REVIEW OF PROGRESS IN QUANTITATIVE NDE
Bowdoin College

Brunswick, Maine

July 29-August 3, 2001

PROGRAM

Monday, July 30, 2001

PLENARY SESSION 1
EVOLUTION OF THERMAL TECHNIQUES
R. B. Thompson, Chairperson
Morrell Gymnasium

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

9:15 AM **Thermal NDE Techniques – From Photoacoustics to Thermosonics**
---R. L. Thomas, Wayne State University, Institute for Manufacturing Research and College of Science, 666 W. Hancock, Room 281, Detroit, MI 48202

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

PLENARY SESSION 2
NEW SENSOR TECHNOLOGY
D. E. Chimenti, Chairperson
Morrell Gymnasium

10:30 AM **Nanoscale Measurements and Nanosensors**
---M. C. Gupta, Old Dominion University, Applied Research Center, 12050 Jefferson Avenue, Newport News, VA 23606

11:15 AM **Micro-Electro-Mechanical Systems (MEMS): Applications in NDE?**
---R. M. White, University of California, EECS Department and the Berkeley Sensor and Actuator Center, Berkeley, CA 94720-1770

12:10 PM ***Lunch***

Thermal NDE Techniques – from Photoacoustics to Thermosonics

---Robert L. Thomas, Institute for Manufacturing Research and College of Science, Wayne State University, 666 W. Hancock, Room 281, Detroit, MI 48202

---The evolution of thermal wave imaging and materials characterization will be traced from its origins during the time of the First International Workshop on Photoacoustics and Photothermal Phenomena in Ames, Iowa in 1979 to the present, and with an eye to the future. In the early days, the heat sources consisted of amplitude-modulated lasers, focused to a spot, and step-scanned across the surface of the object under evaluation. A variety of lock-in detection schemes were used, including microphones in gas cells (photoacoustics), laser optical probes (the mirage effect), photothermal defection, thermoreflectance, and infrared (IR) detection. With the commercial availability of IR cameras, rapid and wide-area synchronous imaging became possible, both in the frequency domain (lock-in imaging), and the time-domain (box-car imaging). Recently, the photoacoustic technique has been “flipped”, with a pulse of sound being used as the *energy source*, and with an IR camera monitoring the subsequent photons emitted in the vicinity of a surface or subsurface defect. This new technique (thermosonics) will be described, along with applications to crack detection in a variety of materials and objects.

Nanoscale Measurements and Nanosensors

---Mool C. Gupta, ODU-ARC Director, Applied Research Center, Old Dominion University, 12050 Jefferson Avenue, Newport News, VA 23606

---Nanoscience and technology have attracted considerable attention recently. Central to this theme has been the development and application of a variety of experimental techniques to perform characterization of structural, electronic, magnetic, optical, and other properties of materials with nanometer scale spatial resolution. In particular, two classes of experimental techniques, scanning-probe methods and electron microscopy, have proven especially adaptable. Continued development of new tools is critical to the pace of further progress in nanoscience and technology as they provide the means to see and manipulate the nanostructures. The focus of the talk will be on new advances in instrumentation and techniques that will help expand the frontiers of nanoscale research through scanning probe methods, near-field optical microscopy, electron microscopy, and related proximal probes. Scanning probe methods now allow information such as hardness, acoustic properties, work function, electrical and magnetic field strength, electrical currents (Tunneling AFM), resistance (scanning spreading resistance microscopy) and capacitance (scanning capacitance microscopy), providing the ability to measure a wide range of properties with nanometer scale resolution. Experimental results on characterization of carbon nanotubes using transmission electron microscopy, atomic force microscopy, near-field scanning optical microscopy and other techniques will be presented. We will also discuss the nanosensors based on unique properties of carbon nanotubes. Nanobalance based on carbon nanotubes can have femtogram level sensitivity.

Micro-Electro-Mechanical Systems (MEMS): Applications in NDE?

---Richard M. White, EECS Department and the Berkeley Sensor & Actuator Center, University of California, Berkeley, CA 94720-1770

---During the past 15 years, micro-electro-mechanical systems have become a topic of widespread research, development and commercial interest, with a projected annual worldwide market value of $40 billion by the year 2002. Made by augmented integrated circuit fabrication techniques and having at least some dimensions in the micron range, these devices have been used extensively in computer printers and vehicles, and are expected to provide the basis for many new types of biomedical, chemical analysis, optical and communications equipment. We will give an overview of MEMS activity, and suggest some possible MEMS applications in NDE. As an example, it is now possible to make communicating autonomous mobile micro-robots that can be used for inspection in narrow spaces, such as pipes and densely filled industrial plants. Another MEMS development, termed Smart Dust, is the realization of means for making disposable, self-powered distributed wireless “motes” measuring one or two millimeters on a side, that are capable of sensing a wide range of variables, storing sensed data, and communicating them back on demand through a self-established network. These devices could be dispensed randomly or by deliberate placement in a volume or on a surface of interest, such as the skin or interior of a structure or vehicle.

Monday, July 30, 2001

SESSION 3

SQUID NDE

H. Weinstock, J. R. Bowler, and W. N. Podney, Co-Chairpersons
Smith Auditorium (Sills)

1:30 PM **High-Tc SQUID Microscopy of Active Corrosion and Electronic Defects**
---F. C. Wellstood, E. Fleet, S. Chatraphorn, S. Lee, J. Gaudestad, and A. Gilbertson, University of Maryland, Center for Superconductivity, Department of Physics, College Park, MD 20742-4111; L. Knauss, Neocera, Inc., Beltsville, MD; A. Abedi and J. Wikswo, Vanderbilt University, Department of Physics and Astronomy, Nashville, TN; N. Tralshawala*, NASA Goddard, *Now at CardioMag Imaging, Inc., Schenectady, NY; H. Weinstock, Air Force Office of Scientific Research, Arlington, VA

2:10 PM **Electromagnetic Microscope Response Model and Reliability Assessment**
---W. N. Podney and M. de Andrade, SQM Technology, Inc., P. O. Box 2225, La Jolla, CA 92038

2:30 PM **Important Issues for the Development of SQUID NDE**
---G. B. Donaldson, C. Carr, and J. C. Macfarlane, University of Strathclyde, Department of Physics and Applied Physics, Glasgow G4 0NG, Scotland

2:50 PM **High Temperature Superconducting Sensors for NDE**
---P. Seidel, F. Schmidl, S. Linzen, F. Schmidt, S. Müller, and K. Peiselt, Institut für Festkörperphysik, Department for Low Temp. Physics, Friedrich-Schiller-Universität Jena, Helmholtzweg 5, D-07743 Jena, Germany

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

3:30 PM **Conductivity Tomography Based on Pulsed Eddy Current with SQUID**
---G. I. Panaitov, H.-J. Krause, and Y. Zhang, Institute of Thin Films and Interfaces, Research Center Juelich, Germany

3:50 PM **Superconductive Pulsed Eddy-Current Probe Signal Evaluation: Response Due to Cracks**
---J. R. Bowler[1], N. Bowler[1], and W. Podney[2], [1]Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011; [2]SQM Technology, Inc., P. O. Box 2225, La Jolla, CA 92038

4:10 PM **SQUID Magnetometer for Laboratory Measurements of the Rate of Hidden Corrosion in Aging Aircraft**
---A. P. Ewing, D. N. Paulson, and R. L. Fagaly, Tristan Technologies, Inc., 6350 Nancy Ridge Drive, San Diego, CA 92121; J. P. Wikswo, F. Baudenbacher, Y. P. Ma, and G. Skeenerton, Vanderbilt University, Department of Physics and Astronomy, Nashville, TN; M. Radparvar, Hypres, Inc., Elmsford, NY; M. E. Inman, Faraday Technology, Inc., Clayton, OH

4:30 PM **High Resolution LTS-SQUID Microscopes**
---F. Baudenbacher, N. T. Peters, L. E. Fong, J. R. Holzer, Z. Trontelj, and J. P. Wikswo, Vanderbilt University, Department of Physics and Astronomy, Nashville, TN

4:50 PM **Detecting Plastic Deformation and Damage in Steel with Scanning SQUID Microscopy**
---T.-K. Lee, D. Clatterbuck, and J. W. Morris, Jr., University of California, Department of Materials Science and Engineering, Berkeley, CA and Center for Advanced Materials, Lawrence Berkeley Laboratory, Berkeley, CA 94720; T. J. Shaw, R. McDermott, and J. Clarke, University of California-Berkeley, Department of Physics, Materials Sciences Division, Lawrence Berkeley Laboratory, Berkeley, CA 94720

High-Tc SQUID Microscopy of Active Corrosion and Electronic Defects

---F. C. Wellstood, E. Fleet, S. Chatraphorn, S. Lee, J. Gaudestad, and A. Gilbertson, Center for Superconductivity, Department of Physics, University of Maryland, College Park, MD, 20742-4111; L. Knauss, Neocera, Inc., Beltsville, MD; A. Abedi and J. Wikswo, Department of Physics and Astronomy, Vanderbilt University, Nashville, TN; N. Tralshawala*, NASA, Goddard, * now at CardioMag Imaging, Inc., Schenectady, NY; H. Weinstock, Air Force Office of Scientific Research, Arlington, VA

---A scanning SQUID microscope works by scanning a sample closely under a small Superconducting Quantum Interference Device. The SQUID is extremely sensitive to magnetic field, and by recording the output of the SQUID as a function of sample position, a false color image of magnetic field can be produced. Under favorable circumstances, such data can be converted directly into an image of the currents that are the sources of the field. Our systems at Maryland allow a 0.05 mm diameter high-Tc YBCO bi-crystal SQUID that is maintained at 77 K to be brought to within about 30 μm of a room temperature object that is in air. Working with a private company, Neocera Inc., we have demonstrated that the microscopes can detect active corrosion of aluminum, locate short circuits in multi-chip modules and computer chips, and identify defects in NbTi wire used in superconducting magnets. I will discuss the operation and performance of our systems for these NDE applications and show images from a variety of samples.---*Supported by Neocera, Inc., the Air Force Office of Scientific Research and the state of Maryland through the Center for Superconductivity Research.

Electromagnetic Microscope Response Model and Reliability Assessment

---Walter N. Podney and Marcio de Andrade, SQM Technology, Inc., P. O. Box 2225, La Jolla, CA 92038

---An electromagnetic microscope uses a superconductive quantum interference device (SQUID) to achieve high sensitivity and resolution at low frequency, making it possible to find small cracks and corrosion hidden deep in multilayered structures. Using pulsed eddy currents with a superconductive probe enables measuring depth and size of cracks. Timing of the magnetic response from a crack tells its depth, and amplitude of the response tells its size. Superconductive probes, operating with pulsed eddy currents, enable imaging a crack, with the image superimposed on a cross sectional view of a part, showing, for example, a fatigue crack at a fastener hole. The image gives depth of a crack below the surface as well as its length and area. The three parameters outline a crack on a section drawing of a part. A color code for the image gives probability of detection for a crack. Measurements of probabilities of detection for isolated cracks 1, 2, and 5 mm long as a function of overburden show the transition from complete certainty to absolute uncertainty occurs at an overburden where the peak response calculated (mean value) equals the threshold value. The response calculated at a set overburden is the mean of measured variations in response, with variability coming from surface clutter. A response model, in effect, calibrates peak amplitude of a crack signal in picohenries with depth in millimeters, needed to convert mean values of measurements to depths.

Important Issues for the Development of SQUID NDE

---Gordon B. Donaldson, Chris Carr, and John C. Macfarlane, Department of Physics and Applied Physics, University of Strathclyde, Glasgow G4 0NG, Scotland

---The future of SQUID NDE depends critically on identifying those problems which are amenable only to this technology, and to distinguishing them clearly from others where room temperature devices, perhaps operated in ways which generations of SQUID users would recognize, such as the flux-locked-loop mode. In this paper, we will discuss some SQUID-only problems, and discuss others, such as NDE of steel plates, where other techniques, such as marginally resonant oscillator systems appear to be just as effective. We will also review recent progress with novel SQUID-based eddy-current techniques, both in our own group and in some other European laboratories. Two issues are important in the development of new generations of thin film SQUID structures to serve these needs. The first is to create magnetic gradiometers with intrinsic balances of 1 part in 10^5 and better: recent designs which have approached this level will be described, and possible new approaches, including software-based active balancing systems will be outlined. The second is the question of convenience and portability, for which new generations of cryocoolers may prove useful. An outline of a miniature extremely portable system which we are developing will be given.

High Temperature Superconducting Sensors for NDE

---Paul Seidel, Frank Schmidl, Sven Linzen, Frank Schmidt, Sven Müller, Katja Peiselt, Institut für Festkörperphysik, Department for Low Temp. Physics, Friedrich-Schiller-Universität Jena, Helmholtzweg 5, D-07743 Jena, Germany

---The detection of signals in the field of non-destructive evaluation (NDE) needs a wide range of different sensor types depending on the investigated object. Weak magnetic signals in the range of some nT down to fT can be detected successfully by superconducting sensors. Superconducting quantum interference devices (SQUIDs) are often coupled to antenna structures to enhance the flux detecting area. Such gradiometer structures were prepared in thin film technology using high-temperature superconducting (HTSC) YBa2Cu3O7-X realizing the dc-SQUIDs by bicrystal Josephson junctions. The main interest for practical applications is the magnetic field noise of the SQUID sensor. The recent possibilities and limitations in shielded as well as in unshielded environment will be discussed. Different gradiometer layouts were tested in a new system for NDE with respect to signal resolution, band width and spatial resolution. Our NDE-system can be used for industrial purposes in magnetically and electrically unshielded environment. We show several applications for measurements of weak magnetic signals. The first application is the measurement of weak permanent magnetic fields, e.g., fields due to magnetic impurities or changes of the hardness of test materials. The second method is the measurement of ac-magnetic fields, for instance fields induced by eddy current technique for crack detection. Further we show the application of HTSC-Hall magnetometers in non-destructive evaluation. This new sensor type can be able to close the gap between the sensitivity of commercial magnetic field sensors and SQUID based systems.

Conductivity Tomography Based on Pulsed Eddy Current with SQUID

---Grigory I. Panaitov, Hans-Joachim Krause, and Yi Zhang, Institute of Thin Films and Interfaces, Research Center Juelich, 52425 Juelich, Germany

---Pulsed eddy current (EC) techniques have the advantage of potentially covering a broader depth range than standard single frequency EC testing. We developed a novel pulsed EC technique using a liquid-nitrogen cooled SQUID magnetometer. For two reasons, SQUID magnetometers are particularly well suited as sensors: first they constitute an extremely sensitive magnetic field sensor, second they measure the field directly which decays more slowly than its time derivative picked up by induction coils. A square waveform transmitter signal was used, with alternating slopes in order to eliminate drift effect, and stacking syncronous to the power line frequency in order to improve signal-to-noise. The early time (high frequency) data of the recorded transient correspond to the upper layers of the conducting medium, while late time data or low frequencies deliver information on deep layers. Measurements of cracks at different depths in a stacked aluminum sample are presented. From the measured data, the apparent conductivity of the sample was calculated for each position and depth by applying a technique known from geophysical data interpretation. Thus, the position and depth of the crack was determined from the tomographic conductivity image of the sample.

Superconductive Pulsed Eddy-Current Probe Signal Evaluation: Response Due to Cracks

---J. R. Bowler[1], N. Bowler[1], and W. Podney[2], [1]Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011; [2]SQM Technology, Inc., P. O. Box 2225, La Jolla, CA 92038

---A highly-sensitive measurement system has been developed by combining pulsed eddy-current technology with the extraordinary magnetic-field sensitivity of superconductive probes. The system is designed to detect embedded cracks in multi-layered aluminum structures. The probe consists of a source coil which emulates a current strip driver and a double-D pick-up loop. The pick-up circuit couples inductively to a remote SQUID in a 5 Kelvin refrigerator. The refrigerator keeps the coils, cryogenic cable and SQUID at approximately 6 Kelvin. Signal interpretation is aided by the use of a theoretical and computational model of the probe interaction with deep lying cracks. Comparisons between model predictions and experimental measurements are reported which confirm the validity of the model.---This publication was supported by a subcontract with Universal Technology Corporation, under Prime Agreement F33615-97-D-5271 from the Air Force Research Laboratory. Any opinions, findings and conclusions or recommendations expressed in this publication are those of the author(s) and recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the views of Universal Technology Corporation or those of the Air Force Research Laboratory.

SQUID Magnetometer for Laboratory Measurements of the Rate of Hidden Corrosion in Aging Aircraft

---A. P. Ewing, D. N. Paulson, and R. L. Fagaly, Tristan Technologies, Inc. 6350 Nancy Ridge Drive, San Diego, CA 92121; J. P. Wikswo, Jr., F. Baudenbacher, Y. P. Ma, and G. Skeennerton, Department of Physics and Astonomy, Vanderbilt University, Nashville, TN; M. Radparvar, Hypres, Inc., Elmsford, NY; M. E. Inman, Faraday Technology, Inc., Clayton, OH

---We have developed a new laboratory instrument that will incorporate a 2-dimensional array of SQUID magnetometers suitable for quantifying the rate at which various forms of corrosion damage accumulate in a range of aerospace structures. This technique will allow determination of instantaneous rates of hidden corrosion in aluminum aerospace structures, such as crevice corrosion in an aircraft lap joint or exfoliation corrosion in the midplane of a thick wing plank. The system has greatly increased "scanning" speeds for more precise spatio-temporal measurements. Our design incorporates important technical innovations, including the use of fractional-turn SQUID sensors, improved scanning technology, and advanced analysis software. The instrument will incorporate a 16-channel SQUID magnetometer system, an 8-element tensor array for noise reduction, a magnetic shield and scanning stage, and an environmental controlled corrosion cell system. The metrics developed allow one to image the "instantaneous" level of magnetic activity, as well as cumulative magnetic activity, indicating regions of high activity. This instrument is designed to provide data on hidden corrosion rates that will reduce the probability of hidden corrosion contributing to the failure of a structurally significant element. Its applications will be in inspection planning and maintenance, cost reduction, and increased aircraft safety and availability.

