magnetic-shape-anisotropy energy, interfacial-anisotropy energy, and magnetoelastic-anisotropy energy. The elastic constants of a multilayer showing PMA are of great importance because they determine the elastic-strain energy, which is associated with the magnetoelastic-anisotropy energy. In this study, we measure the elastic constants of Co/Pt multilayer using resonance ultrasound spectroscopy (RUS) coupled with the laser-interferometory method, which was originally developed by authors. We prepare Co/Pt multilayers with various Co-layer thickness (0.4-4 nm) using a molecular-beam-epitaxy method. We find a correlation between the degree of PMA and elastic constants, the reason will be discussed at the presentation.

Application of SAFT to Layered, Anisotropic Media

---Cody Engstrand and **Ron Kline**, San Diego Center for Materials Research, San Diego State University, San Diego, CA 92182

---The synthetic aperture focusing technique (SAFT) was originally developed to improve signal to noise ratio and lateral resolution capability in radar applications. This approach was later found to be useful for the same purposes in ultrasonic signal processing. While originally used for isotropic media, recently there has been increased interest in extending SAFT to anisotropic media. In this work a new SAFT algorithm for anisotropic media is described. This algorithm was specifically constructed to treat structures with multiple anisotropic layers as commonly used for composite fabrication. Examples will be presented which demonstrate the utility of this approach in a series of samples where the stacking sequence has been systematically varied to introduce varying degrees of material anisotropy. We feel that this approach is useful in many composite applications where attenuation (thick composites, carbon-carbon, etc.) or sensitivity (air-coupled ultrasound, laser ultrasonics) may present problems without additional signal processing.

Characterization of Interfacial Properties of Solids in Elasto-Plastic Contact by an Ultrasonic Method

---A. Baltazar, J-Y Kim, and **S. I. Rokhlin**, The Ohio State University, Nondestructive Evaluation Program, Edison Joining Technology Center, 1248 Arthur E. Adams Drive, Columbus, OH 43221

---To relate the ultrasonically determined interfacial stiffness to topographic features, a micromechanical description of the contact is necessary. Here, we have developed a modified elastic-fully plastic model using the concept of dynamic stiffness to predict the compliance of the interface. The model is compared with values obtained from ultrasonic measurements. In our model, once asperities undergo plastic deformation, we distinguish between the dynamic ultrasonic stiffness, which increases in relation with the area of contact, and the static interfacial stiffness, which decreases as a consequence of the plastic condition at the tip of the asperities. Experiments were performed on aluminum-roughed samples with various rms roughness.

SESSION 30

STRUCTURAL HEALTH MONITORING II

F. Simonetti, Chairperson

Parker Ballroom D/E

3:30 PM **Study of Plate Waves Fields Generated by Piezo-Arrays and Their Application to Structural Health Monitoring**

---**B. Koehler**, F. Schubert, and N. Meyendorf, Fraunhofer IZFP Dresden, Kruegerstrasse 22, D01326 Dresden, Germany; J. L. Blackshire, Air Force Research Laboratory, Nondestructive Evaluation Branch, Wright-Patterson AFB, OH 45449

3:50 PM **Experimental Study of Plate Waves in Isotropic and Anisotropic Materials for Structural Health Monitoring**

---**B. Koehler**, Branch Lab EADQ, Fraunhofer IZFP, Kruegerstrasse 22, 01326 Dresden, Germany

4:10 PM **A Guided Ultrasonic Waves Array for Structural Integrity Monitoring**

---**P. Fromme**, Department of Mechanical Engineering, University College London, London, United Kingdom; P. Wilcox, Department of Mechanical Engineering, University of Bristol, Bristol, United Kingdom; M. Lowe and P. Cawley, Department of Mechanical Engineering, Imperial College London, London, United Kingdom

4:30 PM **Experimental Phased Array Focusing in Pipe Using Ultrasonic Guided Waves**

---**B. J. Gavigan**, L. Zhang, Z. Sun, and J. L. Rose, The Pennsylvania State University, Engineering Science and Mechanics, 212 EES Building, University Park, PA 16802

4:50 PM **Application of Guided Wave Signal Processing to Acoustic Emission Data**

---**P. D. Wilcox**, Department of Mechanical Engineering, University of Bristol, Bristol, United Kingdom

Study of Plate Waves Fields Generated by Piezo-Arrays and Their Application to Structural Health Monitoring

---**Bernd Koehler**, Frank Schubert, and Norbert Meyendorf, Fraunhofer IZFP Dresden, Kruegerstrasse 22, D01326 Dresden, Germany; James L. Blackshire, Air Force Research Laboratory, Nondestructive Evaluation Branch, Wright-Patterson AFB, OH

---Economic aspects are not only important in the design and development of technical systems and products but also for their operation. The life cycle costs of a technical system are mainly composed of the in-service usage costs and the maintenance and inspection costs. To lower life cycle costs Structural Health Monitoring (SHM) has gained considerable importance throughout the last few years in fields like aerospace, automotive or civil engineering. Structural Health Monitoring can be understood as an effective means to enhance system reliability, increase efficiency, and decrease life cycle cost of a complex technical system by introducing condition based maintenance and continuous structural integrity monitoring. To realize Structural Health Monitoring systems for aircraft structures such as wing or fuselage skins Lamb wave propagation methods using surface mounted piezoelectric sensors are one of the most widely discussed approaches. New sensor and monitoring concepts are needed, however, for a thoroughly understanding of the underlying physics which is tackled by numerical modeling and experimental visualization of the waves. Different types of piezoelectric transducers are discussed for this approach including a) piezo-arrays for beam steering and focusing and b) fiber composite arrays with possible applications to wave mode selection. The wave patterns generated by the arrays and wave-defect interactions are studied by numerical modeling and by laser vibrometer detection. Preliminary conclusions about an efficient health monitoring concept are drawn.

Experimental Study of Plate Waves in Isotropic and Anisotropic Materials for Structural Health Monitoring

---**Bernd Koehler**, Branch Lab EADQ, Fraunhofer IZFP, Kruegerstrasse 22, 01326 Dresden, Germany

---Lamb waves have been discussed extensively in the past few years as an effective mean for wide area damage detection in plate-like structures. Automatic damage detection systems can be designed exciting and receiving Lamb waves by appropriate built in or surface mounted transducers. The damage is identified by comparing sensor signals before and after the damage event. The difference is the scatter signal originating from the defect. Efficient structural health monitoring along this line requires a clear understanding of the wave phenomena involved. Dispersion of the Lamb waves in the damage free plate, scattering at structural inhomogeneities like stringers and scattering at damaged areas must be studied. In layered composite materials also the influence of the deviation from elastic isotropy has to be estimated. The wave propagation phenomena were studied by numerical and experimental methods. For numerical analysis the Elastodynamic Finite Integration Technique (EFIT) is applied. On the experimental side a non-contact detection technique using a modified laser vibrometer is used for visualizing wave propagation. Collected data are stored in a computer and animated after the measurement. Having already studied the generation and defect interaction of elastic waves in isotropic plates this paper deals with waves in Carbon Fiber Reinforced Plastics (CFRP) as example of an anisotropic material of increasing practical importance. Effects of acoustic anisotropy and dispersion where found and are shown in the form of slow motion videos. Also the interaction of different wave modes with impact flaws is visualized.

A Guided Ultrasonic Waves Array For Structural Integrity Monitoring

---**Paul Fromme,** Department of Mechanical Engineering, University College London, London, United Kingdom; Paul Wilcox, Department of Mechanical Engineering, University of Bristol, Bristol, United Kingdom; Mike Lowe and Peter Cawley, Department of Mechanical Engineering, Imperial College London, London, United Kingdom

---Many structures in the oil industry, e.g., oil storage tanks and offshore oil platforms, consist of large plate-like components, which can suffer from severe corrosion and the development of cracks during their service life. Constant, long-time monitoring of the structural integrity can be performed using permanently attached remote sensors. Guided ultrasonic waves that propagate along the structure allow the fast inspection of large areas of a structure from a single sensor location. A self-contained, permanently attached array for the inspection of plates has been designed and built. The array consists of a ring of piezoelectric transducer elements for the excitation and reception of the first antisymmetric Lamb wave mode A0. Laboratory measurements for a plate containing various defects have been performed. Corrosion damage often results in large area thickness reduction and is modeled as a circular part-through hole. The results are compared to numerical predictions and the sensitivity of the array device for defect detection is ascertained. The resolution and distinction between several defects is discussed.

Experimental Phased Array Focusing in Pipe Using Ultrasonic Guided Waves

---**Brian J. Gavigan**, Li Zhang, Zongqi Sun, and Joseph L. Rose, The Pennsylvania State University, Engineering Science and Mechanics, 212 EES Bldg., University Park, PA 16802

---The phased array focusing technique is being developed with the intent of inspecting hundreds of feet of pipeline from a single array position. The single array position is beneficial if access to a pipe is limited, e.g. steam pipes onboard U.S. Naval ships. The pipes often have a protective coating which would ordinarily be removed and replaced for an inspection. From a single array position, ultrasonic guided waves propagate under the coating, down the length of the pipe and then returns information about potential defects. Focusing the ultrasonic energy at a predetermined location along the length of the pipe enhances the ability to detect defects that current state of the art inspection systems cannot. Focusing is achieved by applying excitation time delays to a multi-channel signal generation system. The excitation sources are equally spaced about the circumference of the pipe. Time delays are calculated using theoretically generated angular displacement profiles in a hollow cylinder. These theoretical displacement profiles are dependent upon the transducer axial loading length, circumferential loading angle length, and excitation frequency. In this paper, theoretical time delays are used to focus torsional ultrasonic guided waves at a known defect location in a 2 inch diameter pipe using electromagnetic acoustic transducers (EMATs). Focusing studies are also performed using longitudinal guided waves in a 4 inch Schedule 40 pipe with Plant Integrity's Teletest system. Results of the focusing experiments are presented along with some concluding remarks and future work considerations.

Application of Guided Wave Signal Processing to Acoustic Emission Data

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

---Traditionally, AE transducers are highly resonant, narrowband devices for high sensitivity. High sensitivity is essential in certain situations, such as controlled pressure tests, where the AE events are not necessarily repeatable. However, for continuous monitoring of structures subjected to cyclic loading, multiple repeat AE events from the same source occur and a major problem is trying to discriminate signals due to fatigue crack growth from those due to benign events. In such applications, the use of damped, wideband transducers for AE is potentially attractive as it enables information about the frequency characteristics and hence the nature of an AE source to be obtained. Because many practical applications of acoustic emission (AE) for condition monitoring take place on plate-like structures, the propagation of AE signals is in the form of guided waves. This paper presents initial results from an ongoing study to investigate the application of guided wave signal processing techniques to wideband dispersive AE signals. Techniques include, for example, the use of cross-correlation in the wavenumber-domain to enable the effect of dispersion to be removed. The possibility of using the data from four or more sensors to automatically deduce the dispersion characteristics of the structure is also investigated.