High Resolution LTS-SQUID Microscopes

---F. Baudenbacher, Nickolas T. Peters, Luis E. Fong, Jenny R. Holzer, Z. Trontelj, and J. P. Wikswo, Physics and Astronomy, Vanderbilt University, 6301 Stevenson Center, Nashville, TN

---We have developed a scanning superconducting quantum interference device (SQUID) microscope for imaging magnetic fields of room-temperature samples with sub-millimeter resolution. In our design, hand wound niobium pickup coils were coupled to commercially available low temperature SQUID sensors. The SQUID sensor and the pickup coil are in the vacuum space of the cryostat separated typically less than 50 ìm by a thin sapphire window from the room-temperature sample. A computerized non-magnetic scanning stage with sub-micron resolution in combination with a tripod leveling system allows samples to be scanned at levels of 10mm below the sapphire window. For a 20 turns 500 ìm diameter pickup coil we achieved a field sensitivity of 330 fT/Hz-1/2 and for a 10 turns 250 mm diameter coil 2 pT/Hz-1/2 for frequencies above 1 Hz. The SQUID microscope was used to image the distribution of action currents in anisotropic cardiac tissue and single plant cells, the remanent magnetization of the Martian meteorite ALH84001 during thermal demagnetisation and the magnetic susceptibility of biogenic magnetite in the peak of homing pigeons.

Detecting Plastic Deformation and Damage in Steel with Scanning SQUID Microscopy

---Tae-Kyu Lee, David Clatterbuck, and J.W. Morris, Jr., Department of Materials Science and Engineering, University of California, Berkeley and Center for Advanced Materials, Lawrence Berkeley Laboratory, Berkeley, CA 94720; T.J. Shaw, R. McDermott, and John Clarke, Department of Physics, University of California, Berkeley and Materials Sciences Division, Lawrence Berkeley Laboratory, Berkeley, CA 94720

---This research describes the application of a scanning "microscope" based on a high transition temperature Superconducting Quantum Interference Device (SQUID) to the nondestructive evaluation of ferromagnetic materials. Samples are magnetized in a magnetic field using a standardized procedure. The remanent magnetization is scanned with high sensitivity and spatial resolution using the SQUID microscope. The results show that SQUID microscopy can detect the microstructural changes associated with prior plastic deformation; the data correlate well with measurements of hardness. Recent results suggest that this technique provides a sensitive means for monitoring the progression of fatigue damage. These recent results support a conclusion now emerging from research in a number of laboratories, that magnetic measurements offer the best opportunity for non-destructive detection of fatigue. However, SQUID microscopy may be uniquely suited for this purpose, given its combination of magnetic sensitivity and spatial resolution.

Monday, July 30, 2001

SESSION 4
NDE FOR FERROUS MATERIALS
M. Sablik, Chairperson
Sills 117

1:30 PM **The Sensitivity of Eddy Current Measurements to the Material Properties and Case Depth of Case Hardened Steel**
---H. Sun, J. R. Bowler, N. Bowler, and M. J. Johnson, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

1:50 PM **Detecting Compressive Residual Stress in Carbon Steel Specimens of Flat Geometries Using the Remote-Field Eddy Current Technique**
---Y. Sun and T. Ouyang, Innovative Materials Testing Technologies, Inc., 2501 N. Loop Drive, Ste. 1610, Ames, IA 50010; S. S. Udpa, Iowa State University, Dept. EE/Com. Eng., Ames, IA 50011

2:10 PM **Detection of Thermal Damage in X2M Gear Steel Using Barkhausen Noise**
---P. J. Sincebaugh, V. Champagne, M. Pepi, and D. Snoha, U. S. Army Research Laboratory, Weapons and Materials Res. Directory, AMSRL-WM-MD, Aberdeen Proving Ground, MD 21005

2:30 PM **Nondestructive Evaluation of Gradient Properties of Hardened Steel by Surface Acoustic Waves Measurement**
---B. Chenni, Laboratoire d'Acoustique Ultrasonore et d'Electronique, UPRESA CNRS 6068, Université du Havre, Place Robert Schuman, 76610 Le Havre Cedex, France; A. Moreau, Ind. Materials Institute, NRC of Canada, 75 de Mortagne, Boucherville, Quebec, Canada J4B 6Y4

2:50 PM **Characterization of Microstructures in Austenitic and Ferritic Steels Using Ultrasonic Parameters**
---B. Raj, T. Jayakumar, P. Palanichamy, and A. Kumar, Metallurgy and Materials Group, Indira Gandhi Centre for Atomic Research, Kalpakkam, 603102, India

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

3:30 PM **Studies on the Effects of Pulsed-Magnetic Field Treatment on Magnetic Materials**
---M. J. Johnson[1], L. C. Kerdus[3], C. C. H. Lo[1], J. E. Snyder[2,3], J. Leib[2], S. J. Lee[3], M. Mina[4], and D. C. Jiles[1,2,3,4], Iowa State University, [1]Center for NDE, 1915 Scholl Road, Ames, IA 50011; [2]Department of Materials Science; [3]Ames Laboratory, USDOE; [4]Dept. of EE/Com. Eng.

3:50 PM **Relationship Between Magnetostriction and the Magnetostrictive Coupling Coefficient for the Magnetostrictive Generation of Elastic Waves**
---M. J. Sablik, Southwest Research Inst., P. O. Drawer 28510, San Antonio, TX 78228-0510; K. L. Telschow, INEEL, Idaho Falls, ID 83415-2209; B. Augustyniak, J. Grubba, and M. Chmieliewski, Technical University of Gdansk, PL-80-952, Gdansk, Poland

4:10 PM **Numerical Modelization of Magnetic Materials Based on Energy Minimization**
---M. Bernadou, S. Depeyre, and S. He, Pôle Universitaire Léonard de Vinci, 92916 Paris la Défense Cedex, France

4:30 PM **Prediction of Magnetic Microstructure in Iron with a New Finite Element Model**
---M. Bernadou[1], S. Depeyre[1], S. He[1], and P. Meilland[2], [1]Pôle Universitaire Léonard de Vinci, 92916 Paris la Défense Cedex, France; [2]IRSID, Voie Romaine, B. P. 30320, 57283 Maiziéres-les-Metz, France

4:50 PM **Study on Distribution of Elastic Wave Velocity in the Thickness Direction of Anisotropic Steel Plate**
---H. Shirahata, Musashi Institute of Technology, Department of Civil Engineering, 1-28-1 Tamazutsumi, Setagayaku, Tokyo 158-8557, Japan; C. Miki, Tokyo Institute of Technology, 2-12-1 Ookayama, Meguroku, Tokyo 152-8552, Japan

The Sensitivity of Eddy Current Measurements to the Material Properties and Case Depth of Case Hardened Steel

---H. Sun, J. R. Bowler, N. Bowler, and M. J. Johnson, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---Eddy current techniques have been used to assess case hardened steel at least from the time of the pioneering work of F. Förster. The case hardening process modifies the near surface permeability and conductivity of the steel as can be observed through changes in eddy current probe signals measured over a range of frequency. The challenge posed by such measurements is to estimate the case hardening and case depth from the eddy current data. A traditional approach is to combine statistical and empirical methods, thereby establishing a statistical correlation between measurements and the required properties of hardness and case depth. An alternative scheme is to train a neural network to extract the required material properties using a reference set of specimens and measurements. However, both of these approaches depend on acquiring a specific set of test data under controlled conditions. The data is then only useful for estimating the properties of new samples whose treatment conditions and steel quality are consistent with those of the reference set. In this work, the possibility of linking eddy current measurements to the variation of conductivity and permeability with depth has been studied by matching predictions from a physical model with measurements of probe impedance. Experiments have been performed using normal absolute probe coils on flat steel specimens and coils encircling case hardened steel rods. By fitting model results to the experimental data, estimates of the electrical material properties are found. The approach also allows an assessment of the sensitivity of the measurements to the case depth.---This work was supported by the NSF Industry/University Cooperative Research program.

Detecting Compressive Residual Stress in Carbon Steel Specimens of Flat Geometries Using the Remote-Field Eddy Current Technique

---Y. Sun and T. Ouyang, Innovative Materials Testing Technologies, Inc., 2501 N. Loop Drive, Ste. 1610, Ames, IA 50010; Satish S. Udpa, Iowa State University, Department of Electrical and Computer Engineering, Ames, IA 50010

---There is an increasing interest in systems that are capable of characterizing residual stress in critical infrastructure, such as natural gas pipelines. Accurate estimates of residual stresses around defects caused by external mechanical forces are important for calculating the maximum allowable operating and safe operating pressures. A number of techniques employing a variety of physical principles and methodologies have been proposed to address this problem. The remote-field eddy-current (RFEC) technique has proven to be an excellent tool for detecting flaws that are embedded deep in single and multiple layer metallic structures. Experimental studies have shown that the RFEC technique is capable of detecting compressive residual stress in carbon steel specimens of flat geometries. The specimens are of 0.25” and 0.5” thick. Results obtained to date show a surprisingly high level of sensitivity to compressive residual stress occurring deep in thick carbon steel specimens. The signal magnitude obtained appears to be approximately proportional to the pressure that was used to generate the residual stress in a specimen. Experimental results and the test set up employed to obtain the test data will be presented.

Detection of Thermal Damage in X2M Gear Steel Using Barkhausen Noise

---Patrick J. Sincebaugh, Victor Champagne, Marc Pepi, and Daniel Snoha, U. S. Army Research Laboratory, Weapons and Materials Research Directory, AMSRL-WM-MD, Aberdeen Proving Ground, MD 21005

---Vasco X2M steel, in the heat treated and carburized condition, is used to produce critical U.S. Army rotorcraft powertrain components. Grinding is performed to achieve the required dimensional tolerances for precision components while shot peening is performed afterward for the purpose of inducing compressive residual stresses to enhance fatigue resistance. Improper grinding can result in high surface transient temperatures that can reduce the beneficial compressive stresses, or even result in the presence of tensile stresses in the surface layers. If the condition is severe enough it can lead to grinding burns which reduce wear resistance and fatigue strength, potentially causing premature failure of the component. This paper describes the development and implementation of Barkhausen Noise Analysis (BNA) techniques for detecting thermal damage in X2M steel components. BNA is a nondestructive inspection method that has been shown to be sensitive to microstructural and residual stress variations in ferromagnetic materials. BNA data will be presented for X2M samples with various degrees of thermal damage, prior to and subsequent to shot peening. X-Ray Diffraction residual stress measurements and microstructural analysis results will also be presented.

Nondestructive Evaluation of Gradient Properties of Hardened Steel by Surface Acoustic Waves Measurement

---B. Chenni, Laboratoire d'Acoustique Ultrasonore et d'Electronique, UPRESA CNRS 6068, Université du Havre, Place Robert Schuman, 76610 Le Havre Cedex, France; A. Moreau, Industrial Materials Institute, National Research Council of Canada, 75 de Mortagne, Boucherville, Quebec, Canada, J4B 6Y4

---Measurements of velocity dispersion on hardened steel were achieved by means of an absolute method for surface acoustic waves (SAW) based on the Knife-edge technique. SAW are generated and transmitted to the surface sample by interdigital transducers (barium titanate, quartz or lithium niobate). A laser beam sent on this surface is deflected by the ripple produced on it by the SAW and the deviation of the beam is detected by a photomultiplier with a knife in front of it. The steel sample is modeled by a two media system (layer-substrate). Numerical calculations of the Rayleigh wave velocity dispersion are achieved for various thickness values of the surface layer (perturbed steel). Measurements and calculations agree well for a particular value of the surface layer thickness. A confirmation of this value is obtained by similar measurements on the other face of the sample on which a chromium layer was previously deposited. This face is modeled by a 3 media system (Chromium - perturbed steel - bulk steel) and presents a measured dispersion that agrees well with the dispersion calculated using the previously determined parameters of the perturbed steel.

Characterization of Microstructures in Austenitic and Ferritic Steels Using Ultrasonic Parameters

---Baldev Raj, T. Jayakumar, P. Palanichamy, and Anish Kumar, Metallurgy and Materials Group, Indira Gandhi Centre for Atomic Research, Kalpakkam, 603102, India

---Various structural features such as grain size, dislocations, secondary phases, voids and texture influence propagation of ultrasonic waves in materials. These structural features alter the ultrasonic propagation velocity, absorption and scattering behavior. The frequency of ultrasonic waves also plays an important role in the interaction of ultrasonic waves with the structural parameters. Hence ultrasonic parameters such as velocity of different modes, absorption, scattering, attenuation and their frequency dependence can be affectively utilized for unfolding the structural variations in the materials. In this paper, applicability of various ultrasonic parameters for characterization of important structural features in austenitic and ferritic steels has been discussed. Couplant independent ultrasonic spectral parameters by employing transducers with specific spectral response have been identified for determination of grain size in austenitic (higher scattering) and ferritic (lower scattering) steels. A thickness independent ultrasonic ratio parameter has been used to estimate the degree of recrystallization in austenitic stainless steels. The sequence of microstructural changes in AISI type 316LN steel, i.e. formation of Cr-N clusters, coherent Cr_2N precipitates, growth of these precipitates and formation of chi phase could be inferred from the ultrasonic velocity and attenuation measurements. The transition temperatures A_{c3} and A_{c3} and the volume fraction of martensite in microstructures with ferrite and martensite in 9CR-1Mo steel have been evaluated using ultrasonic velocity measurements. The changes in ultrasonic velocity due to thermal aging and creep damage in 9Cr-1Mo steel have been correlated with the microstructural changes.

Studies on the Effects of Pulsed-Magnetic Field Treatment on Magnetic Materials

---M. J. Johnson[1], L. C. Kerdus[3], C. C. H. Lo[1], J. E. Snyder[2,3], J. Leib[2], S. J. Lee[3], M. Mina[4], and D. C. Jiles[1,2,3,4], [1]Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011; [2]Department of Materials Science; [3]Ames Laboratory, USDOE; [4]Department of Electrical and Computer Engineering

---Systematic studies have been carried out to investigate the effects of pulsed-magnetic field treatment (PMT) on the stress state of various magnetic materials including cold worked bulk steel and nickel samples, and sputter-deposited FeSiAl(N) thin films. PMT involves applying a periodic magnetic field with a specific profile or fine structure (the pulsed component) to ferromagnetic, and some also claim non-ferromagnetic, materials. PMT is usually followed by demagnetization cycles at room temperature. A system was constructed that allows complete control of the waveform, frequency and amplitude of the field profile. Magnetic hysteresis and Barkhausen effect (BE) measurements were made on the steel and nickel samples before and after PMT to infer any change in residual stress level. The hysteresis loop parameters and the rms BE voltage remained the same within the measurement uncertainties following PMT. The residual stresses of the FeSiAl films were determined to be compressive by measuring the curvature of the film-substrate system, and were found to remain unchanged after PMT. The magnetic domain structures of the nickel and FeSiAl(N) film samples were imaged with a magnetic force microscope. Similar domain patterns were observed before and after PMT, indicating that strong domain wall pinning at structural defects or by residual stresses persisted in both samples after PMT.---This research was supported by the NSF under grant number CMS-9910147 and by DOE, BES under the contract number W-7405-Eng-82.

Relationship Between Magnetostriction and the Magnetostrictive Coupling Coefficient for the Magnetostrictive Generation of Elastic Waves

---M. J. Sablik, Southwest Research Institute, P.O. Drawer 28510, San Antonio,TX 78228-0510; K. L. Telschow, Idaho National Engineering and Environmental Laboratory, Idaho Falls, ID 83415-2209; B. Augustyniak, J. Grubba, and M. Chmieliewski, Technical Univ. of Gdansk, PL-80-952, Gdansk, Poland

---Magnetostrictive generation of elastic waves (MsS) in steels has come to be a useful technique for interrogating steel pipes to detect corrosion pits. The elastic waves are coupled into the pipes according to the strength of a magnetostrictive coupling coefficient. The relationship between this coupling coefficient and the magnetostriction has been a matter of question. Thompson inferred that this coupling coefficient was proportional to the magnetostriction derivative, whereas Igarashi has imputed the coupling to be proportional to the magnetostriction itself. Based on theory presented by Gurevich, we found that either approach is possible to derive. In particular, the magnetostrictive coupling coefficient could alternatively be represented as proportional to the derivative of the magnetostriction with respect to magnetization or to the ratio of magnetostriction to magnetization. In this paper, we present these alternative theoretical results, and then present experimental results which imply that one of the two representations actually describes the experimental situation. In detail, the magnetostriction and MsS signals have been measured for different static magnetic fields applied to the pipe. The elastic waves peak when the slope of magnetostriction vs. H is largest and go to zero amplitude (within the noise level) when the magnetostriction peaks, confirming proportionality of the coupling coefficient to the derivative of the magnetostriction. The experimental results show other details. The elastic waves generated are detected with a mechanical transducer and are found to change sign when the sign of the magnetostriction derivative is changed. At higher fields when the magnetostriction goes through zero from positive to negative, the sign of the elastic wave remains unchanged. This confirms that the coupling coefficient is proportional to the derivative of the magnetostriction and not to the magnetostriction itself.