SESSION 31

EDDY CURRENT PROBES AND APPLICATIONS

M. Sablik and M. Johnson, Co-Chairpersons
Parker Ballroom A

3:30 PM **A Novel Rotating Magnetic Field Eddy Current Transducer for the Examination of Fuel Channels in PHWR Nuclear Power Plants**
---**R. Grimberg**[1], L. Udpa[2], S. Udpa[2], and A. Savin[1], [1]Nondestructive Testing Department, National Institute of Research and Development for Technical Physics, 47 D. Mangeron Blvd., Iasi 700050, Romania; [2]Department of Electrical and Computer Engineering, Michigan State University, 2120 Engineering Building, East Lansing, MI 48824-1226

3:50 PM **Metallic Bead Detection by Using Eddy-Current Testing Probe with SV-GMR Sensor**
---**S. Yamada**, K. Chomsuwan, T. Hagino, M. Iwahara, and H. Tian, Institute of Nature and Environmental Technology, Kanazawa University, 2-40-20 Kodatsuno, Kanazawa 920-8667, Japan

4:10 PM **Detection and Measurement of Fatigue in Ferromagnetic and Austenitic Steels Using Eddy Current Sensor Arrays**
---**R. Grimberg**, A. Savin, and R. Steigmann, Nondestructive Testing Department, National Institute of Research and Development for Technical Physics, 47 D. Mangeron Boulevard, Iasi, 700050, Romania

4:30 PM **Characteristics of Remote Field Eddy Current Signals from Small Diameter Gas Pipes**
---**Y.-K. Shin**, J.-H. Lee, Y.-T. Lee, and S.-C. Song, School of Electronic and Information Engineering, Kunsan National University, San 68, Miryong-dong, Kunsan, Chonbuk, 573-701, Korea

4:50 PM **Electroelastic Effect for Near-Surface Eddy Current Residual Stress Assessment**
---F. Yu and **P. B. Nagy**, Department of Aerospace Engineering and Engineering Mechanics, University of Cincinnati, ML 0070, Cincinnati, OH 45221-0070

A Novel Rotating Magnetic Field Eddy Current Transducer for the Examination of Fuel Channels in PHWR Nuclear Power Plants

---**R. Grimberg**[1], Lalita Udpa[2], S. Udpa[2], and Adriana Savin[1], [1]Nondestructive Testing Department, National Institute of Research and Development for Technical Physics, 47 D. Mangeron Blvd., Iasi 700050, Romania; [2]Department of Electrical and Computer Engineering, Michigan State University, 2120 Engineering Building, East Lansing, MI 48824-1226

---Fuel Channels in pressurized heavy water reactors (PHWR) consist of two Zr-2.5%Nb alloy tubes that are concentrically held in place by four grater springs. The channels are inspected periodically using optical, ultrasonic and eddy current NDE methods for detecting blisters and discontinuities, measuring the position and tilt of garter springs, and estimating the thickness of oxide layers. This paper presents a novel eddy current transducer, which generates a rotating magnetic field. The probe can measure the position and tilt of the garter springs accurately and offers a high probability of detection with respect to discontinuities. The probe was simulated using a model employing dyadic Green's function for layered cylindrical media. The proposed method locates the position of garter springs to within ±0.5 mm and their tilt to within 5°. The size of discontinuities can be estimated with an accuracy of ±0.2 mm width, ±0.1 mm depth.---This work was partially supported by NSF Grant 0303914 and International Atomic Energy Agency, Vienna under Contract. No 11164/R4.

Metallic Bead Detection by Using Eddy-Current Testing Probe with SV-GMR Sensor

---**S. Yamada**, K. Chomsuwan, T. Hagino, M. Iwahara, and H. Tian, Institute of Nature and Environmental Technology, Kanazawa University, 2-40-20 Kodatsuno, Kanazawa 920-8667, Japan

---Ball Grid Array (BGA) packages present numerous benefits previously unobtainable in a single packaging technology. BGAs provide higher pin counts in less area and utilization of metallic bead (solder ball) can reduce the manufacturing process. Generally, the ball sizes are around 1.0 mm and smaller than these when it is applied to the high-density BGA packages. In addition, the ball diameter and alignment have to examine before BGA packaging process. Eddy-current testing (ECT) technique is a non-contact method that can evaluates metal structure without changing or altering of testing material. In addition, ECT technique has high-sensitivity to material conductivity. From the feature above, the micro-metallic bead size and alignment inspection by mean of ECT technique were proposed in this paper. ECT with planar type meander coil and spin valve giant magneto-resistance (SV-GMR) sensor was used for this proposed. In experiment, the micro-metallic beads with diameter range from 100 to 760 micro m were used as model for inspection. The inspection results were presented that the proposed probe is able to inspect the micro-metallic beads size and alignment precisely.

Detection and Measurement of Fatigue in Ferromagnetic and Austenitic Steels Using Eddy Current Sensor Arrays

---**R. Grimberg**, Adriana Savin, and Rozina Steigmann, Nondestructive Testing Department, National Institute of Research and Development for Technical Physics, 47 D. Mangeron Blvd., Iasi, 700050, Romania

---Fatigue contributes to the formation and growth of martensite phase in ferromagnetic and austenitic steels, which eventually leads to breaking up of grains, and the development of cracks. This paper presents an eddy current array consisting of a transmission coil and a set of receiving coils for the detection and measurement of the fatigue state. The signals are processed using an iterative algorithm employing the maximum likelihood procedure for estimating the level of fatigue. A numerical model based on dyadic Greens functions method is employed for modeling the layered media to determine the weight vector matrix as well as for optimizing the design of the array. Test results obtained using the array compare very favorably with those obtained using X-ray diffraction methods and liquid penetrant tests.---This work was partially supported by US NSF Grant #0303914 and CNCSIS -Romania under Grant 2004.

Characteristics of Remote Field Eddy Current Signals from Small Diameter Gas Pipes

---**Young-Kil Shin**, Jung-Ho Lee, Yun-Tai Lee, and Sung-Chul Song, School of Electronic and Information Engineering, Kunsan National University, San 68, Miryong-dong, Kunsan, Chonbuk, 573-701, Korea

---In this study, characteristics of defect signals, obtained from the remote field eddy current testing of gas pipes with 48.8 mm diameter, are investigated. To decide the operating frequency, the electromotive force (emf) induced in the sensing coil was monitored while it was moved away from the exciting coil. At proper frequencies, sudden changes occurred in both the amplitude and the phase of induced emf at about 1.5 pipe diameters away from the exciting coil. This procedure provided the proper spacing between the two coils as well as the proper operating frequency. When the dimensions of the two coils are similar, the phase signal shows two humps; each one appears as each of the two coils passes a defect. Although numerical modeling study predicted the same two humps, experimental results showed that they are not identical. The hump that appears when the exciting coil passes a defect is smaller for shallow defects, but it becomes bigger than the other hump for deep defects. This result enables us to estimate the defect depth just by comparing the two humps in a single signal. Other characteristics such as linear relationship between defect depth and phase signal strength, equal sensitivity to ID and OD defects, and signal pattern changes due to multiple defects are also observed during the experiment and these observations will be reported.

Electroelastic Effect for Near-Surface Eddy Current Residual Stress Assessment

---Feng Yu and **Peter B. Nagy**, Department of Aerospace Engineering and Engineering Mechanics, University of Cincinnati, ML-0070, Cincinnati, OH 45221-0070

---This paper discusses the relationship between isothermal and adiabatic piezoresistive properties of metals. The piezoresistive effect, i.e., stress-dependence of the electrical resistivity, can be exploited for nondestructive residual stress assessment using eddy current measurements. First, the paper establishes the relationship between the familiar isothermal piezoresistivity coefficients measured under uniaxial tension and hydrostatic pressure and the relevant isothermal electroelastic coefficients measured under uniaxial and biaxial stress conditions either by non-directional circular or directional elliptical eddy current coils. In order to quantitatively assess the prevailing residual stress from eddy current conductivity measurements, the electroelastic coefficients must be first determined. These calibration measurements are usually conducted on a reference specimen of the material to be tested using cyclic uniaxial loads between 0.1 and 10 Hz, which is fast enough to produce adiabatic conditions. It is demonstrated that in high-conductivity metals such calibration measurements must be corrected for the thermoelastic effect, which is always positive, i.e., it increases the conductivity in tension, when the material cools down, and reduces it in compression, when the material heats up.---This work was performed at the University of Cincinnati in cooperation with 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.

SESSION 32

PODS AND NDE RELIABILITY

C. V. Kropas-Hughes, Chairperson
Parker Ballroom C

3:30 PM **Linear Array Ultrasonic Transduers: Sensitivity and Resolution Study**
---**V. A. Kramb**, University of Dayton, University of Dayton Research Institute, Structural Integrity Division, 300 College Park, Dayton, OH 45469-0120

3:50 PM **The Reflection of Ultrasound from Partially Contacting Rough Cracks**
---R. Thomas, D. Liaptsis, and **B. W. Drinkwater**, Department of Mechanical Engineering, University of Bristol, United Kingdom

4:10 PM **Alternative to Single-Pixel C-Scan Analysis for Measuring POD**
---**C. Annis**[1] and D. Annis[2], [1]Statistical Engineering, Palm Beach Gardens, FL 33418-7161; [2]Naval Postgraduate School, Monterey, CA 93940

4:30 PM **Guided Wave Particle Motion in a Hollow Cylinder**
---**L. Zhang** and J. L. Rose, Department of Engineering Science and Mechanics, the Pennsylvania State University, University Park, PA 16802

4:50 PM **An Approach Toward Determining Default POD Curves for Ultrasonic Billet Inspections**
---**R. B. Thompson[1]**, W. Q. Meeker[2], C.-P. Chiou[1], and Y. Wang[2], Iowa State University, [2]Center for NDE, 1915 Scholl Road, and [2]Department of Statistics, Ames, IA 50011

5:10 PM **A Knowledge Based Expert System to Aid Theoretical Ultrasonic Flaw Modelling**
---**R. J. Robinson** and A. McNab, Centre for Ultrasonic Engineering, University of Strathclyde, 204 George Street, Glasgow, Scotland, G1 1XW, United Kingdom

Linear Array Ultrasonic Transducers: Sensitivity and Resolution Study

---**Victoria A. Kramb**, University of Dayton, University of Dayton Research Institute, Structural Integrity Division, 300 College Park, Dayton, OH 45469-0120

---The University of Dayton Research Institute under contract by the US Air Force has designed and constructed a fully automated ultrasonic inspection system for the detection of embedded defects in rotating gas turbine engine components. The automated inspection system, designed and developed under the Turbine Engine Sustainment Initiative (TESI) makes use of phased array ultrasonic technology for increased throughput and detection capability. Linear array transducers have shown good success for inspection applications such as welds and turbine blade roots where the defect types are well characterized and defined. Targets of interest in aerospace applications such as forgings and engine run hardware are less well defined. Inspection system calibration and setup requirements for these applications are based on machined targets such as flat bottom holes and side-drilled holes, but a direct correlation between the response from the setup targets and natural defects is not assured. In order to determine the applicability of linear arrays to aerospace embedded defect inspections UDRI conducted a study to assess the detection sensitivity and resolution for two linear array transducers for machined and synthetically produced targets. This paper will discuss the results of that study, and the relationship between machined and synthetically produced calibration targets.

The Reflection of Ultrasound from Partially Contacting Rough Cracks

---Ruth Thomas, Dimosthenis Liaptsis, and **Bruce W. Drinkwater**, Department of Mechanical Engineering, University of Bristol, Bristol, United Kingdom

---Ultrasound is commonly used to detect and size cracks in a range of engineering components. Modelling techniques are well established for smooth and open cracks. However, real cracks are often rough (relative to the ultrasonic wavelength) and closed due to compressive stress. This paper describes an investigation into the combined effects of crack face roughness and closure on ultrasonic detectability. A contact model has been used to estimate the size and shape of scatterers (voids) at the interface of these rough surfaces. The interaction of ultrasound with this scattering interface has then been predicted using a finite element model. The response to excitation with a longitudinal ultrasonic pulse over a wide range of frequencies has been investigated for different sizes, distributions and shapes of scatterers. The analysis demonstrates that for low frequencies and small scatterer sizes the behavior can be described by a simple mass-spring model. The model also shows that the response at high frequencies is dependent on both the shape and size of the scatterers and cannot be predicted by a mass-spring model. Comparisons have been made between the finite element predictions and experimental results and good agreement obtained.

Alternative to Single-Pixel C-Scan Analysis for Measuring POD

---**Charles Annis**[1] and David Annis[2], [1]Statistical Engineering, Palm Beach Gardens, FL 33418-7161; [2]Naval Postgraduate School, Monterey, CA 93940

---There can be hundreds of thousands of pixels in a C-Scan image making the probability of a false-positive based on a single pixel almost a certainty. Methods have been proposed to use both pixel amplitude and signal-to-noise ratio to control false calls. We propose an alternative algorithm based on the behavior of pixels in a neighborhood, rather than the amplitude of a single pixel. The algorithm uses the statistical properties of the average of the three highest amplitude pixels in a neighborhood containing 43 pixels. Because it is an *average*, this metric does not display the extreme fluctuations of an individual pixel. Because it is the average of the three *largest* amplitude pixels, it can respond to large pixel amplitudes without being diluted by the greater number of usually quiescent pixels populating a neighborhood. The empirical properties of the resulting sampling distribution for "noise" are easily determined given the underlying distribution of pixel background noise. The upper bound of this sampling distribution establishes the false-call rate. The "signal" is also the average of the largest of three highest amplitude pixels in a 43 pixel neighborhood. Given these definitions for "signal" and "noise" POD determination can precede using either *hit/miss*, or $\hat{a}$ *vs* a analysis. The algorithm is demonstrated on a C-scan of the ISU 2.7%N block containing 16 known SHA inclusions of sizes #2, #3, #4, #5 each (64 total).

Guided Wave Particle Motion in a Hollow Cylinder

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

---In the ultrasonic guided wave inspection of hollow cylinders, defect sensitivity of a wave mode is critical for improving results. In order to achieve a high sensitivity of defect detection, it is important to concentrate energy on the expected defect spot. A study of the particle motion contributes to determining the radial energy distribution (known as wave structure) in a pipe. In this paper, the normalized displacements of axisymmetric and non- axisymmetric longitudinal/torsional wave modes are simulated by using the normal mode expansion method. Our investigation shows that wave structures are highly frequency-dependent. Particularly, the dominant particle motion direction, of either a single wave mode or a mode family, changes with frequency variety. Hence, this particle motion study can also help the phased-array focusing inspection technique by determining the particle motion component and the relationship to focusing.

An Approach Toward Determining Default POD Curves for Ultrasonic Billet Inspections

---**R. Bruce Thompson**[1], William Q. Meeker[2], Chien-Ping Chiou[1], and Yurong Wang[2], Iowa State University, [2]Center for NDE, 1915 Scholl Road, and [2]Department of Statistics, Ames, IA 50011

---Currently, a research task within Engine Titanium Consortium (ETC) is underway to update the existing probability-of-defection curves, known as default POD curves, for ultrasonic billet inspections. In this paper, we describe the development and use of a statistical regression model that combines aspects of existing methods, namely, Re and $\hat{a}$ versus a, to carry out such task. Extensive effort was made to examine several past databases as well as a new data set generated from another ETC program known as Contaminated Billet Study (CBS). All databases were both statistically and ultrasonically analyzed to determine their validity and consistency, leading to the selection of the most appropriate data sets. In particular, ultrasonic models were employed to assist in the understanding of the underlying physics, and statistical methods were used to assess consistency across different data sets. We will present recent new results of this study, including the analyses of the databases, and the ultrasonic model predictions and their comparisons with actual measurements.---This material is based upon work supported by the Federal Aviation Administration under Contract #DTFA03-98-D-00008, Delivery Order #029 and performed at Iowa State University's Center for NDE as part of the Engine Titanium Consortium program through the Airworthiness Assurance Center of Excellence.

A Knowledge Based Expert System to Aid Theoretical Ultrasonic Flaw Modelling

---**Robert J. Robinson** and Alistair McNab, Centre for Ultrasonic Engineering, University of Strathclyde, 204 George Street, Glasgow, Scotland, G1 1XW, United Kingdom

---This paper describes the culmination of three years work at the University of Strathclyde in developing an Expert System to aid theoretical flaw modelling. The Expert System utilizes four validated models to simulate flaw modelling scenarios. Under certain conditions the models may break down and produce flaw responses which cannot be considered accurate. Previously a suitably qualified NDT engineer would have to interpret these results and update the original flaw model simulation in order to produce valid results. This was a laborious process and was restricted to those persons who had an in-depth knowledge in the operation of the validated models. The Expert System is capable of interpreting these warning flags and updating the original simulation to produce a valid modelling scenario. This paper gives a brief outline of how the Expert System operates before comparing the response of the Expert System to that of a suitable qualified NDT engineer for a number of worst case defect scenarios. Results are also presented on the performance of the Expert System compared with original methods of executing the validated models. The Expert System is a tool to aid inspection qualification and its benefits are discussed.

SESSION 33

BENCHMARK COMPARISONS

L. W. Schmerr, Jr., Chairperson
Parker Ballroom B

8:30 AM **Results of 2004 UT Modeling Benchmark Obtained with CIVA at CEA: Beam Modeling and Flaws Signal Prediction**
---S. Mahaut, S. Chatillon, **R. Raillon**, and M. Darmon, CEA/LIST, CEA Saclay, 91191 Gif-sur-Yvette, France

8:50 AM **Prediction of Ultrasonic Flaw Signals and Model-to-Experiment Comparison**
---**M. Spies**, Physical Basics Department, Fraunhofer Institute for Nondestructive Testing, IZFP, University of Saarland, Building 37, 66123, Saarbruecken, Germany

9:10 AM **Numerical Modeling Results Obtained with EFIT: 2004 Ultrasonic Benchmark**
---**R. Marklein** and K. J. Langenberg, University of Kassel, Department of Electrical Engineering and Computer Science, Electromagnetic Theory, D-34109 Kassel, Germany

9:30 AM **Ultrasonic Benchmarking with UTDefect**
---**A. Bostrom**, Department of Applied Mechanics, Chalmers University of Technology, Goteborg, Sweden

9:50 AM **Patch Element Model for the Evaluation of Displacement Fields Within an Elastic Solid from a Non-Contact Immersion Transducer: Application to the 2004 Ultrasonic Benchmark Problem**
---**C. V. Krishnamurthy**, M. Shankar, and K. Balasubramaniam, Centre for NonDestructive Evaluation, Department of Mechanical Engineering, Indian Institute of Technology, Chennai, India

10:10 AM ***Coffee Break***

10:30 AM **Model Predictions to the 2004 Ultrasonic Benchmark Problems**
---**S.-J. Song** and J.-S. Park, Sungkyunkwan University, School of Mechanical Engineering, 300 Chonchon-dong, Jangan –gu, Suwon, Kyounggi-do, 440-746, Korea; Y.-H. Choi, S.-C. Kang, and K.-J. Kim, Korea Institute of Nuclear Safety, Daejeon, Korea

10:50 AM **Simulating the Ultrasonic Experiments of the 2004 Ultrasonic Benchmark Problem**
---**L. W. Schmerr, Jr.**[1,2], H.-J. Kim[1], and A. Lopez-Sanchez[1,2], [1]Center for NDE and the [2]Department of Aerospace Engineering, Iowa State University, Ames, IA 50011

11:10 AM **Simplified Numerical Analysis of ECT Probe (Eddy Current Benchmark Problem 3)**
---R. Sikora, S. Gratkowski, **T. Chady**, and K. Stawicki, Faculty of Electrical Engineering, Technical University of Szczecin, Poland

11:30 AM **Modeling of the World Federation's Second MFL Benchmark Problem Using the Element-Free Galerkin Method**
---**Z. Zeng**, B. Shanker, S. Udpa, and L. Udpa, Department of Electrical and Computer Engineering, Michigan State University, 2120 Engineering Building, East Lansing, MI 48824

11:50 AM **2D-Numerical Simulation Results of Magnetic Flux Leakage Benchmark Problem 1**
---M. Ruch, ENDE Comisión Nacional de Energia Atómica, Argentina; J. P. A. Bastos, GRUCAD, Universidad de Santa Catarina, Brazil (Presenter: **M. I. López Pumarega**)

12:10 PM ***Adjourn***

Results of 2004 UT Modeling Benchmark Obtained with CIVA at CEA: Beam Modeling and Flaws Signal Prediction

---S. Mahaut, S. Chatillon, **R. Raillon**, and M. Darmon, CEA/LIST, CEA Saclay, 91191 Gif-sur-Yvette, France

---The CIVA software developed at the French Atomic Energy Commission (CEA) for processing and simulating NDT data (ultrasonics, eddy-current) includes tools for simulating the whole inspection of a component (possibly made of anisotropic heterogeneous materials and of complex geometry CAD defined) in which virtual defects (calibration reflectors or complex shaped flaws) are positioned. Simulated images are directly comparable with measured ones, as same imaging tools are used for both. The field radiated into the component and generated by refraction by an arbitrary transducer (standard, phased-array) from a coupling medium (immersion, contact) is computed using a model of elastodynamic pencils and accounts for transducer diffraction effects under the approximations of Rayleigh integral formulation. Various scattering theories can be used to compute the beam / defect interaction. In this paper, Kirchhoff's approximation was applied. Reciprocity principle allows to predict the reception by the transducer of waves scattered by the defect. Results given and discussed are those obtained for the various problems of the 2004 UT benchmark modeling session. These results concern spherical pores, side-drilled holes and flat-bottomed holes, insonified by normal or oblique incidence compressional and shear waves probes. Radiated beams and flaws signals for those configurations are discussed.