Numerical Modelization of Magnetic Materials Based on Energy Minimization

---M. Bernadou, S. Depeyre, and S. He, Pôle Universitaire Léonard de Vinci, 92916 Paris la Défense Cedex, France

---This contribution presents some results obtained in computation of magnetic structure at microscopic scale. The model is based on the minimization of a total magnetic energy which includes four components: spin exchange, crystalline anisotropy, magnetoelastic and magnetostatic energies. The numerical method combines a minimization algorithm (augmented Lagrangian or conjugate gradient) and an appropriate finite element method. The numerical results display the evolution of magnetic structures (first magnetization, closure domains, walls, hysteresis loops), when the magnetic material is embedded in an evoluting external field. These results can also be extended to other crystals, as long as the corresponding energy function components are known.

Prediction of Magnetic Microstructure in Iron with a New Finite Element Model

---M. Bernadou[1], S. Depeyre[1], S. He[1], P. Meilland[2], [1]Pôle Universitaire Léonard de Vinci, 92916 Paris la Défense Cedex, France; [2]IRSID, Voie Romaine, B.P. 30320, 57283 Maiziéres-les-Metz, France

---An original numerical method based upon an energy minimization allows to describe magnetism at microscopic level and to predict the evolution of magnetic microstructures in a single iron crystal. More precisely, this numerical method allows to describe correctly the Landau-Lifschitz structure. A mesh refinement around the walls shows the inside 2D vortices, in good agreement with experimental observations reported in the literature. Moreover, when the external magnetic field is increasing from small to higher excitations, we observe first a curvature of the Bloch walls, and next the creation of several small flux-closure domains. The numerical simulations have been extended to the case of small nonmagnetic inclusions. Mesh refinements in the vicinity of such an inclusion shows the existence of spike shaped flux-closure domains in good agreement with well-known observations. Further simulations should enable to predict the coercive field and inductive remanence in such a structure, by modifying the position and distribution of inclusions.

Study on Distribution of Elastic Wave Velocity in the Thickness Direction of Anisotropic Steel Plate

---Hiromi Shirahata, Musashi Institute of Technology Department of Civil Engineering, 1-28-1 Tamazutsumi, Setagayaku, Tokyo, 158-8557, Japan; Chitoshi Miki, Tokyo Institute of Technology, 2-12-1 Ookayama, Meguroku, Tokyo, 152-8552, Japan

---Acoustical anisotropy could be induced in the process of rolling of steel plates. Horizontal shear wave ultrasound transducer of normal incident is used to estimate anisotropy of steel plates. Wave velocity is measured by flight time of bottom echo. Two types of wave velocities are measured. One is oscillating in the rolling direction. The other is oscillating perpendicular to the rolling direction. When the ratio of difference between two waves is larger than 2%, anisotropy should be considered in applying ultrasonic test. In this method, wave velocities are averaged in the thickness direction of the plate. The objective of this study is to investigate change of shear wave velocity in the thickness direction of a steel plate. Some types of cubic specimens of different size were cut out of an anisotropic steel plate. By measuring flight time of bottom echoes, wave velocity was obtained. Difference of wave velocity between center and near surface of the plate could be observed. Ultrasonic test of an anisotropic steel plate was carried out. A steel plate with some side drill holes was scanned by SV wave transducer. Locations of side drill holes were 1/8, 1/4, 1/2, 3/4, and 7/8 of the thickness of the plate. B scope displays of those holes were obtained. Estimation of location of those holes would be discussed.

Monday, July 30, 2001

SESSION 5
NDE FOR PROCESS CONTROL
R. Ludwig, Chairperson
Druckenmiller 016

1:30 PM **Measurement of Aluminum Ingot Temperature Using Pulsed Eddy Currents**
---M. J. Johnson, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011; M. F. A. Warchol, Alcoa Mill Products, Bettendorf, IA 52722

1:50 PM **Level Measurement of Molten Metal in Electromagnetic Continuous Casting of Steel**
---G. Kim, K. Oh, and H. Kim, Steel Process and Automation Research Center, Research Institute of Industrial Science and Technology, San 32, Pohang, Kyungpook, 790-330, Korea

2:10 PM **Electromagnetic Detection and Infrared Visualization Techniques for Non-Metallic Inclusions in Molten Metal**
---M. Fei[1], R. Ludwig[1], S. Shankar, and D. Apelian, Metal Processing Institute, [1]Electrical and Computer Engineering Department, Worcester Polytechnic Institute, Worcester, MA 01609-2280

2:30 PM **Ultrasonic Waveguide Techniques for the Measurement of Material Properties**
---T. Vogt, M. J. S. Lowe, and P. Cawley, Imperial College of Science, Technology, and Medicine, Department of Mechanical Engineering, London, SW7 2BX, United Kingdom

2:50 PM **Application of Empirical Mode Decomposition/Hilbert-Huang Transform to Machine Tool Condition/Health Monitoring**
---G. G. Leisk and N. N. Hsu, National Institute of Standards and Technology, Manufacturing Metrology Division, Gaithersburg, MD 20899; N. E. Huang, NASA Goddard Space Flight Center, Laboratory for Hydrospheric Processes, Greenbelt, MD 20771

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

3:30 PM **Smart Ultrasonic System for Process Monitoring and In-Situ Nondestructive Evaluation of Composite Materials**
---P. Lefebure, A. Liot, H. Voillaume, M. Dessendre, and H. Trétout, Dassault Aviation I, Avenue du Parc, Argenteuil, 91500, France

3:50 PM **Ultrasonic Cure Monitoring of Thermosetting Materials: Generic Representation of Data Using Time-Temperature-Transformation (TTT) Diagrams**
---M. E. Unwin and R. E. Challis, University of Nottingham, School of Electrical and Electronic Engineering, University Park, Nottingham NG7 2RD, United Kingdom

4:10 PM **Monitoring and Modeling of Ultrasonic Wave Propagation in Crystallizing Mixtures**
---R. E. Challis, T. Marshall, and A. K. Holmes, University of Nottingham, School of Electrical and Electronic Engineering, University Park, Nottingham NG7 2RD, United Kingdom

4:30 PM **Real-Time Ultrasonic Physical Property Measurements of Non-Newtonian, Flowing Fluids**
---R. A. Pappas, P. D. Panetta, D. M. Pfund, and G. P. Morgen, Pacific Northwest National Laboratory, P. O. Box 999, K5-26, 902 Battelle Boulevard, Richland, WA 99352

Measurement of Aluminum Ingot Temperature Using Pulsed Eddy Currents

---M. J. Johnson, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50010; M. F. A Warchol, Alcoa Mill Products, Bettendorf, IA 52722

---On the production line at Alcoa's Bettendorf facility, huge aluminum ingots wait to be hot rolled in the world's largest rolling mill. It is important that the ingots are at the correct temperature prior to rolling or the resulting material properties will be out of specification and the whole ingot may need to be scrapped. Currently, lowering a contact probe onto the ingot's surface monitors its temperature. Unfortunately, this is slow and not easily adapted to measuring temperature distributions across the ingot. Knowledge of temperature distributions would greatly improve process-control and would lead to further reductions in scrap. A non-contact method is required for which there are two effective choices. The first possibility is to use infer-red measurements, however, low emissivity and environmental issues often preclude this approach. The other possibility is to use an eddy-current technique to monitor temperature. The eddy-current response will be related to the conductivity, and therefore the temperature, of the aluminum. A pulsed eddy-current method for determining aluminum ingot temperature has been shown to provide an elegant solution to a long-term and surprisingly stubborn problem. The technique is insensitive to changes in sensor temperature while probe liftoff can be easily compensated for. The convenience of such a system will increase both throughput and quality in the aluminum production industry. The benefits of this will be immediate; not only will throughput increase but scrap will be reduced and energy saved.---This work was supported by the Industry/University Cooperative Research Program.

Level Measurement of Molten Metal in Electromagnetic Continuous Casting of Steel

---Goohwa Kim, Kijang Oh, and Hoyoung Kim, Steel Process and Automation Research Center, Research Institute of Industrial Science and Technology, San 32, Pohang, Kyungpook, 790-330, Korea

---In continuous casting process of steel, level measurement of molten metal in the mold is a most crucial technology for operation of casting machine as well as sound quality of the products. The widely employed methods for the conventional continuous casting include usages of ¥ã-ray, thermocouple, and electromagnetic induction etcetera. The electromagnetic continuous casting technology for steel aims defect-free products at the surface and sub-surface region. In this process, the molten metal in the mold, particularly the free surface region, is exposed in high electromagnetic field, and thus the conventional apparatus for measuring the level are hardly to work. In this work, a new method for measuring the level was investigated to work with the electromagnetic continuous casting process, based on the principle of electromagnetic induction. Several candidates of magnetic probes and signal processing logics were devised. The performance of the devices was examined with respect to its structural layout, relative position with the mold, conductivity of the melt, and the intensity of the electromagnetic field for casting. The optimal candidate showed that the resolution of the level was within 0.25mm, the dynamic range of sensing was in between the top of the mold and 300mm below the top of the mold, and the response time of sensing was less than 0.05 second under 20kHz electromagnetic field of casting. In its application to commercial scale casting of steel, it worked well with the existent control device to supply the molten metal to the mold. Particularly, it was seen that the measurement followed well with the abrupt change of the level at the initial stage of casting.

Electromagnetic Detection and Infrared Visualization Techniques for Non-Metallic Inclusions in Molten Metal

---Ming Fei[1], Reinhold Ludwig[1], Sumanth Shankar, and Diran Apelian, Metal Processing Institute, [1]Electrical and Computer Engineering Department, Worcester Polytechnic Institute, Worcester, MA 01609-2280

---The role of detecting non-metallic inclusions in hot melts is of major importance during the manufacturing process in that every aspect of quality is affected by the presence of secondary phases. As critical as clean metal processing is to the integrity of the manufacturing process, it is the case that quantitative techniques are not available to detect the level of inclusions in molten metal: what one cannot measure, one cannot control. The applications for such a sensor are in metal casting (automotive, aerospace, etc.), and processing of high-conductive non-transparent fluids. In this paper, we present a general methodology and preliminary experimental results for a magnetic force-based detection system to monitor small inclusions in the several microns range. The method is based on the concept of forcing the non-conducting inclusions to a detection location (the free melt surface) by electromagnetic Archimedes forces. Subsequently, an infrared imaging system can then be applied to detect their thermal signature. The theoretical modeling efforts include the force model, the surface concentration model, and the escape model of the submerged inclusions. The sensing technique developed at MPI exhibits excellent resolution when compared to other on-line electrostatic or filtration methods. Experimentation with liquid aluminum and argon and helium gas surface conditioning has been conducted to verify and validate this measurement concept.

Ultrasonic Waveguide Techniques for the Measurement of Material Properties

---T. Vogt, M. J. S. Lowe, and P. Cawley, Department of Mechanical Engineering, Imperial College of Science, Technology and Medicine, London, SW7 2BX, United Kingdom

---An initial presentation given at the QNDE 2000 meeting explained two techniques based on longitudinal guided wave propagation in wires for the monitoring of epoxy cure. As well as for cure monitoring, these methods prove to be very attractive for the measurement of material properties in general. The first method is based on the measurement of the attenuation of guided waves due to leakage of energy into an embedding material, whereas the second method measures the reflection which occurs at the point where the waveguide enters the material under investigation. Both methods have been further refined. A magnetostrictive transduction mechanism is used to excite and receive longitudinal and torsional waves. Their measurement allows for the calculation of both the longitudinal and the shear velocity of the embedding material. The particularly interesting application to highly attenuative materials, whose acoustic properties are difficult to obtain using conventional ultrasonic methods, will be discussed.

Application of Empirical Mode Decomposition/Hilbert-Huang Transform to Machine Tool Condition/Health Monitoring

---Gary G. Leisk and Nelson N. Hsu, Manufacturing Metrology Division, National Institute of Standards & Technology, Gaithersburg, MD 20899; Norden E. Huang, Laboratory for Hydrospheric Processes, NASA Goddard Space Flight Center, Greenbelt, MD 20771

---Machine tools generate significant vibration levels during operation due to the dynamic nature of the machine and of the cutting process. By recording vibration signals and applying appropriate signal processing algorithms, one can learn a great deal about both normal machine operation and fault states. While a large number of algorithms have been used in such condition monitoring applications, including various Fourier methods, neural networks, wavelets, ARMA, etc., no single algorithm has gained universal acceptance; underlying assumptions related to the non-linear, non-stationary nature of the signals to be analyzed are largely to blame. In this research, a new time-frequency analytical technique, known as Empirical Mode Decomposition /Hilbert-Huang Transform (EMD/HHT) analysis, is used to characterize vibration signals generated by an operating NC milling machine. While EMD/HHT analysis, like other algorithms, can provide insight into the machine tool and process condition in terms of fault detection, the real promise of this technique is in health monitoring.

Smart Ultrasonic System for Process Monitoring and In-situ Nondestructive Evaluation of Composite Materials

---P. Lefebure, A. Liot, H. Voillaume, M. Dessendre, and H. Trétout, Dassault Aviation, 1, avenue du Parc, Argenteuil, 91500, France

---This paper describes the development of a Nondestructive System associated to smart RTM manufacturing in a combined approach calling for process monitoring and in-situ nondestructive evaluation. The chosen technology is an ultrasonic one based on the use of ultrasonic transducers embedded in a mould and working in a transmission mode. The developed and patented system provides in real time during injection, information on the quality of the RTM part at determined locations: 1) the resin front presence, 2) the presence of bubbles, 3) the gelation of the resin, and 4) the presence of residual fluid in the dry fabric before the arrival of the resin. A specific injection mould was manufactured with the abilities for embedding high temperature piezo-electric ultrasonic transducers. Series of test were conducted to analyse the influence of material and process parameters on the transmitted ultrasonic signals. This has enabled the development of a real time acquisition and processing system dedicated to smart RTM monitoring. Further developments are underway in order to tackle more complex geometry parts, such as wave propagation modelling and neural network data processing.

Ultrasonic Cure Monitoring of Thermosetting Materials: Generic Representation of Data Using Time - Temperature - Transformation (TTT) Diagrams

---Marion E. Unwin and Richard E. Challis, School of Electrical and Electronic Engineering, University of Nottingham, University Park, Nottingham NG7 2RD, United Kingdom

---The monitoring of cure in thermosets is important for process and quality control in the manufacture of composite components and adhered structures, particularly in the aerospace and automotive industries. The many methods available include dielectric measurements, differential scanning calorimetry (DSC), NMR, x-ray, and ultrasonic techniques. Ultrasonic techniques have the advantages that they can be achieved at reasonable cost and that they are non invasive. The data from the various techniques can be presented in many different forms and there is a need for a common generic representation that would provide the basis for comparison and correlation between methods and for process models. The TTT diagram has been used in the past to characterize cure from DSC and low frequency mechanical data. The diagram incorporates contours which bound regions representing different physical states of the curing polymer-sol, sol-gel, gel-glass, glass. In this work we consider how high frequency ultrasonic data can be mapped on to TTT diagrams. During polymerization the real parts of the mechanical moduli increase whilst the imaginary parts peak at frequencies/times which track the evolving molecular size. These two are observable through the frequency spectrum of the ultrasonic absorption coefficient and the phase velocity. The best ways to express these data on a TTT diagram are established and it is shown how the diagram can provide the basis for process control.

Monitoring and Modelling of Ultrasonic Wave Propagation in Crystallizing Mixtures

---Richard E. Challis, Thomas Marshall, and Andrew K. Holmes, University of Nottingham, School of Electrical and Electronic Engineering, University Park, Nottingham NG7 2RD, United Kingdom

---Crystallization is a key stage in many processes to manufacture, for example, food, agricultural chemicals, pharmaceuticals, dyestuffs and other speciality chemicals. Product quality requires control of crystal size and concentration and hence regulation of the forming process. This paper demonstrates the potential of ultrasound for monitoring and eventually the control of crystallization processes. A classical theory predicts the growth of the crystal size distribution (CSD) as a seeded supersaturated solution is cooled. The corresponding properties of the continuous phase ore modelled to give the change in its ultrasonic properties as solute is lost to the forming crystals. The CSD and the properties of the continuous phase are incorporated in a scattering model to predict the changing ultrasonic wave attenuation and phase velocity as crystallization proceeds. These results are compared to experiments using a purpose built temperature controlled ultrasonic test cell with a through transmission transducer arrangement and conventional electronics. Measurement of absorption compare well with theoretical prediction although there are small systematic differences between measured and predicted phase velocity. The technique provides the basis for process models which could be incorporated into closed crop control schemes for crystallization reactions.

Real-Time Ultrasonic Physical Property Measurements of Non-Newtonian, Flowing Fluids

---Richard A. Pappas, Paul D. Panetta, David M. Pfund, and Gerald P. Morgen, Pacific Northwest National Laboratory, P. O. Box 999, K5-26, 902 Battelle Boulevard, Richland, WA 99352

---Rheological information of the contents of a process stream can be invaluable in the monitoring and control of product quality. In the manufacture of food and consumer products, there is tremendous practical and economical benefit in applying a continuous ultrasonic measurement of product properties without batch sampling or disrupting the flow. An advanced ultrasonic Doppler velocimetry (UDV) method has been developed that provides non-disruptive rheological measurements of a flowing fluid or slurry. The method is based on an integration of spatially resolved ultrasonic Doppler backscatter measurements and forward-scatter attenuation measurements. The method provides a flow velocity profile and shear stress values across the diameter of the process pipe for both Newtonian and non-Newtonian fluids. A prototype device meeting plant operating requirements for physical size and robustness, including sterilization and clean-in-place procedures, has been built that incorporates advanced sensors, miniaturized electronics, and digital signal processing technologies in a 316 stainless steel spool piece. The device is designed for use on a large variety of products, including food products, consumer products, and polymer process streams. Results from laboratory performance testing on food products are presented.---Pacific Northwest National Laboratory is operated for the U.S. Department of Energy by Battelle under Contract DE-AC06-76RLO18310.