Prediction of Ultrasonic Flaw Signals and Model-to-Experiment Comparison

---**Martin Spies**, Physical Basics Department, Fraunhofer Institute for Nondestructive Testing, IZFP, University of Saarland, Building 37, 66123, Saarbruecken, Germany

---The reliable simulation of experimental results requires the validation of respective physical models. In this respect, the process of comparing model-based simulations has been started recently, where benchmark experiments have been addressed to allow for a comparison of the various models available. As a next phase of these benchmarking activities, the Center for NDE, Iowa State University, has conducted a series of experimental studies to allow a more direct validation of ultrasonic models in some simple testing situations. The experiments involve immersion pulse-echo setups where the reflector (flatbottom hole, side-drilled hole, or spherical pore) is interrogated with normally incident longitudinal waves as well as transverse and longitudinal waves of oblique incidence, generated by circular focused and unfocused transducers, respectively, of 5 MHz center frequency. In this contribution, simulation results obtained using a point source superposition technique are reported. The A-scan responses of the cases of primary interest have been modeled and relative comparisons with the measured A-scan signals have been performed. The (amplitude) spectrum of the measured reference signal is considered to characterize the reference waveform. To predict the electric voltage signal generated in the transducer, Auld's reciprocity formula is used, while the scattering process at the defect is modeled using Kirchhoff's theory. The calculations are performed in frequency domain with subsequent inverse Fourier transform into the time domain.

Numerical Modeling Results Obtained with EFIT: 2004 Ultrasonic Benchmark

---**Rene Marklein** and Karl J. Langenberg, University of Kassel, Department of Electrical Engineering and Computer Science, Electromagnetic Theory, D-34109 Kassel, Germany

---This paper presents the numerical modeling results related to the 2004 Ultrasonic Benchmark. The presented results are obtained with the Elastodynamic Finite Integration Technique (EFIT). The 2004 Ultrasonic Benchmark comprises several classical ultrasonic NDT situations: side-drilled hole (SDH) specimens, a flat-bottom hole (FBH) specimen, and a spherical pore specimen. We have simulated all benchmark problems with the EFIT code. Results are presented and compared to the experimental data provided by the Center for NDE, Iowa State University, USA.

Ultrasonic Benchmarking with UTDefect

---**Anders Bostrom**, Department of Applied Mechanics, Chalmers University of Technology, Goteborg, Sweden

---The computer code UTDefect has been developed for a decade and models the ultrasonic testing of a thick-walled component with a single defect of simple shape. The list of defects includes some cracks and simple volumetric defects like spheres and side-drilled holes. The probes are of contact type but recently also immersion scanning is possible. To solve the wave propagation and scattering problems Fourier representations and singular integral equation techniques are employed. In many cases far field approximations are performed but the methods are otherwise essentially 'exact'. In the present contribution some initial work with the benchmarking problems will be reported. This will only concern unfocussed probes and without the front-echo calibration. Result for unangled probes and side-drilled holes and spherical pores are presented. Possibly, also angled probes will be considered.

Patch Element Model for the Evaluation of Displacement Fields Within an Elastic Solid from a Non-Contact Immersion Transducer: Application to the 2004 Ultrasonic Benchmark Problem

---**C. V. Krishnamurthy**, M. Shankar, and Krishnan Balasubramaniam, Centre for NonDestructive Evaluation, Department of Mechanical Engineering, Indian Institute of Technology, Chennai, India

---The ultrasonic benchmark problem requires models to predict, given a reference pulse waveform, the pulse echo response of cylindrical voids of various radii located in an elastic solid for various incidence angles of a transducer immersed in water. Modeling the response of the flaw depends on, among other things, the ability to evaluate the field that propagates across the fluid-solid interface to the region of the flaw within the elastic solid at various incident angles of the transducer (including the critical angles). We present a conceptually simple yet reliable numerical technique to determine these internal fields in any region of interest within the elastic solid for the specified angles made by the transducer in water. The technique, equivalent to evaluating the Rayleigh-Sommerfeld integral but through a computationally less demanding procedure, regards the transducer as made of elemental rectangular/square patches and uses the well-known expression for the radiation pattern of an elemental patch to obtain the total transducer radiation field. A ray-based method is adopted to propagate the elementary radiation field across a fluid-solid interface. The advantages presented by this method of computing pressure/ displacement fields across any plane of interest are discussed in the context of non-destructive evaluation. The benchmark problem is next addressed using two methods. In the first method, the pulse echo response is predicted using the exact solution based on the separation of variables for a plane S-wave incident on flaws of various radii and compared with the response obtained earlier by us for a plane P-wave. In the second method, we estimate the pulse echo responses by characterizing the scattering from the flaw using the Kirchoff approximation with the internal fields computed by the patch element model.

Model Predictions to the 2004 Ultrasonic Benchmark Problems

---**Sung-Jin Song** and Joon-Soo Park, Sungkyunkwan University, School of Mechanical Engineering, 300 Chonchon-dong, Jangan-gu, Suwon, Kyounggi-do, 440-746, Korea; Young-Hwan Choi, Suk-Chull Kang, and Kyung-Jo Kim, Korea Institute of Nuclear Safety, Daejeon, Korea

---Solving the ultrasonic benchmark problems addressed by World Federation of NDE Centers (WFNDEC) in 2004 involves two subsidiary models: the beam model and the scatterer model. To predict the beam fields produced by ultrasonic transducers, we will adopt two beam models (the multi-Gaussian beam model (MGB) and the generalized Rayleigh-Sommerfeld integral (GRSI)) and compare their predictions to specific problems. To predict the scattering fields generated from three types of flaws (side-drilled holes, flat-bottom holes, and spherical voids), we will rely on the Kirchhoff approximation. Two subsidiary model predictions are combined together with the system efficiency factors obtained from the given reference signals for the prediction of theoretical waveforms corresponding to the experiments conducted by CNDE. This paper will summarize the results obtained by Sungkyunkwan University, Suwon, Korea.

Simulating the Ultrasonic Experiments of the 2004 Ultrasonic Benchmark Problem

---**Lester W. Schmerr Jr**.[1,2], Hak-Joon Kim[1], and Ana Lopez-Sanchez[1,2], [1]Center for NDE and the [2]Dept. of Aerospace Engineering, Iowa State University, Ames, IA 50011

---A set of reference experiments using side-drilled holes, flat-bottom holes, and spherical pores forms the basis for the 2004 ultrasonic benchmark study. We will model the measured A-scan responses of these reference experiments using a combination of beam and flaw scattering models coupled to an overall ultrasonic measurement model. The beam models will be a multi-Gaussian model and a generalized Rayleigh-Sommerfeld integral model. The flaw scattering models will be based on either the Kirchhoff approximation or the method of separation of variables. Measurement models appropriate for 3-D reflectors, like the flat-bottom hole and spherical pore, or 2-D reflectors like the side-drilled hole will also be used. We will compare the capabilities of these various models for predicting the measured responses and the underlying incident and scattered wave fields.---This work was supported by the NSF Industry/University Cooperative Research Center at Iowa State University.

Simplified Numerical Analysis of ECT Probe (Eddy Current Benchmark Problem 3)

---R. Sikora, S. Gratkowski, **T. Chady**, and K. Stawicki, Faculty of Electrical Engineering, Technical University of Szczecin, Szczecin, Poland

---The objective of “Eddy Current Benchmark Problem 3” is optimization of eddy current probe (coil) designed for Inconel tube inspection. The optimal design of the probe should provide the highest possible sensitivity to shallow outer flaws. It can be achieved by maximization of the ratio of the coil impedance in case of the tube with flaw to the impedance of the coil over an unflawed area. In order to solve the problem a mathematical model was proposed and analyzed using finite element method. During optimization process a coil cross-section (number of turns) and a minimal value of lift-off were assumed as constant. Approximation function of the frequency characteristic of the sensor was developed and used in order to reduce number of required calculations. It results in significant speed up of the optimization process. An optimal testing frequency and size of the probe were achieved as a result of the calculation. Intermediate results of the analysis, final solution and conclusions will be given in the full version of the paper.

Modeling of the World Federation's Second MFL Benchmark Problem Using the Element-Free Galerkin Method

---**Zhiwei Zeng**, Balasubramaniam Shanker, Satish Udpa, and Lalita Udpa, Department of Electrical and Computer Engineering, Michigan State University, 2120 Engineering Building, East Lansing, MI 48824

---Finite element (FE) simulation results of the second magnetic flux leakage benchmark problem proposed by the World Federation of NDE Centers have been reported. The geometry of the benchmark problem consists of notches machined on the internal and external surfaces of a rotating steel pipe placed between two yokes that are part of a magnetic circuit energized by an electromagnet. The nonlinear material property of the ferromagnetic pipe must also be taken into account. The objective of the problem is to calculate the radial component of the leaked field at specific positions. This paper presents modeling of the above benchmark problem obtained by using the element-free Galerkin (EFG) method. The EFG method has great advantage over the conventional FE methods in simulating this problem. Since the notches are very small and the pipe is rotating, the FE methods require very dense meshes. This problem is eliminated in EFG method where the domain discretization is done via nodes alone. Consequently, relatively fewer nodes are required to model notches and tight cracks.

2D-Numerical Simulation Results of Magnetic Flux Leakage Benchmark Problem 1

---Marta Ruch* and Joao P.A. Bastos[+], [*]ENDE Comisión Nacional de Energía Atómica – Argentina, [+]GRUCAD- Universidad de Santa Catarina – Brazil (Presenter: **M. I. López Pumarega**)

---Three typical nondestructive benchmark problems were proposed by the World Federation of Nondestructive Evaluation Centers to compare the numerical techniques used by different Federation Members, and validate them against experimental measurements. At QNDE 2001 results were presented by 2 Centers for the MFL Benchmark Problem 1, which is 3D, magnetostatic and nonlinear [1], namely the numerical simulation of the MFL fields produced by a tube with a circumferential slot and three notches in the axial direction. This problem was to be solved by different laboratories using numerical methods. Because many points were still to be elucidated, other groups were invited to take part in the research as from September 2002, invitation which was readily accepted by the NDE group at CNEA. However, the problem being 3D, and the group having only the 2D version of EFCAD, the proposal was unfortunately left aside, until the problem was recently discussed with Dr. Pignotti, who suggested a 2D analysis of the problem would be interesting too. Because the actual defects are flat bottom notches 10 mm long in the axial direction, the distribution of magnetic induction B on a cross-section of the tube containing the defect should be a valid representation of the 3D problem at mid-length of each notch. Results obtained with a new 2D-version of EFCAD with a regular mesh generator. These results compare well with those from the 3D simulations of the ISU and PUC groups presented at a previous condçference.

SESSION 34
LASER ULTRASONICS
M. Dubois, Chairperson
Parker Ballroom A

8:30 AM **Laser Based Ultrasonic Technique for All-Optical Determination of Photo-Elastic Constants**
---**R. J. Filkins**[1], G. J. Saulnier[2], and P. K. Das[3], [1]GE Global Research, Niskayuna, NY; [2]Rensselaer Polytechnic Institute, Troy, NY; [3]University of California, San Diego, CA

8:50 AM **Analysis of Laser-Ultrasonic Dispersive SAW Waveforms for Thin-Film Inspection**
---**C. M. Flannery**, Engineering Division, Colorado School of Mines, Golden, CO 80305; D. C. Hurley, Materials Reliability Division, National Institute of Standards and Technology, Boulder, CO 80305

9:10 AM **Laser Ultrasonic Inspection of Subsurface Defects in Flip-Chips**
---**T. L. Steen** and T. W. Murray, Boston University, Department of Aerospace and Mechanical Engineering, 110 Cummington St., Boston, MA 02215; M. B. Klein, Lasson Technologies, Inc., Culver City, CA

9:30 AM **Broadband Attenuation Measurement for an Absorbing Plate**
---**K. Luangvilai** and L. J. Jacobs, School of Civil and Environmental Engineering, Georgia Institute of Technology, Atlanta, GA 30332-0355; P. D. Wilcox, University of Bristol, Department of Mechanical Engineering, Bristol, BS8 1TR, United Kingdom; M. J. S. Lowe, Imperial College, Department of Mechanical Engineering, London, SW7 2AZ, United Kingdom; J. Qu, School of Mechanical Engineering, Georgia Institute of Technology, Atlanta, GA 30332-0405

9:50 AM **Improved Laser Technology for Industrial Laser Ultrasonics**
---**T. Drake**, M. Osterkamp, K. Yawn, and T. Do, Lockheed Martin, Laser Ultrasonic Technology Center, Fort Worth, TX 76101

10:10 AM ***Coffee Break***

10:30 AM **Laser-Ultrasonic Inspection of Mg/Al Castings**
---**A. Blouin**, D. Lévesque, and J.-P. Monchalin, Industrial Materials Institute, National Research Council of Canada, 75 de Mortagne Blvd., Boucherville, Quebec, J4B 6Y4, Canada

10:50 AM **Simple Laser-Ultrasonic System Using a Single-Frequency Pulsed Laser Oscillator**
---**A. Blouin**, L. Carrion, C. Padioleau, P. Bouchard, and J.-P. Monchalin, Industrial Materials Institute, National Research Council of Canada, 75 de Mortagne Blvd., Boucherville, Quebec, J4B 6Y4, Canada

11:10 AM **Progress Towards a Portable Laser-Based Ultrasound Sensor Using Gas-Coupled Laser Acoustic Detection**
---**J. N. Caron**, D. M. Huber, and C. J. Rollins, Research Support Instruments, Lanham, MD 20706

11:30 AM **Laser Acoustic Imaging of Film Bulk Acoustic Resonator (FBAR) Lateral Mode Dispersion**
---**K. L. Telschow**, Physics Department, Idaho National Engineering and Environmental Laboratory, Idaho Falls, ID 83415-2209

11:50 AM **An Innovative Interferometer for Industrial Laser Ultrasonic Inspection**
---**B. Pouet**, S. Breugnot, and P. Clemenceau, Bossa Nova Technologies, 1234 Cabrillo Avenue, Venice, CA 90291

12:10 PM ***Adjourn***

Laser Based Ultrasonic Technique for All-Optical Determination of Photo-Elastic Constants

---**Robert J. Filkins**[1], Gary J. Saulnier[2], and Pankaj K. Das[3], [1]GE Global Research, Niskayuna, NY; [2]Rensselaer Polytechnic Institute, Troy, NY; [3]University of California, San Diego, CA

---We report on an all-optical technique for determination of the photo-elastic properties of optical materials. The technique is a two-laser approach; requiring a high power laser to generate ultrasound, and second low power laser to probe bulk ultrasonic waves. The wavelength and pulse width of the generation laser are shown to have a large effect on the ultrasonic bandwidth and strength of the diffraction. The probe signal is the direct result of a bulk acousto-optic interaction. Detection of the acousto-optic interaction, and characterization of the strength of the interaction is reviewed. Ultimately, the diffraction efficiency of the probe beam is directly proportional to the photo-elastic constants of the materials under investigation. The photo-elastic constants are then determined for unknown materials by analysis of the ultrasonic signals collected from a stack comprised of an unknown sample and a reference sample.

Analysis of Laser-Ultrasonic Dispersive SAW Waveforms for Thin-Film Inspection

---**Colm M. Flannery,** Engineering Division, Colorado School of Mines, Golden, CO 80305; Donna C. Hurley, Materials Reliability Division, National Institute of Standards and Technology, Boulder, CO 80305

---In laser-ultrasonics, signal-to-noise ratio is often the greatest hindrance to good-quality data. Analysis of wideband dispersive waveforms is something of a black art, with few publications explicitly discussing waveform analysis. Here we present our in-house-developed algorithms for analysis of dispersive surface acoustic waves (SAWs) on thin-film/substrate systems. For dispersive waveforms the high-frequency components contain the most information but are often hidden in noise - limiting the quality and bandwidth of extracted frequency-dependent velocity dispersion curves. An efficient processing algorithm is crucial to extract the best quality dispersion curve from noisy waveforms in a repeatable fashion, and to extend this dispersion curve to the maximum bandwidth possible. We discuss how to overcome the 2PI phase jump problem and show how the use of phase tracking and analysis of multiple waveforms can extend the dispersion curve by up to 30 % in frequency - allowing more accurate elastic constant measurement. Measured and simulated results for both the loading and stiffening cases are discussed, and sensitivity of results to noise and choice of spectral window is examined. The method is quite robust and can easily be applied to other dispersive signals, such as bulk acoustic waves.

Laser Ultrasonic Inspection of Subsurface Defects in Flip-Chips

---**Thomas L. Steen** and Todd W. Murray, Boston University, Department of Aerospace and Mechanical Engineering, 110 Cummington St., Boston, MA 02215; Marvin B. Klein, Lasson Technologies, Inc., Culver City, CA

---Flip-chips play an important role in electronic packaging; allowing for increased packaging density while maintaining or improving the reliability of the circuits. In a flip-chip, the silicon die is placed upside down on the circuit board and the input/output connections are made through solder balls on the underside of the die. Epoxy underfill is typically required to enhance bonding of the flip-chip to the substrate as well as to protect the solder-bumps from thermal cycling and mechanical vibrations. We report on the use of laser based ultrasonic microscopy for the non-contact and nondestructive inspection of flip-chips. A pulsed laser source is used for ultrasonic wave generation at the chip surface, and the return echoes from the chip/substrate interface are measured using a Michelson interferometer. A 2D scanning system has been implemented to perform raster scans over flip-chips, and images are produced allowing for the detection and sizing of subsurface inhomogeneities such as voids in the epoxy underfill. Our results indicate that laser based ultrasonic microscopy provides an attractive alternative to convention immersion scanning acoustic microscopy for the inspection of electronic packaging.

Broadband Attenuation Measurement for an Absorbing Plate

---**Kritsakorn Luangvilai** and Laurence J. Jacobs, School of Civil and Environmental Engineering, Georgia Institute of Technology, Atlanta, GA 30332-0355; Paul D. Wilcox, University of Bristol, Department of Mechanical Engineering, Bristol, BS8 1TR, United Kingdom; Michael J. S. Lowe, Imperial College, Department of Mechanical Engineering, London, SW7 2AZ, United Kingdom; Jianmin Qu, School of Mechanical Engineering, Georgia Institute of Technology, Atlanta, GA 30332-0405

---This research demonstrates the effectiveness of combining laser ultrasonic and appropriate time-frequency signal analysis techniques for attenuation measurement of leaky Lamb waves. Laser ultrasonic techniques provide a non-contact, high-fidelity system of generating and detecting Lamb waves, which is critical for an amplitude measurement. Time-frequency signal analysis techniques are used to study dispersive behavior of Lamb waves and interpret broadband, transient signals. With a series of narrowband, bandpass filtering of time-domain signals from two positions, attenuation for each mode at specific frequencies can be calculated. This combined technique is tested with an aluminum plate with water half-space on one side. The experimental results show that the proposed technique captures changes in multi-mode attenuation over a broad frequency range, and is in good agreement with the results predicted by an analytical model. These results are then used to investigate a three-layered system capable of modeling concrete repaired with a thin composite patch.