Monday, July 30, 2001

SESSION 6
NEW SENSORS AND SYSTEMS
J. Rose, Chairperson
Cleaveland 151 (Druckenmiller)

1:30 PM **Fiber Bragg-Grating Ultrasound Sensor for Process Monitoring and NDE Applications**
---P. A. Fomitchov and S. Krishnaswamy, Northwestern University, Center for Quality Engineering and Failure Prevention, 2137 N. Sheridan Road, Evanston, IL 60208

1:50 PM **Optical Fiber Sensor for an On-Line Monitoring of Epoxy Resin/Amine Reaction**
---F. Fouchal and J. A. G. Knight, De Montfort University, Faculty of Technology and Computing Science, The Gateway, Leicester, LE1 9BH, United Kingdom

2:10 PM **Summary of Results from an Ultrasonic In-Flight Wing Ice Detection System**
---D. D. Hongerholt, BFGoodrich Aerospace, Aircraft Sensors, 14300 Judicial Road, M/S FF14, Burnsville, MN 55306-4898; J. L. Rose, The Pennsylvania State University, Engineering Science and Mechanics, University Park, PA 16802

2:30 PM **A Low-Frequency Wheel Probe for Automotive Adhesive-Bond Inspection**
---A. M. Robinson and B. W. Drinkwater, University of Bristol, Department of Mechanical Engineering, Queen's Building, University Walk, Bristol, BS8 1TR, United Kingdom

2:50 PM **Design and Performance of Wireless Sensors for Structural Health Monitoring**
---D. Watters, P. Jayaweera, A. Bahr, and D. Huestis, SRI International, 333 Ravenswood Avenue, Menlo Park, CA 94025

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

3:30 PM **The Effect of Magnetic Field Sensor Lift-Off on SMFM Crack Signals**
---A. H. Salemi, S. H. H. Sadeghi, and R. Moini, Department of Electrical Engineering, Amirkabir University of Technology, 424 Hafez Avenue, Tehran 15914, Iran

3:50 PM **The Use of Embedded Sensors for Composite NDE**
---K. A. Lavere, L. D. Thompson, and R. A. Kline, San Diego Center for Materials Research, San Diego State University, 5500 Campanile Drive, San Diego, CA 92182

4:10 PM **Fidelity of an Analytical Time Reversal Sensor**
---A. D. Puckett and M. L. Peterson, University of Maine, Department of Mechanical Engineering, Orono, ME 04469-5711

4:30 PM **Development of Giant Magnetoresistive (GMR) Inspection System for Detection of Deep Fatigue Cracks Under Airframe Fasteners**
---B. Wincheski, M. Namkung, and D. Perey, NASA Langley Research Center, Hampton, VA 23681; J. Simpson and E. Scales, Lockheed Martin Engineering and Sciences Corporation, Hampton, VA 23681

4:50 PM **A Multiplexed Two-Wave Mixing Interferometer for Laser Ultrasonic Measurements of Material Anisotropy**
---Y. Zhou, T. W. Murray, and S. Krishnaswamy, Northwestern University, Center for Quality Engineering and Failure Prevention, 2137 N. Sheridan Road, Evanston, IL 60208-3020

Fiber Bragg-Grating Ultrasound Sensor for Process Monitoring and NDE Applications

---Pavel A. Fomitchov and Sridhar Krishnaswamy, Center for Quality Engineering and Failure Prevention, Northwestern University, 2137 N. Sheridan Road, Evanston, IL 60208

---A fiber Bragg-grating ultrasonic sensor for detection of ultrasonic waves in liquids and solid structures is proposed. The sensing element of the device is a narrow-band fiber optic Bragg-grating. The sensor consists of a single mode optical fiber Bragg-grating, a tunable laser source with linewidth smaller than the bandwidth of the Bragg-grating, and a photodetector. During operation, the laser source is tuned to a wavelength within the linear region of the Bragg-grating spectrum. When an ultrasonic wave impinges on the fiber, the pitch of the grating is modulated by both acoustically induced mechanical strain and photoelastic effect. This changes the reflectivity of the grating and results in ultrasonic induced intensity modulation. The Bragg-grating ultrasonic sensor is characterized in terms of its sensitivity, directionality, and frequency response. It is shown that the sensor can be used for detection of ultrasound from piezoelectric and laser ultrasonic sources in fluids and solid structures. The main advantages of the sensor are (i) direct modulation of laser intensity by ultrasound, which eliminates the need for optical phase demodulators, (ii) simplicity of design, (iii) high sensitivity over broad frequency range (0.01-5 MHz), (iv) insensitivity to electrical fields, and (v) easy multiplexing of sensors. The areas of potential applications are in process monitoring, in health monitoring of smart structures, and in biomedical applications.

Optical Fiber Sensor for an On-Line Monitoring of Epoxy Resin/Amine Reaction

---Farid Fouchal and Jeffery A. G. Knight, Faculty of Technology and Computing Science, De Montfort University, The Gateway, Leicester, LE1 9BH, United Kingdom

---An optical fiber sensor is described; it permits a rapid determination of the state of chemical reaction in epoxy resin diglycidyl ether or bisphenol A (DGEBA), and Triethylenetetramine stoichiometric ratio. Mid Infrared Fourier transform technique is used to analyze the mixture via an embedded optical fiber connected to an FTIR spectrometer, which operates in the region 4000-700 cm-1 of the electromagnetic waves. An accurate monitoring of the concentrations versus time of epoxy; amine and hydroxyl groups gave a good estimate of extent of reaction and description of physical state of the produced matrix. The chemical group peaks 1130 cm-1 and 3300-3400 cm-1 were used to follow the disappearance of the epoxy, and the amine respectively, while the peak 2970 cm-1 was used as reference peak. A review of a number of other techniques used in the study of the curing of epoxy resins as well as a number of on-line monitoring methods used in thermoset resin cure process is referred to.

Summary of Results from an Ultrasonic In-Flight Wing Ice Detection System

---Derrick D. Hongerholt, BFGoodrich Aerospace, Aircraft Sensors, 14300 Judicial Road, M/S FF14, Burnsville, MN 55306-4898; Joseph L. Rose, Engineering Science and Mechanics, The Pennsylvania State University, University Park, PA 16802

---Discussions and sample results are presented for an in-flight wing ice accretion/sublimation detector based on newly developed ultrasonic guided wave sensors and measurements. Detection over a fairly large area can be accomplished with these sensors. The sensors are also adaptable to various airfoil geometries. Physical principles, hardware, and computational methods are outlined along with a description of two flight demonstration programs. Excellent results are obtained, pointing to the potential for immediate field use of this new ice detection technology.

A Low-Frequency Wheel Probe for Automotive Adhesive-Bond Inspection

---Alex M. Robinson and Bruce W. Drinkwater, Department of Mechanical Engineering, Queen's Building, University of Bristol, University Walk Bristol, BS8 1TR, United Kingdom

---A new form of dry-coupled wheel-probe and method of operation have been developed to allow improved quality assurance of in-process adhesive bonding during vehicle manufacture. The new probe operates at a much lower frequency than existing wheel probes for bond testing - now having a center-frequency of 500 kHz, and allows a more robust detection technique to be employed. This new technique measures the resonant ringing of a specimen region after reflection of an ultrasound pulse to determine the geometry and hence the bond state of that locality. This method can identify the very wide range of permissible adhesive thicknesses found in automotive structures, allowing reliable detection of disbonded regions. The device has also been integrated into a scanning system and portable data analysis and recording instrument allowing its use in a production environment. An account is given of the technical design of the probe, including the need to understand and remove unwanted sound reverberations within the wheel structure. Results demonstrating the probe's intrinsic performance, including its much lesser dependence on accurate alignment than earlier probes, and an analysis of the contact pressures required are presented. Recorded scans of both prepared laboratory specimens and actual joints from production vehicles are also included.

Design and Performance of Wireless Sensors for Structural Health Monitoring

---D. Watters, P. Jayaweera, A. Bahr, and D. Huestis, SRI International, 333 Ravenswood Avenue, Menlo Park, CA 94025

---SRI International is currently developing a series of wireless sensors for various applications in structural health monitoring. These devices are based on integrating a sensor with a commercial radio-frequency identification (RFID) chip. The chip is passive and is activated by inductively coupled power from a remote interrogator/reader. When activated, the chip responds with a digitally encoded signal that not only identifies the sensor, but also contains information about the sensor state. To date, we have developed two devices: Once indicates whether a particular temperature threshold has been exceeded and is intended for monitoring the heat exposure of the material underneath the thermal protection system (tiles) on the Space Shuttle. The other device is being designed to monitor the level of chloride ingress into concrete bridge decks, with an ultimate goal of including these sensors in the concrete pour when the deck is constructed. This paper discusses the basic concepts and design issues associated with such RFID/sensor hybrids and presents preliminary performance data.

The Effect of Magnetic Field Sensor Lift-off on SMFM Crack Signals

---Amir H. Salemi, Seyed H. H. Sadeghi, and Rouzbeh Moini, Department of Electrical Engineering, Amirkabir University of Technology, 424 Hafez Avenue, Tehran 15914, Iran

---The Surface Magnetic Field Measurement (SMFM) technique has proved to be an accurate means for crack detection and sizing cracks in ferrous metals. The technique involves the use of two U-shaped current-carrying wires of sufficiently high frequency while measuring the discontinuity in the resultant magnetic field at the crack edge with an appropriate magnetic field sensor. In the model developed for the SMFM technique, it is assumed that the sensor is placed very close to the metal surface and is capable of monitoring point measurements of the surface magnetic field. In practice, however, the surface of the work-piece may be covered with such layers of insulating materials as paint, so that the close proximity of the sensor and the metal surface may not be possible. As a result, the output signal of the SMFM sensor can be affected by the sensor left-off distance from the metal surface, causing some measurement errors. In this work, we describe a mathematical model to predict SMFM crack signals for an arbitrary sensor lift-off. Predicted crack signals for various values of crack depth and sensor lift-off will be presented. It is shown that the sensor lift-off trends to smear out the discontinuity in the crack signal. Also, for large sensor lift-off distances, the conventional inversion technique introduces significant errors in crack sizing.

The Use of Embedded Sensors for Composite NDE

---K. A. Lavere, L. D. Thompson, and R. A. Kline, San Diego Center for Materials Research, San Diego State University, 5500 Campanile Drive, San Diego, CA 92182

---The development of rapid, on-line monitoring techniques to evaluate the current state of critical elements in complex structures has been the objective of many recent research studies. "Smart" materials offer the promise of being able to detect and identify potential material performance problems in the early stages of their development, before they reach criticality, and substantially degrade material performance capabilities. Practical examples of this technology are beginning to emerge in a wide variety of areas including automotive, aircraft and civil infrastructure where it is important to detect and diagnose potential problems in their early stages of development. In this work we employ a novel approach to composite NDE by embedding sensor wire directly into the composite. These wires are formed from a steel alloy that exhibits a phase transformation from a paramagnetic phase to a ferromagnetic phase with deformation (TRIP, Transformation Induced Plasticity steel). These wires serve as passive strain monitors and provide a means of determining the peak strain experienced at any particular point in the composite simply by measuring how much ferrous material is present. This can be achieved with a variety of electromagnetic sensor approaches including SQUID (Superconducting Quantum Interference Device) magnetometers (as reported in an earlier paper) or eddy current probes and GMR (Giant Magneto Resistive) sensors, as used in this work. TRIP steel wires were placed directly into the laminate prior to curing. The cured composite was then subjected to mechanical load (tension, flexure) or impact and electromagnetically interrogated. From these measurements, the resolution capability of the approach can be evaluated both in terms of strain sensitivity and spatial resolution. Results are compared with conventional ultrasonic C-scans from the impact-loaded specimens to evaluate the utility of this approach.

Fidelity of an Analytical Time Reversal Sensor

---Anthony D. Puckett and Michael L. Peterson, University of Maine, Department of Mechanical Engineering, Orono, ME 04469-5711

---Waveguides are commonly used in high temperature ultrasonic monitoring applications. The waveguides used in these applications distort the input signal due to dispersion and the generation of multiple modes. A time reversal process can be used to reconstruct the modes and remove the effects of dispersion. Experiments were performed to demonstrate the fidelity of a simple time reversal process. An analytic transfer function was also developed to predict the time-reversed signal from an input signal. The analytic transfer function was applied to the time-reversed signal to reproduce the original input signal. The fidelity of the transfer function was evaluated by the ability to reproduce the original signal. The time-reversed signal was then used to demonstrate the applicability of the techniques to high temperature monitoring of oxidation of composite materials.

Development of Giant Magnetoresistive (GMR) Inspection System for Detection of Deep Fatigue Cracks under Airframe Fasteners

---Buzz Wincheski, Min Namkung, and Dan Perey, NASA Langley Research Center, Hampton, VA, 23681; John Simpson and Ed Scales, Lockheed Martin Engineering and Sciences Corporation, Hampton, VA, 23681

---Giant magnetoresistive sensors offer many advantages for electromagnetic inspection of deeply buried flaws in conductive materials. Previous work has shown that a GMR based self-nulling probe could detect flaws buried up to 1 cm in an aluminum alloy test specimen, and that the probe design was compatible with the NASA LaRC developed Rotating Self-Nulling Probe System. Continued development has resulted in a prototype system for field deployment. A redesign of the GMR based Self-Nulling Probe has been performed based upon initial experimental and finite element analyses. The resulting probe footprint has been greatly reduced without significantly effecting the depth of detection of the device. Electronics for the probe drive and signal detection circuitry have also been updated. The new electronics deliver variable phase outputs for drive and feedback signals and produces high gain at flaw detection frequencies. The complete system configuration is presented, along with results for the detection of fatigue cracks in sub-layer airframe components.

A Multiplexed Two-Wave Mixing Interferometer for Laser Ultrasonic Measurements of Material Anisotropy

---Yi Zhou, Todd W. Murray, and Sridhar Krishnaswamy, Northwestern University, Center for Quality Engineering and Failure Prevention, 2137 Sheridan Road, Catalysis Building, Room 331, Evanston, IL 60208-3020

---At Northwestern University, we have previously demonstrated a method to optically measure ultrasonic displacements simultaneously over an array of detection points. Optical phase gratings are used to create a detection-array of laser beams that are directed to the specimen. The detection array can be arranged in several ways on the test object. The scattered beams from the detection-array are collected and combined with a single reference beam in a photorefractive crystal to from a multiplexed two-wave mixing (MTWM) configuration. Each of the output beams from the photorefractive crystal is imaged on to a separate element of a photodetector array. The resulting MTWM system is capable of providing simultaneous optical detection (with high spatial resolution and sub-nanometer displacement sensitivities) at several points on a test object. The MTWM system can be used in several modes for laser ultrasonic NDE of flaws and materials characterization. In this paper, the MTWM is used to characterize material anisotropy. Surface acoustic waves (SAWs) are generated using a pulsed laser focused to a point on a test object. The resulting SAW propagation is monitored optically simultaneously at 8 points arranged circularly around the generating spot. The scattered beams from the eight detection points are processed simultaneously in the MTWM setup. The group velocity slowness curve is obtained directly from the measured signals from the MTWM array. Results are shown for silicon and quartz. It is shown that the MTWM enables rapid experimental determination of material anisotropy.