Improved Laser Technology for Industrial Laser Ultrasonics

---**Thomas Drake**, Mark Osterkamp, Kenneth Yawn, and Tho Do, Lockheed Martin, Laser Ultrasonic Technology Center, Fort Worth, TX 76101

---LaserUT® has been used for testing complex composite materials for advanced fighter aircraft since June, 2000. During this time, nearly 5000 production parts have been evaluated which has provided important data regarding system reliability and operational cost. This paper will review the basics of the LaserUT technology, describe the three systems installed in Fort Worth, and present new approaches for lowering operational costs and improving system reliability. Historically, the most expensive consumable of the LaserUT system has been the large arrays of laser diodes used to pump the detection laser. A program was initiated in 2002 to improve reliability, lower cost, and extend service intervals of the detection laser. Data will be presented describing our fourth-generation solid-state detection laser. Reliability data was collected for individual diode sub-arrays to establish upper limits on diode lifetime in ideal operation conditions. This study showed infant mortality failure statistics, gradual power degradation, and catastrophic failures related to drive current. This information was used to construct a new laser system using diode life as a design variable. Lifetime testing of the entire laser system was conducted simulating years of operation. This new laser has demonstrated a service interval in excess of 10 billion shots, which represents roughly 400,000 square feet of inspected material.

Laser-Ultrasonic Inspection of Mg/Al Castings

---**Alain Blouin**, Daniel Lévesque and Jean-Pierre Monchalin, Industrial Materials Institute, National Research Council of Canada, 75 de Mortagne Blvd., Boucherville, Quebec, J4B 6Y4, Canada

---In the search for a lighter automotive engine, a Magnesium/Aluminum composite design has been proposed for the single heaviest component, i.e. the cylinder crankcase. The manufacturing method consists to make the cylinder barrels, the main bearings and the water jacket from a hypereutectic aluminum alloy and to subsequently cast magnesium around it in a die-casting process. A nondestructive technique is required to assess the metallurgical bond between both materials in the part. This paper presents experiments, signal processing and results of the use of laser-ultrasonics, which is based on the generation and detection of ultrasound, for detecting defects without contact at the Mg/Al interface of cast parts. In many situations, the large acoustic impedance mismatch and the inverted echo polarity have been successfully used as signatures of voids. However, for Mg/Al interface not parallel to the Mg surface of inspection, ultrasonic waves are obliquely reflected from the interface and may not be properly detected. The Fourier domain Synthetic Aperture Focusing Technique (F-SAFT) is used to overcome this problem. F-SAFT scanning and processing then allow reconstruction and imaging of curved Mg/Al interfaces. Results obtained in both situations will be presented.

Simple Laser-Ultrasonic System Using a Single-Frequency Pulsed Laser Oscillator

---**Alain Blouin**, Lionel Carrion, Christian Padioleau, Paul Bouchard, and Jean-Pierre Monchalin, Industrial Materials Institute, National Research Council of Canada, 75 de Mortagne Blvd., Boucherville, Quebec, J4B 6Y4, Canada

---We present a new pulsed laser oscillator and system for the optical detection of ultrasound in materials. A single-frequency laser oscillator based on a pulse pumped Nd:YAG rod inside a ring cavity is proposed. The laser delivers single-frequency pulses of 35 W power. Power of about 1 kW can be obtained when the second rod of a dual-rod pumping chamber is used as an amplifier. Performance of the system is then investigated with a GaAs photorefractive crystal-based two-wave mixing phase demodulator. In particular, the intensity noise of the laser can be made small enough to allow the detection limit to be set by the shot-noise of the laser. The coherence length of the laser is about 20 m, which makes it a versatile laser-ultrasonic inspection system operated with a two-wave mixing based phase demodulator. A complete compact and affordable system is obtained when the second rod of the pumping chamber is used as a generation laser of ultrasound. Tests of this laser-ultrasonic system on metallic samples are presented. In that case the second rod of the pumping chamber is used as an ultrasound generation laser.

Progress Towards a Portable Laser-Based Ultrasound Sensor Using Gas-Coupled Laser Acoustic Detection

---**James N. Caron**, David M. Huber, and Chris J. Rollins, Research Support Instruments, Lanham, MD 20706

---Gas-coupled Laser Acoustic Detection (GCLAD) has proven to be a viable alternative to interferometric detection of ultrasound for noncontact inspection of materials. Unlike other laser-based detection techniques, GCLAD operates independently of the optical properties of the sample surface. Instead, the probe laser intercepts the ultrasound wave after it has been transmitted to air. It is effective on any surface, particularly those with poor or varying surface reflectivity or optical smoothness. In this effort, the concept is being researched as part of an efficient, ultrasound sensor, with hangar-to-hangar portability, for interrogating flight-critical aircraft structural supports. Two concepts are being considered. The first is a robotic scanning deck system that would deliver laser light via optical mirrors or fiber optics to the detection point. This system would enable scanning of moderate-sized areas that are somewhat flat, for example airplane wings. Scanning of more complex parts can be handled through next-generation modifications. The second system is a hand-held scanning device that can perform spot checks anywhere on the airplane surface. In this case, fiber optics deliver the laser light to the scanning head through an umbilical cord from the electronics housing.

Laser Acoustic Imaging of Film Bulk Acoustic Resonator (FBAR) Lateral Mode Dispersion

---**Ken L. Telschow**, Physics Department, Idaho National Engineering and Environmental Laboratory, Idaho Falls, ID 83415-2209

---A laser acoustic imaging microscope has been developed that measures acoustic motion with high spatial resolution without scanning. Images are recorded at normal video frame rates and heterodyne principles are used to allow operation at any frequency from Hz to GHz. Fourier transformation of the acoustic amplitude and phase displacement images provides a direct quantitative determination of excited mode wavenumbers at any frequency. Results are presented at frequencies near the first longitudinal thickness mode (~ 900 MHz) demonstrating simultaneous excitation of lateral modes with nonzero wavenumbers in an electrically driven AlN thin film acoustic resonator. Images combined at several frequencies form a direct visualization of lateral mode dispersion relations for the device under test allowing mode identification and a direct measure of specific lateral mode properties. Discussion and analysis of the results are presented in comparison with plate wave modeling of these devices taking account for material anisotropy and multilayer films.

An Innovative Interferometer for Industrial Laser Ultrasonic Inspection

---**B. Pouet**, S. Breugnot, and P. Clemenceau, Bossa Nova Technologies, 1234 Cabrillo Avenue, Venice, CA 90291

---Laser Ultrasonics is one the most promising technology for industrial online inspection and process control. Because it is non-contact and presents high optical bandwidth detection, Laser Ultrasonics has the potential to be integrated in factory without disturbing the production process, and can be used for accurate, on the fly inspection, in situations where access is difficult.
However, Laser Ultrasonics main drawback remains in its inability to sustain the harsh conditions of industrial environments where objects under inspection are subject to various motions and their surfaces are unfriendly to optical waves. As a result, today, high-cost solutions are often used or sought to overcome those reliability issues. In fact, the current state of the art of Laser Ultrasonics is limited to very few industrial applications where higher cost is justified. In this article, we will present a new interferometer scheme that will greatly improve performances of Laser Ultrasonic systems. Its architecture combines a classical interferometric design with an innovative multi-speckle processing technique. Our interferometer is compact and exhibits a large depth of field and a high sensitivity on rough surfaces without requiring any optical path stabilization. We will demonstrate that it opens new low-cost possibilities to Laser Ultrasonics for industrial applications.

SESSION 35

X-RAY DEVELOPMENTS AND APPLICATIONS

K. Lipetsky, Chairperson
Parker Ballroom C

8:30 AM **A Review of the Radiography Simulation Efforts**
---**F. Inanc**, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

8:50 AM **Application of NDE Simulation to Estimate Probability of Detection**
---**J. Gray**, I. Zhang, and I. Gray, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

9:10 AM **X-Ray Bremsstrahlung Spectrum: Modeling and Experiment**
---**S. Wendt** and J. Gray, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

9:30 AM **3D Reconstruction from Narrow-Angle Radiographs**
---**L. Fournier**, L. Chatellier, B. Charbonnier, and B. Chassignole, Electricite de France, Research and Development Division, 6 Quai Watier, BP 49, 78401 Chatou, France

9:50 AM **Simulation of Phase Contrast Imaging for Mesoscale NDE**
---**M. Aufderheide**, A. Barty, and H. Martz, Lawrence Livermore National Laboratory, L-096, P. O. Box 808, Livermore, CA 94551

10:10 AM ***Coffee Break***

10:30 AM **Estimation of the Thickness of Overlapping Materials by Using Neural Networks**
---N. Reen, **I. N. Tansel**, P. Chen, and X. Wang, Florida International University, Mechanical Engineering Department, Center for Engineering and Applied Science, 10555 West Flager Street, (EAS-3473), Miami, FL 33174; F. Inanc, Iowa State University, Center for NDE, Ames, IA 50011; C. Kropas-Hughes, AFRL/MLLP, Wright Patterson AFB, OH 45433

10:50 AM **Quantitative Corrosion Inspection in Pipelines by Radiography**
---K. Edalati, **N. Rastkhah**, A. Kermani, and M. Seiedi, Department of NDT, Protection and Safety Technology Center, Atomic Energy Organization of Iran, Tehran, Iran

11:10 AM **An Algorithm for Decomposition of the Charged Particle Scattering Cross Sections into Singular and Regular Components**
---**F. Inanc**, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

11:30 AM **Development of a High-Resolution CT System and 3D Data Visualization Tool**
---**J. Zhang**, C. Zhou, T. Jensen, and J. Gray, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

12:10 PM ***Lunch***

A Review of the Radiography Simulation Efforts

---**Feyzi Inanc**, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---In the last two decades, radiography simulation efforts reached significant levels and many simulation codes and software tools were developed to simulate the radiography process. Since radiography is a widely used imaging technology both in the industrial and medical fields, it attracted a lot of attention and researchers in a wide geographical area contributed to the activities in this field. As a result, there has been significant progress in that area and some activities reached levels where the resulting codes have been introduced into commercial arena for routine implementation of radiography simulations. Therefore, it is a good time to stop and evaluate the progress and state of the simulation codes. This presentation will provide a tally of the radiography simulation efforts and then provide further information on the technical approaches adopted by individual simulation projects.---This work has been funded by the contract IPRT-CATD-03-27.

Application of NDE Simulation to Estimate Probability of Detection

---**Joe Gray**, Jie Zhang, and Irving Gray, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---The use of NDE simulations to evaluate the effect parameters on the ability of an inspection to detect a defect is an emerging new capability. The use of these simulation tools as an adjunct to existing experimental data and especially in the planning stage of a POD study can result is efficient use of resources available for the POD study and can provide a significant extension of the parameters that can be evaluated in the study. We present an example of using an x-ray simulation tool, XRSIM, to plan and develop a POD study. A key element of this tool is a means to automatically determine a detectable indication in an x-ray image. We present two dimensional detectability criteria that perform very close to that of a human eye. Using this detectability criterion, we will demonstrate the use of an x-ray simulation package to plan a POD study. Parameters such as optimal kilovoltage, orientation of the part, flaw morphology and flaw composition will be examined.---This work was done at NDE Technologies.

X-Ray Bremsstrahlung Spectrum: Modeling and Experiment

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

---We present a model for the generation of x-ray tube sources that allows the computation of the x-ray bremsstrahlung spectra as a function of the tube kilovoltage, inherent filtration, selection of filters and target material. The model uses a relativistic electron beam interaction with the bound electrons of the target atoms. Published one photon bremsstrahlung production cross sections are used. The model uses the energy dependent electron penetration depth in the target, the angle between the target surface and the electron beam together with the tube vacuum window material and thickness to calculate the inherent filtration for the tube. External filters can be specified and used to alter the white x-ray spectrum. The current and tube voltage are can be selected. Measurement of the white x-ray bremsstrahlung spectra over commonly available tube voltages, up to 450KVp, is difficult due to the ease of saturation of the energy dispersive detectors. We will present spectra measured from typical high power x-ray tubes with the corrections needed to eliminate the detector artifacts. The measurements are done with a cooled germanium detector with standard MCA photon counting equipment. The detector efficiency, scatter from the detector shielding, detector loss due to Compton scattering will be discussed. Experimental results comparing the model predictions will be presented.---This work was supported by the NSF Industry/University Cooperative Research Program.

3D Reconstruction from Narrow-Angle Radiographs

---**Louis Fournier**, Laurence Chatellier, Bruno Charbonnier, and Bertrand Chassignole, Electricite de France, Research and Development Division, 6 Quai Watier, BP 49, 78401 Chatou, France

---In order to detect and to characterize some potential defects on cast components, a program of in-service inspections is carried out by non-destructive evaluation (NDE) techniques among which is x- or g radiography. The experts are faced with the delicate task of establishing a complete diagnostic including the precise positioning of defects. But the characterization of the defect by X-ray only can be very difficult. In such cases, signal processing techniques can be very helpful for the interpretation of the data and for the characterization of the defect. This paper presents a 3-D reconstruction processing technique in conditions representative of pipe inspections : the incidence angle is very narrow and thus the radiographs contain very little information along the vertical direction. The reconstruction process relies on the estimation of the attenuation, also called inversion because it restores the attenuation from both data and prior information. In this way, we obtain a 3-D representation of the defects. The method has been developed on the radiographs of a mock-up with real defects. The performance, evaluated on another mock-up with several electro-dynamically manufactured cylindrical defects, proves the usefulness of the 3-D reconstruction in sensitive situations in terms of radiograph interpretation.

Simulation of Phase Contrast Imaging for Mesoscale NDE

---**M. Aufderheide**, A. Barty, and H. Martz, Lawrence Livermore National Laboratory, L-096, P. O. Box 808, Livermore, CA 94551

---High energy density experiments, such as those planned at the National Ignition Facility (NIF), use mesoscale targets with the goals of studying high energy density physics, inertial confinement fusion, and the support of national security needs. Mesoscale targets are typically several millimeters in size and have complex micrometer-sized structures composed of high-density metals and low-density foams and ices. These targets are designed with exacting tolerances that are difficult to achieve at present. Deviation from these tolerances can result in compromise of experimental goals and thus it is necessary to determine as-built properties of these targets using NDE techniques. Phase contrast radiography and computed tomography are being used to investigate these targets, but the mix between phase and absorption information is difficult to separate, making interpretation of results difficult. We have recently improved the HADES radiographic simulation code to include phase in simulations, as an aid for doing NDE on mesoscale targets. In this paper we report on how we extended HADES to incorporate phase contrast, and compare simulations with a variety of experimental test results.---This work was performed under the auspices of the U.S. Department of Energy by University of California, Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.

Estimation of the Thickness of Overlapping Materials by Using Neural Networks

---N. Reen, **I. N. Tansel**, P. Chen, and X. Wang, Florida International University, Mechanical Engineering Department, Center for Engineering and Applied Science, 10555 West Flager Street, (EAS-3473), Miami, FL 33174; F. Inanc, Iowa State University, Center for NDE, Ames, IA 50011; C. Kropas-Hughes, AFRL/MLLP, Wright Patterson AFB, OH 45433

---Dual energy method has been developed and successfully used to estimate the thickness of two overlapping materials by using analytical expressions when the coefficients of the materials are available. Previously, neural networks were used for identification of single material and its thickness when two materials exist and they do not overlap. In this paper, performance of the neural networks is investigated when they overlap. X-ray images were prepared by x-ray radiography simulation program XRSIM using an inspection scenario eliminating scattered flux. To train the neural networks, X-ray images of two overlapping virtual step wedges were prepared. The aluminum wedge had 10 steps with 3 mm step heights. The brass wedge had the same number of steps with 0.5 mm step heights. Aluminum wedge has been positioned over brass wedge with a 90-degree rotation. XRSIM provided synthetic images for 200 kVp and 300 kVp tube voltage cases that used 4 mA and 2 mA respectively. The exposure time was 120 seconds for both cases. The simulation was repeated after aluminum and brass base with the half of the height of the steps of each wedge were located on the wedges to generate the test thicknesses. The average estimation error was less than 4% and 7% (respect to the range) on the training and test data respectively. Results showed that neural networks could be effectively used to estimate the thickness of overlapping parts after a brief training.---This work was performed at the Florida International University in cooperation with 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.

Quantitative Corrosion Inspection in Pipelines by Radiography

---K. Edalati, **N. Rastkhah**, A. Kermani, and M. Seiedi, Department of NDT, Protection and Safety Technology Center, Atomic Energy Organization of Iran, Tehran, Iran

---Corrosion, erosion, wear and deposit formation result in reduction pipes lifetime. Ultrasonic test (UT) is the common method for corrosion detection in pipe lines. Insulate should be removed for ultrasonic testing. Surface condition and corrosion type also affect the deviation of UT measurements. Thickness losed can be determined by radiography testing (RT). Two RT methods can be used for corrosion inspection in pipes: (a) Tangential Radiography Testing and (b) Double wall Radiography Testing. In double wall radiography method, the thickness lose of pipe is determinable via a densitometry of radiograph. In this method a larger area of pipe can be investigated in comparison with the other corrosion detection methods in an equal time. Defect types such as pitting, stress cracking and fatigue cracking also are detectable in this method and defective area can be quantified. Density of radiograph as well as accuracy of this method is depending on the geometry of pipe and location of investigated region in relation to the radiation axis. In this investigation the thickness profile of pipes, with 6-10 inch (150-300 mm) in diameter and 4.2-14.8 mm in thickness, was determined by using radiograph density measurements. It was concluded that thickness lose of 10, 20 and 50 percent and corrosion surface can be detected by this method in pipes. Also some Formulas were suggested for this method with high than 95% precision.

An Algorithm for Decomposition of the Charged Particle Scattering Cross Sections into Singular and Regular Components

---**Feyzi Inanc**, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---Any radiography simulation effort that involves high energy photons should also address charged particle transport problem as well. The scattering cross sections with the charged particles, namely electrons and positrons, go through elastic and inelastic scattering interactions that are highly anisotropic. The conventional Boltzmann operator used in the transport computations can not represent the highly anisotropic scattering interactions. One way is to implement Fokker-Planck operators. The implementation of Fokker-Planck operators requires decomposition of scattering kernels into singular and regular components. This presentation introduce an algorithm on how to decompose the elastic and inelastic scattering cross sections into singular and regular components and how to compute momentum transfer and stopping power coefficients from singular components. The introduction of these parameters and cross sections into the transport source computations is shown as well.

Development of a High-Resolution CT System and 3D Data Visualization Tool

---J. Zhang, C. Zhou, T. Jensen, and **J. Gray**, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---The need for material characterization covers broad areas including new materials development, failure analysis, biomedical applications and process development and characterization. Length scales of 0.1μ through 500μ are of key importance to if processes are to be understood and a measure of control on those processes achieved. Computed tomography (CT) imaging of objects is increasingly important in that it can provide 3D information nondestructively about the internal features of interest. We present results from a recently developed μCT system based on a 130 kVp microfocus tube, an amorphous Si array detector and a micro-stepped positioner. At present the highest resolutions available are voxel sizes of 2.5 microns with a field of view of 4 mm. The data volumes are several gigabytes and have 1400x1400x500voxels. Larger fields of view can be obtained at lower resolution. In generating these 3D data sets a number of issues need to be addressed including detector noise and artifacts, transfer of data from systems, efficient reconstruction of the large data sets, visualization of the data and finally, extraction of information from the data. Parallel processing for the CT reconstruction is implemented on a 64 node Linux cluster and provides reconstruction of a 3D volume in 12 minutes. A custom 3D visualization tool implements volume rendering on a PC and provides 3D viewing of the objects. Users have various functions such as histogram lookup table, mapping, region of interest clipping, normalization, and transparency to explore and interrogate the data. Examples from the CT scanning system will be presented. MicroCT, 3D visualization, reverse engineering, parallel processing.---This material is based upon work supported by the Federal Aviation Administration under Contract #DTFA03-98-D-00008, Delivery Order #IA004 and performed at Iowa State University's Center for NDE as part of the Center for Aviation Systems Reliability program.