Tuesday, July 31, 2001

SESSION 7

ULTRASONIC TRANSDUCER ARRAYS

R. C. Addison, Jr., Chairperson
Smith Auditorium (Sills)

8:30 AM **Boosting the Application of Ultrasonic Arrays**
---M. Spies and W. Gebhardt, Fraunhofer-Institute for Nondestructive Testing, IZFP, University Building 37, 66123 Saarbrucken, Germany

8:50 AM **Element Parameters for Ultrasonic Phased Arrays**
---M. D. C. Moles, R/D Tech, 1200 Aerowood Drive, Unit #30, Mississauga, Ontario, Canada L4W 2S7; F. Cancre, R/D Tech USA, 240 Bear Hill Road, Suite 104, Waltham, MA 02154

9:10 AM **Optimum Phased Array Element Shapes**
---S.-C. Wooh and F. J. Pompei, Massachusetts Institute of Technology, Department of Civil and Environmental Engineering, 77 Massachusetts Avenue, Cambridge, MA 02139

9:30 AM **Phased Array Ultrasonic System for the Inspection of Titanium Billets**
---Benoit Lacroix, R/D Tech Inc., 4495, Boul. Wilfrid-Hamel, Quebec, G1P 2J7, Canada; Vincent Lupien, Acoustic Ideas, Inc., 25 Eaton Street, Wakefield, MA 01880; Andy Kinney and Tim Duffy, Honeywell Engines and Systems, 111 S. 34th Street, M/S 301-227, Phoenix, AZ 85034; Pramod Khandelwal, Rolls-Royce Corporation, P. O. Box 420, W-5, Indianapolis, IN 46206-0420; Harpreet S. Wasan, Pratt & Whitney, 8801 Macon Road, Columbus, GA 31908

9:50 AM **Phased Array Ultrasonic Examination of Space Shuttle Main Engine Nozzle Weld**
---M. Suits, NASA-Marshall Space Flight Center, Huntsville, AL; J. Engel, Boeing Space and Communications, Huntington Beach, CA; S. James, Boeing Space and Communications, Canoga Park, CA; D. Kimbrough, Boeing Space and Communications, Canoga Park, CA

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

10:30 AM **Evaluation of Phased Array Ultrasonics for Aging Aircraft Applications**
---R. W. Engelbart and R. J. Lord, The Boeing Company, P. O. Box 516, M/C S1021322, St. Louis, MO 63166

10:50 AM **Two-Dimensional Phased Array Probe Shape Corrections**
---V. Lupien, Acoustic Ideas, Inc., 25 Eaton Street, Wakefield, MA 01880; F. Cancre and B. Lacroix, R/D Tech Inc.; J. T. Miller and J. J. Selman, Lockheed-Martin; A. Kinney and T. Duffy, Honeywell Engines and Systems; P. G. Herzog, Air Force NDI Office, Tinker AFB, Oklahoma City, OK 73125

11:10 AM **Inspection of Aircraft Fastener Holes Using a Conically Shaped Multi-Element Phased Array Probe**
---J. J. Selman and J. T. Miller, Lockheed Martin Aeronautics Company, Marietta, GA 30063-0617; M. D. C. Moles and O. Dupuis, R/D Tech Inc., Quebec, PC, Canada; P. G. Herzog, Air Force NDI Office, Tinker AFB, Oklahoma City, OK 73125

11:30 AM **Modeling and Application of Phased Array Techniques Dedicated to Complex Geometry Inspection**
---S. Mahaut, O. Roy, S. Chatillon, and P. Calmon, GEA, DRT/LIST/STA, CEA Saclay, 91191 Gif-sur-Yvette, Cedex, France

12:10 PM ***Lunch***

Boosting the Application of Ultrasonic Arrays

---Martin Spies and Wolfgang Gebhardt, Fraunhofer-Institute for Nondestructive Testing, IZFP, University Bldg. 37, 66123 Saarbrucken, Germany

---Single- or dual-element angle beam transducers exhibit operating characteristics suitable for a large range of practical field applications. These capabilities can be improved by operating such transducers as phased arrays, where each of the array elements can be pulsed with appropriate time delays, thus controlling the shape and the sound beam direction on a large scale. However, the usually complicated handling of the available array systems - together with their high costs - have been an obstacle to a wider application of this technique. Our contribution describes the strategy currently pursued at IZFP to improve this situation and to simultaneously optimize the performance of ultrasonic arrays. The first part of this strategy is aiming at the improvement of piezoelectric composite materials, which are characterized by a high electromechanical coupling coefficient, broad bandwidth and mechanical flexibility. The piezo-composites are at present fabricated using the dice-and-fill technique, which will in the near-future be replaced by a sol-gel technique leading to a considerable reduction of costs. The second part of our strategy is pursued within a close corporation of three Fraunhofer-Institutes, where phased array components are designed and developed on the basis of highly integrated electronic units. Finally, appropriate software has been elaborated for delay time calculation with respect to a large variety of inspection problems. Appropriate models are used to simulate and optimize the generated beam fields and the detected flaw signals, where curved surfaces and interfaces as well as specific material properties such as anisotropy and viscoelasticity can be accounted for. This bundle of measures is intended to open a wider field of applications by reducing the costs and at the same time improving the capabilities and the reliability of ultrasonic array systems. Illustrative examples and results will be presented.

Element Parameters for Ultrasonic Phased Arrays

---Michael D. C. Moles, R/D Tech, 1200 Aerowood Drive, Unit #30, Mississauga, Ontario, Canada L4W 2S7; Fabrice Cancre, R/D Tech USA, 240 Bear Hill Road, Suite 104, Waltham, MA 02154

---Ultrasonic phased arrays offer major advantages for inspections of a wide variety of components. Phased arrays permit the ultrasound beam to be swept, steered, scanned and focused statically or dynamically. However, selection of the array is critical to optimize the inspection, and to minimize equipment requirements. Specifically, the choice of element size dictates most of the other features of the inspection system; the element size is normally based on the beam steering and grating lobe specifications. The array design is also critical: for most regular phased array inspections (e.g. welds, corrosion mapping), a linear array is adequate; for three-dimensional inspections (e.g. turbine blades and trees), a matrix array is required to provide full beam steering; for large components (e.g. billets), a variable focus is required, and these typically use a sectorial-annular design. The array design and element size is custom designed to the application. Smaller elements give better beam steering and resolution. Normally, actual element size becomes a practical trade-off between costs and requirements. This presentation will describe a number of applications using smaller elements, which show the benefits of reducing array element size, and increasing frequency. Different array configurations will be described, from matrix arrays to sparse arrays. Examples will be presented from aerospace, heavy industry and power generation, with arrays of up to 500 elements.

Optimum Phased Array Element Shapes

---Shi-Chang Wooh and F. Joseph Pompei, Department of Civil and Environmental Engineering, Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, MA 02139

---Most techniques for suppressing grating lobes in phased arrays while relaxing the interelement spacing requirement involve redistributing array elements in sparse aperiodic patterns, or varying the transmit-receive beam patterns. An alternative is presented which uses oversized array elements to eliminate grating lobes as a direct consequence of the element shape. It is shown that by using carefully shaped, overlapping elements, maximum scan angle can be exchanged for a reduced interelement spacing requirement.

Phased Array Ultrasonic System for the Inspection of Titanium Billets

---Benoit Lacroix, R/D Tech Inc., 4495, Boul. Wilfrid-Hamel, Quebec, G1P 2J7, Canada; Vincent Lupien, Acoustic Ideas, Inc., 25 Eaton Street, Wakefield, MA 01880; Andy Kinney and Tim Duffy, Honeywell Engines and Systems, 111 S. 34th Street, M/S 301-227, Phoenix, AZ 85034; Pramod Khandelwal, Rolls-Royce Corporation, P. O. Box 420, W-5, Indianapolis, IN 46206-0420; Harpreet S. Wasan, Pratt & Whitney, 8801 Macon Road, Columbus, GA 31908

---Titanium billets are used as raw material for the manufacturing of airplane engine parts. A phased array ultrasonic system was developed by R/D Tech mainly to improve the detectability and reduce the number of probes to inspect a large range of billet diameters, compared to the existing conventional and multi-zone focusing ultrasonic systems. The Dynamic Depth Focusing (DDF) technique is used to expand the depth of field of the probe and inspect the whole depth range by firing only once. The phased array probes are made of a pre-focused segmented elliptic annular array of piezocomposite elements designed to create a constant diameter and round focal spot throughout the inspected depth range. The probes are characterized after manufacturing and an electronic correction can be made if necessary to correct for non-negligible position errors of the elements. Billets from 5" to 14" of diameter were inspected using only two phased array probes. The results obtained show a high detectability on flat bottom holes and validate the DDF algorithm improving inspection speed. Finally, a complete system with customized software interface was developed to fit the operational method used by the titanium manufacturers to inspect the billets.

Phased Array Ultrasonic Examination of Space Shuttle Main Engine Nozzle Weld

---M. Suits, NASA – Marshall Space Flight Center, Huntsville, AL; J. Engel, Boeing Space and Communications, Huntington Beach, CA; S. James, Boeing Space and Communications, Canoga Park, CA; D. Kimbrough, Boeing Space and Communications, Canoga Park, CA

---This paper describes a Phased Array Ultrasonic Examination approach that was developed for the examination of a limited access circumferential Inconel 718 fusion weld used on the Space Shuttle Main Engine Nozzle - Cone. The paper discusses the basic principles of ultrasonic wave manipulation using phased array technology, the selection and formation criteria used for the phased array focal laws on this application, and interpretation of the results. Several unique constraints present during this examination included physical interferences that limited probe movement to a single axis and one-sided access to the weld. The weld configuration included an electro-deposited nickel plating on the inaccessible inside diameter surface and a chem-milled step adjacent to the weld zone on the outside diameter. Detection of an embedded 0.012" deep x 0.300" long EDM notch (oriented at 30 degrees from normal within the weld zone) was the targeted calibration requirement for this application. The development of the reference standard that simulated these conditions, laboratory demonstration of the examination concept, and the results will be presented.

Evaluation of Phased Array Ultrasonics for Aging Aircraft Applications

---Roger W. Engelbart and Robert J. Lord, The Boeing Company, P. O. Box 516 M/C S1021322, St. Louis, MO 63166

---Detection of corrosion and cracking in aging airframes are currently major military logistics concerns. Reducing maintenance and inspection costs are also of interest. Ultrasonic inspection is often used to detect the referenced anomalies. For the most part, these inspections are still performed manually using single element transducers. A multiple element approach, also known as a phased array, offers some promise in improving ultrasonic inspection from the standpoints of probability of detection, data interpretation and cycle time. A study was recently conducted to evaluate an ultrasonic phased array for detection of corrosion and cracks around installed fasteners. Specimens extracted from actual aircraft wing structure served as standards for the evaluation. A prototype 128-element array was used to scan around fastener holes that contained corrosion and simulated cracks. It was concluded that the promising results derived from this initial feasibility study warranted a follow-on effort to optimize arrays for specific applications. This paper describes the results of this feasibility study along with recommendations for future work.

Two-Dimensional Phased Array Probe Shape Corrections

---Vincent Lupien, Acoustic Ideas, Inc., 25 Eaton Street, Wakefield, MA 01880; Fabrice Cancre and Benoit Lacroix, R/D Tech Inc. Tech Inc.; Ted Miller and John Selman, Lockheed-Martin; Andy Kinney and Tim Duffy, Honeywell Engines and Systems; Pamela G. Herzog, Air Force NDI Office, Tinker AFB, Oklahoma City, OK 73125

---The availability of non-destructive testing hardware capable of controlling large numbers of elements has made possible forays into two-dimensional arrays. Here, we explore two such arrays. The first is a conical matrix array for three-dimensional imaging of fastener holes in aircraft wing structures, and the second is an annular-sectorial array with a compound radius of curvature for the inspection of aircraft engine grade billets. In both prototypes, significant departures of the true shape the probe face from its ideal value are observed. Since the shape aberrations are many wavelengths in magnitude, it is impossible to arrive at the desired beam profile using the beamforming parameters for the ideal probe shape. We detail our approach for correcting the beamforming process. It is based on a combination of parametric representations of probe shape families and experimental measurements with specially designed targets. While exposing current limitations in the probe manufacturing process, our results demonstrate that complicated probe malformations of many wavelengths in magnitude can easily be corrected and that the spatially disjoint nature of two-dimensional arrays becomes an opportunity for such corrections.

Inspection of Aircraft Fastener Holes Using a Conically Shaped Multi-Element Phased Array Probe

---John J. Selman and James T. Miller, Lockheed Martin Aeronautics Company, Marietta, GA 30063-0617; Michael Moles and Olivier Dupuis, R/D Tech Inc., Quebec, PC, Canada; Pamela G. Herzog, Air Force NDI Office, Tinker AFB, Oklahoma City, OK 73125

---In early 1999, the USAF initiated a project to replace the Autoscan - a fastener hole inspection system developed in the late 1970's to detect faying surface cracks in the first layer around the base of a fastener hole with fasteners installed. A novel inspection technique using phased ultrasonic arrays is being developed for rapidly and reliably inspecting the area around fastener holes with no moving parts. This technique uses a newly designed ultrasonic phased array probe incorporating a two-dimensional matrix of ultrasonic elements arranged in a conical configuration encircling the fastener head. This arrangement permits deflection of the ultrasonic beam in three dimensions, i.e., in two planes, and adapts to different hole sizes and skin thickness. Full circumferential scans are performed using a pre-programmed sequence of phased array focal laws. The inspection method uses pulse-echo at a variety of angles incident on the crack (primarily corner trapping), plus local scanning in a volume around the base of the hole. Overall, this capability provides improved coverage of the fastener hole and surrounding area, and is designed to detect cracks as small as 0.030" in length. The new inspection method is scheduled to undergo validation testing in the fall of 2001.

Modeling and Application of Phased Array Techniques Dedicated to Complex Geometry Inspection

---S. Mahaut, O. Roy, S. Chatillon, and P. Calmon, GEA, DRT/LIST/STA, CEA Saclay, 91191 Gif-sur-Yvette Cedex, France

---Ultrasonic inspection of complex geometry components has to cope with different problems: limited access of the area assumed to be insonified, beam misorientation and distortions, loss of sensitivity. Those harmful effects can lead to inspection performance degradations, especially in terms of defect detection and characterization. Phased array techniques may be used to overcome such difficulties, as they can provide an optimal mastering of the ultrasonic beam radiated through the inspected component. This paper presents some studies of phased array techniques carried out by the French Atomic Energy Commission (CEA) to improve inspections of components with varying profile. Such inspection configurations have been simulated using standard and phased arrays transducers. Optimal delay laws have been computed to preserve the beam characteristics in spite of the varying profile geometry encountered as the phased array transducer was moved over the component. Those delay laws, which allowed to efficiently compensate the beam distortions generated by the profile geometry, were computed using a specific model, and compared to experimental delays obtained using through transmission tests. Experimental and simulation results showed that the defect detection and characterization performances were greatly enhanced using phased array techniques. In the presented examples, with standard transducers, defects located below the irregular parts of the specimen were partially detected, inaccurately located or even missed, whereas phased array inspections enabled to detect and locate all of these defects.

SESSION 8
ADHESIVE BONDS, FILMS, AND COATINGS
M. Lowe, Chairperson
Sills 117

8:30 AM **Shear Wave Velocity Measurements of Thin Epoxy Adhesive Samples Using Broadband EMATs**
---S. Dixon, C. Edwards, and S. B. Palmer, University of Warwick, Department of Physics, Gibbet Hill Road, Coventry, CV4 7AL, United Kingdom

8:50 AM **Ultrasonic Determination of Environmental Degradation of Interfacial Properties in Adhesive Bonds**
---A. Baltazar, B. Xie, L. Wang, and S. I. Rokhlin, The Ohio State University, NDE Program, Edison Joining Technologies Center, 1248 Arthur E. Adams Drive, Columbus, OH 43221

9:10 AM **Investigation of Moisture Ingress into Adhesive Joints Using Ultrasonic and Dielectric NDE Techniques**
---V. L. Weise and G. Armstrong, QinetiQ, Structures and Materials Center, Griffith Building (A7), Ively Road, Farnborough, Hampshire, GU14 0LX, United Kingdom

9:30 AM **A Robust Technique for Disbond Detection in the Automotive Industry**
---J. Allin, M. J. S. Lowe, and P. Cawley, Imperial College of Science, Technology, and Medicine, Department of Mechanical Engineering, London, SW7 2BX, United Kingdom

9:50 AM **Anisotropic Layer Characterization Using Phase Velocities of Ultrasonic Bulk Waves Generated and Detected with Lasers**
---B. Audoin and F. Reverdy, Laboratoire de Mécanique Physique, UMR CNRS n? 5469, Université Bordeaux I, 351 Cours de la Libération, 33405, Talence, Cedex, France

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

10:30 AM **Laser Ultrasonic Measurement of Mechanical Properties of Nanometer-Sized Thin Film MEMS Structures**
---C. M. Hernandez, T. W. Murray, and S. Krishnaswamy, Northwestern University, Center for Quality Engineering and Failure Prevention, 2137 N. Sheridan Road, Evanston, IL 60208-3020

10:50 AM **Elastic Properties of Organic Thin Film by Acoustic Microscopy**
---J. Du, C. Miyasaka, and B. R. Tittmann, The Pennsylvania State University, Dept. of Engineering Science and Mechanics, 212 Earth and Eng. Science Bldg., University Park, PA 16802

11:10 AM **Effects of Optical Penetration in Axisymmetric Wave Propagation in Thin Films**
---C. Cetinkaya, J. Lin, and R. Vanderwood, Clarkson University, Center for Advanced Materials Processing, Department of Mechanical and Aeronautical Engineering, CAMP 241, Box 5725, Potsdam, NY 13699-5725

11:30 AM **Nondestructive Evaluation of Cermet Coatings Using Eddy Current and Ultrasonic Techniques**
---B. Rogé[1], J. S. R. Giguere[2], K. I. McRae[2], and A. Fahr[1], [1]Institute for Aerospace Research, NRC of Canada, 1200 Montreal Road, Building M-14, Ottawa, Canada; [2]Air Vehicle Research Section, National Defense Headquarters, 1200 Montreal Road, Building M-7, Ottawa, Canada

11:50 AM **Laser-Ultrasonic Characterization of a Zinc Layer on a Steel Substrate Using Surface Acoustic Waves**
---B. Chenni, Laboratoire d'Acoustique Ultrasonore et d'Electronique, UPRESA CNRS 6068; Université du Havre, Place Robert Schuman, 76610 Le Havre Cedex, France; A. Moreau, Ind. Materials Institute, NRC of Canada, 75 de Mortagne, Boucherville, Quebec, Canada J4B 6Y4

12:10 PM ***Lunch***

Shear Wave Velocity Measurements of Thin Epoxy Adhesive Samples Using Broadband EMATs

---S. Dixon, C. Edwards, and S. B. Palmer, University of Warwick, Department of Physics, Gibbet Hill Road, Coventry, CV4 7AL, United Kingdom

---This paper describes an ultrasonic analysis of thin epoxy resin samples using broadband normal incidence radially polarized shear wave ElectroMagnetic Acoustic Transducers (EMATs). The adhesive thickness in the experiments was approximately 0.5mm, which is slightly higher than would be expected in an ideal bond, but is the optimum thickness for experimental measurement using shear waves at megahertz frequencies. Measurements were taken at a range of elevated temperatures of adhesive cure. Two part cartridge adhesive systems were used, where the adhesive is mixed by injection through a mixing nozzle. The technique gives an accurate measurement of the shear wave velocity in the thin adhesive layer to within 1.5% error. We observed unexpected variations in the elastic properties of the cast resin from a single cartridge which appears to depend on the order that the adhesive was extruded from the cartridge. The non-contact nature of the EMATs and their ability to operate in a send-receive mode makes them a viable candidate for ultrasonic measurements in an industrial environment.