SESSION 36

NEW INSTRUMENTS AND SYSTEMS

B. Larson, Chairperson
Parker Ballroom D/E

8:30 AM **Non-Contact Reading of Resistive Strain Gages**
---**W. F. Schmidt**, University of Arkansas, Mechanical Engineering Department, Fayetteville, AR 72701; O. H. Zinke, International Validators, Inc., 817 North Jackson, Fayetteville, AR 72701

8:50 AM **Adaptive Correction for Acoustic Imaging in Difficult Materials**
---S. D. Sharples, **I. J. Collison**, M. Clark, and M. G. Somekh, School of Electrical and Electronic Engineering, University of Nottingham, University Park, Nottingham, NG7 2RD, United Kingdom

9:10 AM **A Two-Wave Mixing Interferometer for Phase and Wavelength Demodulation of Fiber-Optic Ultrasound Sensors**
---**Y. Zhou**, Y. Qiao, and S. Krishnaswamy, Center for Quality Engineering and Failure Prevention, Northwestern University, Evanston, IL 60208-3020

9:30 AM **Elastodynamic Green's Functions for Laminated Piezoelectric Cylinders**
---**H. Bai**, Lakehead University, Mechanical Engineering, 955 Oliver Road, Thunder Bay, Ontario P7B 5E1, Canada; A. Shah, University of Manitoba, Civil Engineering, Manitoba, Canada, S. B. Dong, University of California, Civil and Environmental Engineering, Los Angeles, CA 90095-1593

9:50 AM **A Boroscope Based Optical Surface Characterization Approach**
---**F. Inanc**, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

10:10 AM ***Coffee Break***

10:30 AM **The Remotely Operated Nondestructive Examination System for Examining the Knuckle Region of Hanford's Double Shell Waste Tanks**
---**S. L. Crawford** and A. F. Pardini, Pacific Northwest National Laboratory, Richland, WA 99352

10:50 AM **Detection of Shape and Depth of Defects in Aluminum Structures Using SQUIDs**
---**R. Selim**, M. McFarlane, and J. Mast, Physics, Computer Science and Engineering Department, Christopher Newport University, Newport News, VA 23606; B. Wincheski, NASA Langley Research Center, Hampton, VA 23681; J. Simpson, Lockheed Martin Space Operation, Hampton, VA 23681

11:10 AM **Crack Inspection by EddyTherm**
---**G. Zenzinger**, J. Bamberg, and P. Nutz, MTU Aero Engines, 80995 Munich, Germany

11:30 AM **A Low Cost Comparative Pulsed Eddy Current Inspection System for Defect Detection**
---**N. Eua-anant**, Khon Kaen University, Department of Computer Engineering, Khon Kaen, 40002, Thailand

11:50 AM ***Adjourn***

Non-Contact Reading of Resistive Strain Gages

---**William F. Schmidt**, University of Arkansas, Mechanical Engineering Department, Fayetteville, AR 72701; Otto Henry Zinke, International Validators, Inc., 817 North Jackson, Fayetteville, AR 72701

---The output from resistive strain gages is read non-contact using a magnetic bridge to sense the gage change resulting from strain. This technique allows isolating the gages from ground in a bridge configuration. The readings are in AC, simplifying circuitry for measurement of very small values of strain. In situations where strain gages are used for modal analysis, the oscillating strain would be recorded as a modulation on a carrier. Comparisons of non-contact strain measurements with typical DC measurements are presented.

Adaptive Correction for Acoustic Imaging in Difficult Materials

---Steve D. Sharples, **Ian J. Collison**, Matthew Clark, and Mike G. Somekh, School of Electrical & Electronic Engineering, University of Nottingham, University Park, Nottingham, NG7 2RD, United Kingdom

---This paper describes the key technological developments in the design of an adaptive optical scanning acoustic microscope. Adaption is a key technological advance because it enables the microscope to correct for the deleterious effects of the material microstructure, and gain robust instrument performance on a wide range of samples. The two important requirements for the instrument are a multi-channel acoustic wavefront detector to measure the aberration in the acoustic wavefront, and a highly adaptive acoustic source to correct for the effects of aberration. As well as describing the novel aspects of the instrument that allow it to adapt, we present experimental images acquired with the instrument that indicate the degree of performance improvement (including image quality and probability of detection) that can be achieved when adaption is used to correct for material aberration.

A Two-Wave Mixing Interferometer for Phase and Wavelength Demodulation of Fiber-Optic Ultrasound Sensors

---**Yi Zhou**, Yi Qiao, and Sridhar Krishnaswamy, Center for Quality Engineering and Failure Prevention, Northwestern University, Evanston, IL 60208-3020

---A two-wave mixing (TWM) interferometer using InP:Fe in the C-band wavelength at 1550nm is demonstrated. The system can be used as a conventional phase-demodulator for laser ultrasonic applications. In addition, a wavelength demodulation configuration of the TWM interferometer will be presented for use with Fiber Bragg-Grating (FBG) ultrasound sensors. In this configuration, the FBG is illuminated with a broadband source, and any strain in the FBG is encoded as a wavelength change of the light reflected by the FBG. The reflected light from the FBG is spilt into two unbalanced paths and both beams (pump and signal) are mixed in the TWM system. A small wavelength change in the FBG reflected light can be thought of as an equivalent phase change between the pump and signal beams as they travel unbalanced path lengths. FBG demodulation using TWM enables selective monitoring of dynamic strains induced by ultrasound and acoustic emissions, even in the presence of large quasi-static strains that otherwise would cause the FBG sensor to drift. Since TWM interferometers can be readily multiplexed, the proposed technique can be used to demodulate signals from a network of FBG ultrasound (acoustic emission) sensors for use in structural health monitoring.

Elastodynamic Green's Functions for Laminated Piezoelectric Cylinders

---**Hao Baj**, Lakehead University, Mechanical Engineering, 955 Oliver Road, Thunder Bay, Ontario P7B 5E1, Canada; Arvind Shah, University of Manitoba, Civil Engineering, Manitoba, Canada; Stanley B. Dong, University of California, Civil and Environmental Engineering, Los Angeles, CA 90095-1593

---Elastodynamic Green's function for a piezoelectric structure represents the electro-mechanical response due to a steady state point source, which is either a unit force or a unit charge. Herein, Green's functions for a circular laminated piezoelectric cylinder is constructed by means of the superposition of modal data from the spectral decomposition of the operator of the equations governing its dynamic behavior. These governing equations are based on a semi-analytical finite element formulation where the discretization is through the cylinder's thickness. The cylinder's profile through its thickness consists of any number of perfectly bonded, concentric cylindrical layers, with each having its own distinct piezoelectric properties. Examples of a homogeneous PZT-4 cylinder and a two layer cylinder composed of a PZT-4 material at crystal orientations of with the longitudinal axis are presented. Numerical implementation details for these two circular cylinders show the convergence and accuracy of the Green's functions.

A Boroscope Based Optical Surface Characterization Approach

---**Feyzi Inanc**, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---Most of the tools used for surface characterization rely on optical reflection from the object surface and the quantitative evaluation of the surface is done by processing the reflection data. Although there are many approaches and commercial devices capable of surface characterization, they usually characterize surface under stationary conditions where the access to the sample surface is not an issue. In this presentation, we will present an approach under development for the quantitative characterization of surfaces that are not easily accessible. The approach is based on utilization of commercially available boroscope technology in conjunction with laser lights that are shined to the surface through an auxiliary boroscope. The proof of the principle is demonstrated and some examples showing depth profiles are presented.---This material is based on work supported by NASA under award NAG-1-029-98.

The Remotely Operated Nondestructive Examination System for Examining the Knuckle Region of Hanford's Double Shell Waste Tanks

---**Susan L. Crawford** and Allan F. Pardini, Pacific Northwest National Laboratory Richland, WA 99352

---The Pacific Northwest National Laboratory has developed a technology to address the examination requirements associated with the knuckle region of Hanford's double shell waste tanks. This examination poses a significant technical challenge because the area that requires examination is in a confined space, high radiation region and is not accessible using conventional measurement techniques. This paper describes the development, deployment, and modification of the remotely operated nondestructive examination (RONDE) system that utilizes a technique known as Synthetic Aperture Focusing (SAFT). The system detects stress corrosion cracking in the high stress region of the knuckle and characterizes the crack with tandem SAFT. PNNL has qualified the system to perform inspections on the entire knuckle region of Hanford's double shell waste tanks.

Detection of Shape and Depth of Defects in Aluminum Structures Using SQUIDs

---**Raouf Selim**, Michael McFarlane, and Jeff Mast, Physics, Computer Science and Engineering Dept., Christopher Newport University, Newport News, VA 23606; Buzz Wincheski, NASA Langley Research Center, Hampton, VA 23681; John Simpson, Lockheed Martin Space Operation, Hampton, VA 23681

---We have developed a low temperature SQUID measurement system for detection of defects deep under the surface of aluminum structures using eddy current techniques. The system uses an orthogonal planar inducer with two different excitation frequencies. We have developed a data analysis software program that enabled us to distinguish between round defects (holes), straight defects (cracks) and cracks close to holes simulating cracks around fasteners in aluminum structures. We were able to detect defects that are 8mm below the surface. We have also measured the change in phase of the detected signal as a function of depth of the defect. This relationship can be used to determine the depth of hidden flaws. A similar system using High Temperature Squid with better spatial resolution was also able to detect cracks close to holes in layered aluminum sample.

Crack Inspection by EddyTherm

---**Guenter Zenzinger**, Joachim Bamberg, and Patrick Nutz, MTU Aero Engines, 80995 Munich, Germany

---The thermographic crack inspection method EddyTherm uses pulsed eddy currents to heat the metallic part which has to be inspected. Cracks distort the current path and therefore also the uniform heat transfer. The local differences in the temperature profile around the crack position are detected by an infrared camera. The special advantage of this technique is that even large areas can be inspected with high lateral resolution by only one induction heat pulse. Furthermore, it is possible to inspect complex shaped parts. The geometry of the coils and their induction heating behaviour on the inspected parts are calculated and optimized by finite element modelling. Some examples of inspected parts are presented. Possibilities and limits of this non-destructive testing technique are shown. The results are compared with conventional crack detection techniques. The main focus for further developments of EddyTherm lies on automation and reliable detection of small hidden cracks. By using a robot for the handling of the parts, a short pulse high frequency generator for induction heating and sophisticated algorithms for post-processing of the thermographic data, a first build up of an automatic crack inspection system for aero engines compressor blades was obtained.

A Low Cost Comparative Pulsed Eddy Current Inspection System for Defect Detection

---**Nawapak Eua-anant**, Khon Kaen University, Department of Computer Engineering, Khon Kaen, 40002, Thailand

---The new eddy current technique using an impulse signal for defect detection is proposed. Unlike traditional eddy current techniques that use single frequency sinusoidal excitation, in the proposed method, an impulse signal generated by a computer is used to excite the probe. The induced pulse signal is picked up from the reflection probe via a data acquisition card and recorded digitally. This signal is later compared with the reference signal obtained from a good sample. The subtracted signal exhibits bipolar characteristics indicating the presence of a crack in the test part. Both positive and negative peaks of the subtracted signal can be displayed in a B-scan mode or plotted in a 2-D plane analogous to an impedance plane. Unlike traditional eddy current techniques that require sophisticated analog circuits for processing signals, the proposed system handles signals mainly in digital domain using simple arithmetic operations. Importantly, the low cost system can be implemented using only a personal computer and a multifunction data acquisition card.

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