Ultrasonic Determination of Environmental Degradation of Interfacial Properties in Adhesive Bonds

---A. Baltazar, B. Xie, L. Wang, and S. I. Rokhlin, The Ohio State University, Nondestructive Evaluation Program, Edison Joining Technologies Center, 1248 Arthur E. Adams Drive, Columbus, OH 43221

---Environmental degradation of interface properties in adhesive bonds is studied using an angle beam ultrasonic spectroscopy. The experimental results were obtained for aluminum joints bonded with a commercial FM-73 adhesive. To avoid the adhesive creep in an environment, the bonded sample was prepared without Al surface anodization and priming assuring fast interface degradation. The degradation was controlled by time in the environment, which consisted of NaCl saturated water at 68?C. To simulate the changes of interfacial properties, the interface imperfections are modeled with normal and shear springs. The inverse reconstruction of unknown interfacial and bulk adhesive properties of the bonded area was performed as a function of the degradation time. It is shown that in the environment predominantly shear stiffness changes with time indicating water diffusion to the interface. It is also shown that the bulk adhesive and interfacial properties could be decoupled by the analysis of the resonance frequency shift when the interfacial stiffness of the layered system is varied.---This work was sponsored by the Federal Aviation Administration under contract #DTFA03-98-D-00008 and performed at The Nondestructive Evaluation Program at The Ohio State University as part of the Center for Aviation Systems Reliability program through the Airworthiness Assurance Center of Excellence.

Investigation of Moisture Ingress into Adhesive Joints Using Ultrasonic and Dielectric NDE Techniques

---Victoria Weise and Gordon Armstrong, QinetiQ, Structures and Materials Centre, Griffith Building (A7), Ively Road, Farnborough, Hampshire GU14 0LX, United Kingdom

---The use of adhesives in industry, particularly the aerospace industry, is widespread for many types of application, including those of structural significance. During service, military and civilian aircraft are exposed to harsh environmental conditions with moisture being responsible for the majority of bond failures. By identifying and characterizing the causes of such bond failures, improved production quality, yield and cost reduction may be achieved. This paper presents the results from a study of ultrasonic and dielectric NDE techniques for measuring the environmental degradation of adhesive joints and these are compared to the (destructive) mechanical strength of the joint. The water-ingress into the joint was monitored and the effects of different aluminum surface treatments assessed. It has been possible to track water ingress and the onset of corrosion in adhesive joints using ultrasonic time-domain techniques such as: narrow-band pulsed spectrometry and shear-wave propagation. Further, by low frequency dielectric analysis, the ingress of water was monitored and quantified. Segregated mechanical tests on the joints indicated that a large decrease in shear strength had occurred which was consistent with the detection of marked changes observed in the ultrasonic NDE data and dielectric measurement.

A Robust Technique for Disbond Detection in the Automotive Industry

---J. Allin, M. J. S. Lowe, and P. Cawley, Department of Mechanical Engineering, Imperial College of Science, Technology and Medicine, London, SW7 2BX, United Kingdom

---Current methods for disbond detection in adhesive bonded joints used in the aerospace industry are not generally suitable for use in the automotive industry. This is due primarily to wide variations in adhesive thickness (a range of 0.1-3.0mm in acceptable joints is commonly found), and also a requirement for dry contact testing after the curing and painting process. This paper describes the development of a robust technique for the detection of disbonds in bonded joints, based on the fundamental through-thickness resonance (mode 1) frequency of joint. The specified adhesive thickness range in fully bonded joints is used to predict a corresponding range of mode 1 frequencies, which are much higher when the joint is disbonded. During testing, the mode 1 resonance is excited in the joint and the received time domain signal is windowed to leave only the 'ringing' of this first mode. If the frequency of this ringing falls into the range predicted for the bonded joint, then the bond integrity is confirmed. Further investigation has shown that narrow beads of adhesive and tapered adhesive layers, which occur in practice, do not affect the reliability of this technique. Successful implementation with a dry contact 'dabber' probe has enabled the test to be done without contaminating the painted surface, and the technique has been programmed into a stand-alone instrument to give a direct readout of bond condition on the production line.

Anisotropic Layer Characterization Using Phase Velocities of Ultrasonic Bulk Waves Generated and Detected with Lasers

---B. Audoin and F. Reverdy, Laboratoire de Mécanique Physique, UMR CNRS n? 5469, Université Bordeaux 1, 351, Cours de la Libération, 33405-Talence, Cedex, France

---Protective layers are receiving growing attention for several industrial applications. As a consequence, there is a need to develop nondestructive testing methods for the monitoring of defects, such as the appearance of microcracks, in the layer. In this work, a noncontact laser-ultrasonic technique is described that allows the determination of stiffness properties of an anisotropic layer bounded to a substrate. The method requires access to only one side of the structure. Plane waves are synthesized by scanning the surface with a laser line source at judiciously chosen intervals. By doing so, the intricacies associated with the reflection of an acoustic ray off the interface between the anisotropic media are avoided. The plane-wave reflections off the interface are simply governed by Snell's law. The identification of the stiffness-tensor components is based on the inversion of the phase velocities of these reflected plane waves. The accuracy of the method is demonstrated using simulated signals. The components of the stiffness tensor of a 2.5 mm thick composite layer, lying on a concrete substrate, are then experimentally measured without any contact to the specimen.

Laser Ultrasonic Measurement of Mechanical Properties of Nanometer-Sized Thin Film MEMS Structures

---Carmen M. Hernandez, Todd W. Murray, and Sridhar Krishnaswamy, Northwestern University, Center for Quality Engineering and Failure Prevention, 2137 Sheridan Road, Room 327, Evanston, IL 60208-3020

---Many MEMS devices such as pressure sensors and optical-switches use thin film membranes that are nanometers thick and microns wide. To characterize such MEMS devices, it is important to accurately and nondestructively measure elastic stiffnesses and residual stresses in free-standing thin films. Current methods for obtaining mechanical properties and residual stresses include nano-indentation, bulge, and resonance frequency tests. Unfortunately these measurements are either destructive or depend critically on knowledge of how the thin films are supported. Laser ultrasonics (photo-acoustics) is a potentially powerful tool for nondestructive, in situ, MEMS device characterization. This paper discusses the use of narrowband photo-acoustics to characterize the properties of free-standing nanometer-sized thin films. Photo-acoustic generation is achieved by use of a micro-chip laser which deposits pulsed laser energy (10 ?J in 300 picoseconds) in the form of a spatially periodic source on the structure. The resulting narrowband ultrasonic modes are monitored using a Michelson interferometer. By varying the geometry of the spatially-periodic source, a wide range of wavenumbers is probed. Experiments were conducted on two-layer Al/Si3N4 membranes (aluminum thickness: 300-500nm; silicon nitride thickness: 240-400nm). For such thin films, only the two lowest order modes are generated and these in turn can be related to sheet and flexural modes in plates. The mechanical properties and residual stress in the thin films are evaluated from the dispersion curves for these two lowest order modes.

Elastic Properties of Organic Thin Film by Acoustic Microscopy

---Jikai Du, Chiaki Miyasaka, and Bernhard R. Tittmann, Department of Engineering Science and Mechanics, The Pennsylvania State University, 212 Earth and Engineering Science Building, University Park, PA 16802

---The rapid screening of organic films and coatings on high modulus substrates is emerging as an important aspect of material characterization in many fields ranging from microelectronics to anticorrosion protection to recovery of hidden art paintings. This use of acoustic microscopy is appealing because of its ability to image sub-surface and to measure some elastic properties. However one major dilemma is the inability to generate surface acoustic waves in the films which are typically of low velocity and high attenuation. In this paper an analytical acoustical microscopy V(z) model for a two-layer system (organic thin film (low modulus) on thick substrate (high modulus)) is developed, from which the elastic properties of thin film can be separated from the substrate and determined. The reflectance function is derived and V(z) curves are numerically simulated at different frequencies (200 and 400 MHz) on thin films of different property and thicknesses. Experimental results are obtained on different samples, such as biological tissue on fused quartz, and the reflectance functions are calculated from V(z) curves through Fourier transform techniques. Through analyses of theoretical and experimental results and comparison between them, it can be seen that at proper frequencies and film thicknesses, the different modes can be observed and their phase velocities and reflection coefficients can be measured. These are then used to calculate the elastic properties of organic thin films. Limitations of the method will be also discussed.

Effects of Optical Penetration in Axisymmetric Wave Propagation in Thin Films

---C. Cetinkaya, J. Lin, and R. Vanderwood, Clarkson University, Center for Advanced Materials Processing, Department of Mechanical and Aeronautical Engineering, CAMP 241, Box 5725, Potsdam, NY 13699-5725

---A first principal-based fully-coupled thermoelastic formulation based on the equations of motion and heat equation is developed to study the effects of optical penetration in axisymmetric wave propagation in thermoelastic layers and layered structures. The current approach is based on Laplace and Hankel integral transforms in time and space. It is shown that while the optical penetration has no effect on the entries of the sextic transfer matrix, it introduces a forcing term for all state variables (i.e., displacements, stress, heat and temperature) for the both surfaces of a thermoelastic layer. This forcing term is functions of excitation frequency, radial wave number, penetration decay rate, and material properties. Complexities in wavefields due to the nature of the forcing term are demonstrated. A method based on the current formulation for determining the optical penetration depth is proposed. The formulation developed can also be used for layered structures. Applications include in (1) NDE of thin films and/or layered coatings, (2) measurement of the optical penetration depths, (3) use as a manufacturing method for opening up interfaces between a film and substrate, and (4) study of wavefield and beam directionality due to the optical penetration.

Nondestructive Evaluation of Cermet Coatings Using Eddy Current and Ultrasonic Techniques

---B. Rogé[1], J. S. R. Giguère[2], K. I. McRae[2], and A. Fahr[1], [1]Institute for Aerospace Research, National Research Council of Canada, 1200 Montreal Road, Bldg. M-14, Ottawa, Canada; [2]Air Vehicle Research Section, National Defense Headquarters, 1200 Montreal Road, Bldg. M-7, Ottawa, Canada

---Surface modification processes are cost effective methods to improve the performance of components in cases where the increased resistance is only required at the surface. The aerospace industry has taken advantage of these methods for critical applications, such as aircraft landing gears. Of specific interest are cermet coatings such as tungsten carbide with Cr-Co matrix. These coatings are composites consisting of both ceramic and metallic phases and are deposited via high velocity oxygen fuel (HVOF) thermal spray systems. This deposition process yields very dense coatings with reduced changes in the phase composition of the material. The coating effectiveness is dependent on composition, microstructure and overall structural integrity. This requirement justifies the use of nondestructive evaluation (NDE) methods to assess the uniformity of the coating thickness and to detect discontinuities or degradation. Thus, the aim of this work is to evaluate the applicability of eddy current and ultrasonic techniques for the NDE of a tungsten carbide coating in terms of quantitative assessment of thickness uniformity and detection of internal flaws.

Laser-Ultrasonic Characterization of a Zinc Layer on a Steel Substrate Using Surface Acoustic Waves

---B. Chenni, Laboratoire d'Acoustique Ultrasonore et d'Electronique, UPRESA CNRS 6068, Université du Havre, Place Robert Schuman, 76610 Le Havre Cedex, France; A. Moreau, Industrial Materials Institute, National Research Council of Canada, 75 de Mortagne, Boucherville, Quebec, Canada J4B 6Y4

---Laser-ultrasound spectroscopy, a non-contact ultrasonic technique was used to characterize the Lame coefficients, density and thickness of a Zn layer on a steel substrate. This characterization is based on the adjustment of measured velocity dispersion curve of surface acoustic waves (SAW) on a calculated one using the conjugates gradients algorithm (C.G). A short laser pulse was used to generate a wideband pulse of ultrasound and a laser interferometer is used for its detection. From a large number of echoes we identified the one corresponding to the SAW. Furthermore other useful information were obtained from these data like attenuation and surface skimming longitudinal wave. The velocity dispersion curve of the Rayleigh wave was calculated in the frequency range of 1-200 MHz and measurements were achieved up to 70 MHz. The evaluation of layer's parameters performed for similar cases, on a pseudo-experimental model, were obtained with accuracy better then 1% for density, thickness and the "Mu" Lame coefficient; and about 4% to 6% for the "Lambda" coefficient.
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Tuesday, July 31, 2001

SESSION 9
EDDY CURRENT THEORY AND APPLICATION
R. Clark, Chairperson
Druckenmiller 016

8:30 AM **Interpretation of Pulsed Eddy Current Signals for Locating and Quantifying Metal Loss in Thin Skin Lap Splices**
---B. A. Lepine[1], J. S. R. Giguere[2], D. S. Forsyth[1], J. M. S. Dubois[3], and A. Chahbaz[4], [1]National Research Council of Canada, Institute for Aerospace Research, Ottawa, Canada; [2]Air Vehicle Research Section, Defense R&D Canada, Ottawa, Canada; [3]Royal Military College of Canada, Kingston, Canada; [4]Tektrend International Inc., Montreal, Canada

8:50 AM **Signal Phase Indication of Flaw Depth by a Lift-Off Noise Free Eddy Current Probe**
---H. Hoshikawa, K. Koyama, and M. Maeda, Nihon University, Izumicho Narashino Chiba, 275-8575, Japan

9:10 AM **Eddy Current Decay Patterns in Aluminum Alloys**
---M. Namkung and B. Wincheski, NASA Langley Research Center, MS 231, Hampton, VA 23681; S. M. Paik, Institute of Computer Application in Science and Engineering, Hampton, VA 23681

9:30 AM **A Method of Large Crack Discrimination in Saturated Eddy Current Signals by Integration**
---T. J. Braun and G. C. Upton, Veridian Engineering, Systems Integration Group, 2800 Indian Ripple Road, Dayton, OH 45440-3896

9:50 AM **Edge Processing Technique for Differential Reflection Eddy Current Probes**
---T. J. Braun, Veridian Engineering, Systems Integration Group, 2800 Indian Ripple Road, Dayton, OH 45440-3896

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

10:30 AM **Pulsed Eddy Current for Metal Surface Cracks Inspection: Theory and Experiment**
---C.-C. Tai, D.-S. Liang, and H.-C. Yang, Department of Electrical Engineering, National Cheng Kung University, 1 University Road, Tainan, Taiwan 701, China

10:50 AM **Recent Advances in Modeling Eddy-Current Probes**
---H. A. Sabbagh, E. H. Sabbagh, and R. K. Murphy, Victor Technologies, LLC, P. O. Box 7706, Bloomington, IN 47407-7706

11:10 AM **Validation of a Volume-Integral Eddy-Current Code by Benchmark Experiments**
---H. A. Sabbagh, E. H. Sabbagh, and R. K. Murphy, Victor Technologies, LLC, P. O. Box 7706, Bloomington, IN 47407-7706

11:30 AM **Method and Software for Eddy Current NDE Analysis**
---P. A. Kurbatov, V. P. Lunin, and Y. V. Kulayev, Moscow Power Engineering Institute, Department of Electrical Engineering, Moscow, Russia

11:50 AM **Role of Electric Potential in Eddy Current Testing Phenomena**
---H. Hoshikawa, K. Koyama, and M. Maeda, Izumicho Narashino Chiba, 275-8575, Japan

12:10 PM ***Lunch***

Interpretation of Pulsed Eddy Current Signals for Locating and Quantifying Metal Loss in Thin Skin Lap Splices

---B. A. Lepine[1], J. S. R. Giguere[2], D. S. Forsyth[1], J. M. S. Dubois[3], [1]National Research Council of Canada, Institute for Aerospace Research Ottawa, Canada; [2]Air Vehicle Research Section, Defense R&D Canada, Ottawa, Canada; [3]Royal Military College of Canada, Kingston, Canada

---Recent efforts in pulsed eddy current (PEC) NDE research have focused on the development of probes and signal interpretation methods for quantifying hidden corrosion in aircraft fuselage lap splices. Several key features in the pick-up coil's transient responses have been identified and related to specific test parameter and material property changes. While many features are related to flaw size and location, most, such as maximum amplitude, are severely affected by probe lift-off variations and interlayer separations in multi-layered structures. The "pillowing" effect exhibited in lap splices due to corrosion products or manufacturing imperfections, for example, not only cause probe lift-off, but also increase interlayer gaps that exaggerate or falsely create corrosion indications. In previous work, a lift-off insensitive feature, known as the lift-off point of intersection (LOI), was developed into an effective scanning technique for detecting and estimating corrosion damage in real-time. We present several other PEC signal features and interpretation techniques for locating and quantifying metal loss in calibration specimens and naturally corroded lap splices in the presence of both lift-off and interlayer gap variations. The results obtained using these new PEC techniques are compared with data from teardown inspections of naturally corroded lap splices removed from aircraft.

Signal Phase Indication of Flaw Depth by a Lift-off Noise Free Eddy Current Probe

---Hiroshi Hoshikawa, Kiyoshi Koyama, and Masashi Maeda, Nihon University, Izumicho Narashino Chiba, 275-8575, Japan

---The conventional surface eddy current probes suffer from large lift-off noise which makes eddy current testing unable to utilize the signal phase for the flaw evaluation. Since the eddy current testing using conventional probes estimate flaws only based on the signal amplitude that changes due to variations of length, depth and width of flaws, the conventional eddy current testing has hardly ever been considered as a quantitative method evaluating the depth of flaws. The authors have devised a new eddy current surface probe that is lift-off noise free. The probe is comprised of a circular exciting coil and a rectangular tangential detecting coil arranged at the center of the exciting coil. The exciting coil induces axi-symmetrical eddy current in the test material and the detecting coil generates a signal only when some of the eddy current flows along the detecting coil. The probe generates no signal as long as the induced eddy current is kept axi-symmetrical. Thus the probe generates no lift-off noise. The probe was named **T-**probe because of its shape of the coil windings when seen from its top. The eddy current testing using the probe provides the phase information on the flaw depth just like the inner bobbin coil probe used for the eddy current inspection of tubing. The authors reported experimental results of non-magnetic material by the probe at the 27th QNDE conference in 2000. The authors have conducted experiments of ferromagnetic material by the **T-**probe. The results have shown that the signal phase changes according to the depth of surface flaws in ferromagnetic material. Thus the phase of the flaw signal can be utilized to evaluate the depth of flaws in ferromagnetic materials and the new probe can make the eddy current testing quantitative to evaluate the depth of flaws in ferromagnetic material.

Eddy Current Decay Patterns in Aluminum Alloys

---Min Namkung and Buzz Wincheski, NASA Langley Research Center, MS 231, Hampton, VA 23681; Sun Mok Paik, Institute of Computer Application in Science and Engineering, Hampton, VA 23681

---Eddy current decay experiments were performed with aluminum alloy specimens of varying thickness. A GMR sensor and a digital scope were used to record the magnetic field amplitude. The decay rate of eddy current increased upon increasing the specimen thickness up to 6 mm. Numerical calculation was performed for a step function input signal by integrating the eddy current response expression of Dodd and Deeds. The results of experiments and calculation are in excellent agreement. Experiments were also performed for a given specimen thickness while varying the distance between the excitation coil and specimen surface (lift-off distance). When re-scaled, all the decay patterns for a given specimen thickness collapse into a single curve regardless of lift-off distance, proving that the decay pattern is a unique function of test specimen thickness.

A Method of Large Crack Discrimination in Saturated Eddy Current Signals by Integration

---Timothy J. Braun and Gabriel C. Upton, Systems Integration Group, Veridian Engineering, 2800 Indian Ripple Road, Dayton, OH 45440-3896

---The use of the shape or bobbin coil probe to inspect dovetail slots on jet engine disks has been implemented for several years on the Veridian Eddy Current Inspection System which is heavily utilized on the USAF Retirement for Cause program. This type of probe offers wide zone coverage comparable to array probes but requires only a single drive and two receive elements for full compatibility with the US500 eddyscope or it's older counterpart the NDT25. In this application the axis of the coil windings are oriented roughly parallel to the slot axis and is also coincident with the direction of slot cracking. Amplitude response versus crack size is linear on a log-log scale for crack lengths shorter than a critical percentage of the coil thickness but at larger crack sizes system response flattens. At this point simple amplitude discrimination between varying sizes is no longer feasible. However signal duration and crack length have been shown to correlate well and simple signal integration techniques obtain desired levels of response gradient for size discrimination. The integration method and pre and post processed data will be presented for this technique.

Edge Processing Technique for Differential Reflection Eddy Current Probes

---Timothy J. Braun, Systems Integration Group, Veridian Engineering, 2800 Indian Ripple Road, Dayton, OH 45440-3896

---The resultant signal from an eddy current probe crossing an edge is problematic in which to resolve crack indications. A common technique to reduce edge signal response is to employ a differential reflection "D" probe oriented such that receive coils differentiate along the edge. However even in the best circumstances in which carefully electrically balanced coils are precisely positioned and scanned by a robot, in our case the Veridian Eddy Current Inspection System ECIS, these differentiation methods often yield edge signals which mask the desired defect signal. To account for this undesired effect Veridian Engineering has developed a series of algorithms based on signal subtraction techniques which have successfully provided the necessary edge suppression to allow adequate crack detection in this area. However early endeavors to solve this problem have produced convoluted algorithms that often fail to converge under initial seed values and may require multiple reiteration prior to obtaining a solution. Aside from increased inspection times on an already heavily burdened ECIS, software maintainability is cumbersome due to the complexity of code. The presented material represents an accumulation of work to the development of a simplified series of algorithms in which conversion is often achieved in a fewer number of steps. By the technology provided Veridian has been able to achieve a 90 percent POD on cracks as small as 10 x 10 and 5 x 5 mil in production and laboratory environments respectively.

Pulsed Eddy Current for Metal Surface Cracks Inspection: Theory and Experiment

---Cheng-Chi Tai, Dong-Shong Liang, and Hung-Chi Yang, Department of Electrical Engineering, National Cheng Kung University, 1 University Road, Tainan, Taiwan 701, China

---The pulsed eddy current (PEC) technique applied on inspecting metal surface cracks from theoretical and experimental aspects will be demonstrated in this work. In the previous work, we have showed that the PEC technique can be used to inspect surface cracks with depth 0.5 mm to 9 mm. The results showed that the relationship between PEC signals and crack depth is obvious. In this work, we further study this topic from both theoretical and experimental aspects. More experimental results, including measurements on fatigue cracks, will be showed and compared. We also try to give time-domain predication that based on transformation from frequency-domain theoretical calculations.

Recent Advances in Modeling Eddy-Current Probes

---Harold A. Sabbagh, Elias H. Sabbagh, and R. Kim Murphy, Victor Technologies, LLC, P. O. Box 7706, Bloomington, IN 47407-7706

---The ability of VIC-3D? , a proprietary volume-integral code, to model eddy-current probes has been significantly enhanced to include coils of virtually any shape, such as racetrack, D-shaped, and square, and oriented in virtually any direction. This allows the ability to model such well-known probes as the split-core differential probe, even when tilted relative to the workpiece, and the plus-point probe, that is often used in the nuclear power industry. We briefly describe the mathematical theory behind these general probe models, and give an example or two of computed results.

Validation of a Volume-Integral Eddy-Current Code by Benchmark Experiments

---Harold A. Sabbagh, Elias H. Sabbagh, and R. Kim Murphy, Victor Technologies, LLC, P. O. Box 7706, Bloomington, IN 47407-7706

---Model computations of the response of eddy-current probes to a variety of flaws are compared to data provided by benchmark experiments. VIC-3D? , a proprietary volume-integral code, is used to provide the model results, which are then compared to experimental data for (a) cracks in a double-plate system (suggestive of airframes), (b) cracks with discontinuous profiles, and (c) cracks with complex, double-peaked shapes (suggestive of multi-site damage). The model calculations agree closely with the experimental data in all cases.

Method and Software for Eddy Current NDE Analysis

---Pavel A. Kurbatov, Valery P. Lunin, and Yuri V. Kulayev, Department of Electrical Engineering, Moscow Power Engineering Institute, Moscow, Russia

---The calculations of impedance for test problem WF of NDE are done by authors. Impedance calculations types: flaw impedance of 100 coil positions, 4 value of current frequency, 2 types of 2D system (ring flaw), 2 types of 3D system (limited flaw) and 3 gap values between differential coils. The mathematical model based on spatial integral equations for electromagnetic field sources. For reaching a demanded exactitude the formula concerning difference field sources is used. This formula allows to dedicate influence of flaws to impedance. The difference formula allows to divide an initial problem on basic (field calculation in a flawless area) and difference (field calculation in simple flaw) without usage of padding simplifications. Besides such approach allows to reduce number of alternatives up to 2400 for 2D-flawless systems and 8 alternatives of a system with 2D-flaw and as much for 3D-flaw. The calculation results are presented by the way of hodograph of impedance from flaw. The calculations are conducted using the author's software in Moscow Power Engineering Institute, Department of Electrical Engineering.

Role of Electric Potential in Eddy Current Testing Phenomena

---Hiroshi Hoshikawa, Kiyoshi Koyama, and Masashi Maeda, Izumicho Narashino Chiba 275-8575, Japan

---It is well known that electromagnetic induction induces eddy current in conducting material. However, the role of electric potential has hardly ever been reported in eddy current testing. The authors have studied the eddy current induced around small discontinuities such as a slit flaw and have clarified that electric potential plays a major role in inducing eddy current around small discontinuities. Test coils and materials are arranged axi-symmetrically in most cases of eddy current testing. When the exciting coil and test material are arranged axi-symmetrically in electromagnetic induction, no electric potential is generated in the material and the eddy current is induced only by electromotive force by electromagnetic induction. As a result, attention has been concentrated to the eddy current induced by electromagnetic induction and the role of electric potential has hardly ever been taken into consideration in eddy current testing although a lot of reports have been published on the analysis of eddy current testing. The authors indicate at the conference presentation that electric potential plays important roles in eddy current phenomena. When the exciting coils and test material are not arranged axi-symmetrically, the electromotive force by electromagnetic induction is converted to the electric potential. The gradient of the potential causes eddy current to flow in different directions from the electromagnetic induction vector in the area where there is a discontinuity such as a crack in the test material. It is electric potential that diverts the eddy current around discontinuities. Thus electric potential plays an important role in inducing eddy current in the test materials. The authors also propose an aquarium model where the water circulates in the aquarium in order to help understand the electromagnetic induction phenomena in conducting material.

Tuesday, July 31, 2001

SESSION 10
THERMAL WAVE NDE
X. Han, Chairperson
Cleaveland 151 (Druckenmiller)

8:30 AM **Discriminating Porosity in Composites Using Thermal Depth Imaging**
---H. I. Ringermacher, D. R. Howard, and R. S. Gilmore, General Electric Research and Development Center, P. O. Box 8, Schenectady, NY 12301

8:50 AM **Industrial Uses of a New Hybrid Ultrasonic/Infrared NDT Technique**
---D. L. Simon, General Motors Corporation, Advanced Engineering Staff B/60, 30300 Mound Road, Warren, MI 48090-9040

9:10 AM **Ultrasound Burst Phase Thermography – Elastic Waves for Defect Selective NDT**
---A. Dillenz, T. Zweschper, N. Krohn, and G. Busse, University of Stuttgart, Institute for Polymer Testing and Polymer Sciences – Nondestructive Testing (IZP-ZFP), Pfaffenwaldring 32, 70569, Stuttgart, Germany

9:30 AM **Single Sided Thermal Diffusivity Imaging with a Shuttered Thermographic Inspection System**
---W. P. Winfree, NASA Langley Research Center, MS 231, Hampton, VA 23681-2199; J. N. Zalameda, U. S. Army Research Laboratory, Vehicle Technology Directorate, Hampton, VA 23681

9:50 AM **Recent Developments in Thermosonic Crack Detection**
---X. Han, Wayne State University, Electrical and Computer Engineering, 5050 Anthony Wayne Drive #3140, Detroit, MI 48202; L. D. Favro, Z. Ouyang, and R. L. Thomas, Wayne State University, Institute for Manufacturing Research, 666 W. Hancock, Detroit, MI 48202

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

10:30 AM **Parallel Processing and Analysis of Thermographic Data**
---S. M. Shepard, D. Wang, J. R. Lhota, T. Ahmed, and B. A. Rubadeux, Thermal Wave Imaging, Inc., 845 Livermois, Ferndale, MI 48220

10:50 AM **Pulsed Thermographic Modeling**
---I. Perez, Naval Air Warfare Center, Aircraft Division, Materials Division, Patuxent River, MD 20670; X. Han, Wayne State University, Electrical and Computer Engineering, 5050 Anthony Wayne Drive #3140, Detroit, MI 48202

11:10 AM **Analysis of Quantitative Measurement of Defect by Pulsed Thermal Imaging**
---J. G. Sun, Energy Technology Division, Argonne National Laboratory, 9700 South Cass Avenue, Argonne, IL 60439-4825

11:30 AM **Theoretical Modeling of Thermosonic Imaging of Cracks**
---Z. Ouyang, L. D. Favro, and R. L. Thomas, Wayne State University, Institute for Manufacturing Research, 666 W. Hancock, Detroit, MI 48202; X. Han, Wayne State University, Electrical and Computer Engineering, 5050 Anthony Wayne Drive #3140, Detroit, MI 48202

11:50 AM **Applications for ThermoSoniX**
---A. A. Richards, Indigo Systems Corporation, 5385 Hollister Avenue, Suite 103, Santa Barbara, CA 93117

12:10 PM ***Lunch***

Discriminating Porosity in Composites Using Thermal Depth Imaging

---H. I. Ringermacher, D. R. Howard, and R. S. Gilmore, General Electric Research and Development Center, P. O. Box 8, Schenectady, NY 12301

---Porosity evaluation in composites has been extensively studied with ultrasonics. There are far fewer examples of porosity evaluation using thermal imaging. One reason for this dearth of work has been the qualitative nature of most thermal characterization. In this paper we use quantitative thermal depth imaging to identify, for the first time, the characteristic signature of planes of dense porosity in composites. The observations are compared with results from thermal theory and modeling of porosity and with ultrasonic characterization. This approach should eventually lead to a quantitative thermal evaluation of volume % porosity in composites.

Industrial Uses of a New Hybrid Ultrasonic/Infrared NDT Technique

---Daniel L. Simon, General Motors Corporation, Advanced Engineering Staff B/60, 30300 Mound Road, Warren, MI 48090-9040

---A new NDT technique is being investigated that combines ultrasonic energy to excite a defect in a material with infrared imaging to detect that defect. Defects such as cracks, delaminations, disbands, and others can be made to self heat when ultrasonic energy is introduced into a fabricated part. Infrared thermal imaging is used to capture the location and orientation of that defect for subsequent analysis. General Motors Corporation is exploring the different uses of this technique for possible implementation as a new NDT technique in its continuous efforts to increase quality of its products, increase safety of its employees, lower the cost of manufacturing and reduce scrap. Several visual and thermal images will be presented to show the capability of this technique to detect various defects in metals and other materials. A list of possible applications will be reviewed to help kick start the implementation of this NDT technique into U.S. industry.

Ultrasound Burst Phase Thermography – Elastic Waves for Defect Selective NDT

---Alexander Dillenz, Thomas Zweschper, Nils Krohn, and Gerd Busse, Institute for Polymer Testing and Polymer Sciences – Nondestructive Testing (IZP-ZFP), University of Stuttgart, Pfaffenwaldring 32, 70569, Stuttgart, Germany

---Ultrasound Burst Phase Thermography (UPT) is a rapid and reliable non-destructive technique derived from Ultrasound Lock-In Thermography (ULT) which was established a few years ago. Both ULT and UPT provide defect selective imaging using thermal waves that are generated by absorption of elastic waves. The mechanism involved is local friction or hysteresis which turns a variably loaded defect into a heat source which is identified by thermography even in the presence of complicated intact features. In comparison to the sinusoidal excitation of the ULT method, UPT uses only short ultrasound bursts. Therefore UPT combines the advantages of both lockin and pulse thermography. It allows for faster measurements with a better reproducibility. However, the advantages of phase images are the same: depth resolved detection of defects, suppression of inhomogeneous infrared emissivity and temperature gradients. We present the application of UPT to the defect detection of aircraft materials and components.

Single Sided Thermal Diffusivity Imaging with a Shuttered Thermographic Inspection System

---William P. Winfree, NASA Langley Research Center, MS 231, Hampton, VA 23681-2199; Joseph N. Zalameda, U. S. Army Research Laboratory, Vehicle Technology Directorate, Hampton, VA 23681

---Most diffusivity images of specimens are obtained from measurement configurations with an infrared imager and a flash heating source on the opposite sides of the specimen. This paper discusses a measurement configuration where shutters are placed in front of the imager and the flash lamps. Proper timing for the opening and closing of the shutters eliminates a direct interaction between the imager and flash lamps for a single sided measurement, enabling accurate measurement of the thermal response of a specimen. The time dependence of thermal response can be analyzed to produce an image of the effective diffusivity of the specimen. In regions with a constant diffusivity through the thickness, this techniques yields diffusivity values which are in good agreement with two sided measurement results. In regions with discontinuities in the diffusivity through the thickness, the single side measurement yields a measurement of the depth of the discontinuity, which is difficult to obtain with two sided techniques. Results on composite specimens with delaminations are presented.

Recent Developments in Thermosonic Crack Detection

---Xiaoyan Han, Electrical and Computer Engineering, Wayne State University, Detroit, MI 48202; Lawrence D. Favro, Zhong Ouyang, and Robert L. Thomas, Institute for Manufacturing Research, Wayne State University, 666 W. Hancock, Detroit, MI 48202

---We will describe recent developments in thermosonic crack detection. This technique, uses a single short pulse of sound to cause cracks to heat up and become visible in the infrared. A low frequency (15 to 40 kHz) ultrasonic transducer fills the sample with sound that causes frictional heating at crack interfaces. We will show that the technique can be applied equally well to quite large and irregularly shaped objects, and to small delicate objects using the same apparatus. We will present examples of this technology to cracks as small as 20 microns and as large as several inches, and to materials ranging from brittle ceramics, to soft metals and composites. The initial phases of this work were supported by the Institute for Manufacturing Research (IMR), Wayne State University.---The work is currently being supported by DOT/FAA William J. Hughes Technical Center's Airworthiness Assurance Center of Excellence (AACE), under Contract Number DTFA0398D-00008, by the U.S. Navy, NSWC, under P. O. Number N00167-00-M0498, by Universal Technology Corporation, under Contract Number F33615-97-D-5271, Task Order 0002-030, Subcontract Agreement 01-S437-002-30-C1, and by IMR. We also wish to thank Dr. Thomas Moran of AFML for supplying some of the titanium fatigue samples.

Parallel Processing and Analysis of Thermographic Data

---Steven M. Shepard, David Wang, James R. Lhota, Tasdiq Ahmed, and Bruce A. Rubadeux, Thermal Wave Imaging, Inc., 845 Livermois, Ferndale, MI 48220

---Pulsed Thermography has become a widely used NDE technique for a variety of manufacturing and in-service applications in the energy, aerospace and automotive industries. However, inspection of large structures (e.g. aircraft rudders, elevators and stabilizers) poses a challenge, since data can be acquired quickly, but serial processing and analysis of individual files may require several additional hours. Furthermore, the ability of Pulsed Thermography to evaluate massive structures or deeply buried defects is limited because of the inherent effects of diffusion. By creating a "synthetic" signal for the time evolution of each pixel from the raw data, we have been able to reduce the size of the data structure representing an acquisition by an order of magnitude, and significantly increase the (temporal) signal to noise content of the data set. The net result is a compact, noise reduced structure that can be easily manipulated. In fact, multiple data sets can be manipulated simultaneously, so that an entire array of data sets acquired from a large structure inspection can be viewed an analyzed at once. Automated processing and depth measurement can also be performed on the array of data sets. Examples on aircraft and turbine engine components will be presented.

Pulsed Thermographic Modeling

---Ignacio Perez, Naval Air Warefare Center, Aircraft Division, Materials Division, Patuxent River, MD 20670; Xiaoyan Han, Department of Electrical and Computer Engineering, Wayne State University, 5050 Anthony Wayne Dr., #3140, Detroit, MI 48202

---A simple thermographic model has been developed that accurately describes the surface temperature response of a panel with flat bottom holes of different depths and diameters to a short heat pulse. This model assumes that a thin layer of material absorbs a radiant pulse of duration t and that it subsequently cools off due to lateral and normal diffusion of the deposited energy into the bulk of the material. The model takes into account other experimental parameters such as sample thickness, density, specific heat, in-plane and out-of-plane thermal conductivity and defect size and depth. In this talk we will present experimental and modeling results on an aluminum panel with flat bottom holes of different radii and depth. The effects of heat pulse duration will be presented and discussed. The experimental results were collected with standard pulse thermographic equipment and the experimental data was analyzed with our model.

Analysis of Quantitative Measurement of Defect by Pulsed Thermal Imaging

---J. G. Sun, Energy Technology Division, Argonne National Laboratory, 9700 South Cass Avenue, Argonne, IL 60439-4825

---Pulsed infrared thermal imaging is now commonly used as a nondestructive evaluation technique to detect defects in structural components. However, defect detectability and quantitative measurement of defects by this technique and the reliability of the technique are not well established. Using a three-dimensional transient-heat transfer code, we performed a numerical analysis to simulate the heat transfer process during a pulsed thermal-imaging test for axisymmetric plates that contained various internal defects. A lateral air gap of various sizes and thicknesses was considered the defect. Numerical data were fed into conventional experimental programs to determine either a thermal-diffusivity map or a defect-depth map. Because the numerical simulations assumed ideal conditions, i.e., without material variations and experimental-system noises, the results represent optimal sensitivity to defect detection by the pulsed thermal imaging technique. The numerical analysis and results will be discussed.---Work supported by the U.S. Department of Energy, Energy Efficiency and Renewable Energy, Office of Industrial Technologies, Industrial Materials for the Future Program, under Contract W-31-109-ENG-38.

Theoretical Modeling of Thermosonic Imaging of Cracks

---Zhong Ouyang, Lawrence D. Favro, and Robert L. Thomas, Institute for Manufacturing Research, Wayne State University, 666 W. Hancock, Detroit, MI 48202; Xiaoyan Han, Electrical and Computer Engineering, Wayne State University, Detroit, MI 48202

---We present a theoretical model to describe the thermosonic imaging of surface-breaking and subsurface cracks. Theoretical images will be presented for various geometries and depths, and for various orientations with respect to the surface being imaged. Illustrative comparisons with experimental observations will be presented.---The initial phases of this work were supported by the Institute for Manufacturing Research (IMR), Wayne State University. The work is currently being supported by DOT/FAA William J. Hughes Technical Center's Airworthiness Assurance Center of Excellence (AACE), under Contract Number DTFA0398D-00008, by the U.S. Navy, NSWC, under P. O. Number N00167-00-M0498, by Universal Technology Corporation, under Contract Number F33615-97-D-5271, Task Order 0002-030, Subcontract Agreement 01-S437-002-30-C1, and by IMR.

Applications for ThermoSoniX

---Austin A. Richards, Indigo Systems Corporation, 5385 Hollister Avenue, Suite 103, Santa Barbara, CA 93117

---Austin Richards will discuss applications for the ThermoSoniX test station, a commercial product based on the sonic infrared technology developed at Wayne State University. ThermoSoniX is a compact, portable sonic IR system that uses a cooled indium antimonide infrared camera to image flaws in materials. The ThermoSoniX test station uses a 400 watt ultrasonic source for excitation of parts under test. This system has been used for detecting cracks in different specimens. Results from some of the applications will be presented and discussed.

Tuesday, July 31, 2001

SESSION 11 - POSTERS
SENSORS, ELECTROMAGNETIC METHODS, ULTRASONIC MODELING AND APPLICATIONS, NDE OF PROCESS AND PROCESS CONTROL
Smith Union: Morrell and Lamarche Lounges

1:30 PM

Sensors

Intrinsic Fiber-Optic Ultrasonic Sensor Array Using Multiplexed Two-Wave Mixing Interferometry
---P. Fomitchov, T. W. Murray, and S. Krishnaswamy, Northwestern University, Center for Quality Engineering and Failure Prevention, 2137 N. Sheridan Road, Evanston, IL 60208

Measurement of Air-Coupled Transducers Characteristics for Ultrasonic Nondestructive Evaluation
---C. Biateau and B. Hosten, Laboratoire de Mécanique Physique, Université Bordeaux I, UMR CNRS 5469, 351 Cours de la Libération, 33405 Talence, Cedex, France; D. Roziere, Fogale Nanotech Parc Kennedy, Bat. 3, 285 Rue Gilles Roberval, 30900 Nimes, France

Development of a Fully Automated Knife Edge Inspection Using the Veridian Eddy Current Inspection System
---J. E. Ruthenberg, Veridian Engineering, Systems Integration Group, 2700 Indian Ripple Road, Dayton, OH 45440-3638; K. Oldson, Uniwest Corporation, Pasco, WA

Detection of Discontinuity in the Reflector-Radiator Adhesive Layers Based on the Electromagnetically Induced Acoustic Signals Evaluation
---Y. I. Bulbik[1] and B. A. Belyaev[2], [1]Siberian Aerospace Academy, Krasnoyarsk 660014; [2]Institute of Physics, Siberian Division of Russian Academy of Sciences, Krasnoyarsk 660036

Resonant Ultrasonic Vibration Detection Study
---T. C. Hale and T. J. Asaki, Los Alamos National Laboratory, Measurement Technology Group-ESA, Mail Stop C914, Los Alamos, NM 87545

Magnetic Field Gradient Measurement on Magnetic Cards with Magnetic Force Microscopy
---C. C. H. Lo and D. C. Jiles, Iowa State University, Center for NDE, Ames, IA 50011; J. Leib, Iowa State University, Department of Materials Science and Engineering, Ames, IA 50011; W. C. Chedister, Circle Systems, Inc., Hinckley, IL 60520

Requirements for Reproducible, High-Power, Short Rise-Time Pulser for Thick-Transducer Applications
---P. M. Gammell, 6139 Pleasant Cove Drive, Exmore, VA 23350; G. R. Harris, Food and Drug Administration, Center for Devices and Radiological Health, Rockville, MD 20850

Parametric Studies of Laser Ultrasonic Signals in Ablative Regime: Time and Frequency Domains
---B. Mi and C. Ume, Georgia Institute of Technology, Woodruff School of Mechanical Engineering, 801 Ferst Drive N.W., Atlanta, GA 30332-0405

CPC-48—A System for Noncontact Film Build Measuring in Production
---K. Paige, S&G Technologies, 1 Whitmore Road, Unit 18, Woodbridge, Ontario L4L 8G4, Canada

Electromagnetic Methods

Numerical Simulation of the Measurement Coils for Damage Detection in Large Metallic Corps
---A. Lukjaniuk and A. Jordan, Technical University of Bialystok, Institute of Electrical Engineering, Grunwaldzka str. 11/15, 15-893 Bialystok, Poland

The Implementation of a Flexible Bobbin Coil to Inspect Dovetail Slots
---G. C. Upton, Veridian Engineering, Systems Integration Group, 2700 Indian Ripple Road, Dayton, OH 45440; K. Oldson, Uniwest Corporation, Pasco, WA; S. Pickering, Pratt & Whitney, Hartford, CT; G. Taube, Aeronautical Systems Center/Propulsion Directorate, Wright-Patterson AFB, OH 45433

Comparison of Different Measurement Configurations for Nondestructive Testing of Well-Conducting Materials
---R. Sikora, Technical University of Szczecin, Electrical Engineering Faculty, Ul. Sikorskiego 37, 70-313-Szczecin, Poland; R. Palka, Technical University of Braunschweig, Institut f. elektr. Maschinen, Braunschweig, Germany

The Interaction of Pulsed Eddy Current with Metal Surface Crack for Various Coils
---H.-C. Yang and C.-C. Tai, National Cheng Kung University, Department of Electrical Engineering, 1 University Road, Tainan, Taiwan 701, China

Detection of Surface Cracks of Arbitrary Shape in Metals Using an Open-Ended Waveguide Probe
---F. Mazlumi, S. H. H. Sadeghi, and R. Moini, Amirkabir University, Department of Electrical Engineering, 424 Hafez Avenue, Tehran 15914, Iran

Microwave Analysis of Accelerated Chloride Ingress in Type I/II, III and V Mortar
---T. Case, K. Donnell, D. Hughes, and R. Zoughi, University of Missouri-Rolla, Applied Microwave Nondestructive Testing Laboratory (*amntl*), Electrical and Computer Engineering Department, Rolla, MO 65409; K. E. Kurtis, Georgia Institute of Technology, School of Civil and Environmental Engineering, Atlanta, GA 30332-0355

Microwave Detection of Delaminations Between Fiber Reinforced Polymer (FRP) Composites and Concrete Substrate
---D. Hughes[1], A. Prota[2], R. Zoughi[1], and A. Nanni[2], [1]University of Missouri-Rolla, Applied Microwave Nondestructive Testing Laboratory (*amntl*), Electrical and Computer Engineering Department, Rolla, MO 65409; [2]University of Missouri-Rolla, Center for Infrastructure Engineering Studies (CIES), Rolla, MO 65409

Multiplexed HTS rf SQUID Magnetometer Array for Eddy Current Testing of Aircraft Rivet Joints
---S. Gaertner, H.-J. Krause, N. Wolters, D. Lomparski, W. Wolf, and J. Schubert, Institute of Thin Films and Interfaces, Research Center Juelich, Germany

Ultrasonic Modeling and Applications

Determination of the Effective Focal Characteristics of Bicylindrically Focused Ultrasonic Transducers
---F. J. Margetan, R. Roberts, C.-P. Chiou, and R. B. Thompson, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

Ultrasonic Scattering Analysis of Flaws by Gauss-Hermite Beam Model and a Boundary Element Method
---H. Jeong, Wonkwang University, Division of Mechanical Engineering, Iksan, Chonbuk, Korea; J.-H. Kim, Pusan National University, School of Mechanical Engineering, Pusan, Korea

A Matrix Method for Numerical Computation of Field Radiated and Receipted by Acoustic Transducers
---W.-J. Xu and M. Ourak, Institut d'Electronique et de Microélectronique du Nord (UMR CNRS 8520), Département Opto-Acousto-Electronique, Université de Valenciennes, Valenciennes, France

Inverse Scattering Analysis for a Defect in a Plate
---Y. Hara and S. Hirose, Tokyo Institute of Technology, Department of Mechanical and Environmental Informatics, 2-12-1 O-okayama, Meguro-ku, Tokyo 152-8552, Japan

Theoretical Stress Evaluation of Intact and Cracked Ellipsoidal Inhomogeneity Using FEM
---Y. T. Cho[1] and K. H. Im[2], [1]Institute of Engineering and Technology, Jeonju University, 1200 Hyoja-dong 3-ga, Wansan-gu, Jeonju 560-759, Korea; [2]Woosuk University, Department of Automotive Engineering, 490 Hujung-ri, Samrae-up, Wanju-gun, Chonbuk, 565-701, Korea; H. G. Kim, Jeonju University, School of Mechanical Engineering, 1200 Hyoja-dong 3-ga, Wansan-gu, Jeonju 560-759, Korea; S. K. Park and O. S. Kim, Yosu National University, Division of Mechanical and Automotive Engineering, San 96-1 Dunkduck-dong, Yosu, Chonnam 550-749, Korea; J. Y. Ko, Mokpo National Maritime University, Faculty of Ocean System Engineering, 571-2, Chukyo-dong, Mokpo, Chonnam 530-739, Korea; J. W. Park, Chosun University, RRC and School of Architecture and Ocean Engineering, 375 Sosok-dong, Dong-gu, Kwangju, 501-749, Korea

Estimating the Ultrasonic Reflectivity of Naturally Occurring Flaws
---R. S. Gilmore, General Electric Research & Development, P. O. Box 8, Schenectady, NY 12301

Further Development of 3D Ultrasonic Ray Tracing in AutoCAD
---D. Reilly, NDTSoft, 47 Hazel Road, Abronhill, Cumbernauld, Glasgow, G67 3BN, Scotland; A. McNab, University of Strathclyde, Center for Ultrasonic Engineering, Department of Electronic and Electrical Engineering, Glasgow, G1 1XW, Scotland

A Software Package for Simulating Ultrasonic Inspections in 3D CAD Geometry
---M. Garton and T. Gray, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

Recent Advances in CAD-Based UT Simulation in CIVA
---P. Calmon, S. Chatillon, L. Le Ber, and S. Le Berre, French Atomic Energy Comission, CEA/LIST/CEA-Saclay, bât. 611, 91191 Gif-sur-Yvette, Cedex, France

The Effect of Defect Depth, Axial, and Circumferential Extent on the Reflection of Extensional Guided Waves in Pipes
---F. Simonetti, M. J. S. Lowe, P. Cawley, and C. Chevalier, Imperial College of Science, Technology, and Medicine, Department of Mechanical Engineering, London, SW7 2BX, United Kingdom; B. Roosenbrand, Shell Global Solutions, Badhuisweg 3, 1031 CM Amsterdam, P. O. Box 38000, The Netherlands

Flexural Mode Tuning in Pipe Inspection
---Z. Sun and J. L. Rose, The Pennsylvania State University, Engineering Science and Mechanics Department, State College, PA 16803; M. Quarry and D. Chinn, Lawrence Livermore National Laboratory, Livemore, CA 94550

NDE of Process and Process Control

A Study on the Strain Measurement of Butt Welded Zone by the Laser System
---B.-S. Sung, C.-E. Park, and I.-S. Kim, Mokpo National University, Department of Mechanical Engineering, Muan-gun, Chonnam, 534-729, Korea; Y.-H. Cha, Chosun University, Department of Mechanical Engineering, Kwangju City, Korea

Ultrasonic Phased Arrays for Weld Inspections
---M. D. C. Moles, R/D Tech, 1200 Aerowood Drive, #30, Mississauga, Ontario, Canada L4W 2S7

High Temperature Monitoring of the Process of Sintering Using EMATs
---D. K. Rehbein and J. C. Foley, Ames Laboratory, USDOE, 211A Metals Development, Ames, IA 50011

Evaluation of Cure Process of Damaged Ceramics with Surface Wave Dispersion
---K. Kawashima, T. Shima, and T. Hayashi, Nagoya Institute of Technology, Nagoya, Japan; S. Uchimura, H. Ishiguro, and S. V. Ceracs, Toyokawa, Aichi, Japan

Mathematical Simulation as an Instrument for QNDE
---V. Makhnenko, Paton Electric Welding Institute of the National Academy of Sciences of Ukraine, 11 Bozhenko Street, Kyiv-150, 03680, Ukraine

Accuracy of Measurement of Thickness of a 6061 Aluminum Sample at 1-mm Lift Off
---W. F. Schmidt, University of Arkansas, Department of Mechanical Engineering, Fayetteville, AR 72701; O. H. Zinke, International Validators, Inc., 817 North Jackson, Fayetteville, AR 72701

Developments in Using Ultrasound for QNDE of Polymer Melts
---D. C. Seto and W. H. Weber, UTEX Scientific Instruments, Inc., 2319 Dunwin Drive, Unit #8, Mississauga, L5L 1A3, Ontario, Canada

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

Intrinsic Fiber-Optic Ultrasonic Sensor Array Using Multiplexed Two-wave Mixing Interferometry

---Pavel Fomitchov, Todd W. Murray, and Sridhar Krishnaswamy, Center for Quality Engineering and Failure Prevention, Northwestern University, Evanston, IL 60208

---An intrinsic multiplexed laser interferometer is presented which allows for the simultaneous detection of acoustic waves detected by an array of fiber optic sensors. The interferometer contains an Argon laser source, an array of fiber optic sensors, and a single phase demodulator based on an adaptive two-wave mixing setup. The Argon laser beam is split into four beams, three of which are coupled into polarization-maintaining fibers to form an array of intrinsic ultrasonic sensors. The fourth beam is used as a reference. The sensing fibers are embedded into a graphite epoxy composite panel. The light from each element of the fiber sensor array is mixed with the reference beam in a photorefractive crystal. The output beams from the photorefractive crystal are imaged onto separate photo-detectors to create a multiplexed two-wave mixing (MTWM) system. The intrinsic MTWM system has several advantages over conventional fiber sensors. It allows for simultaneous demodulation of the signals from a large fiber sensor array. Also, the adaptive nature of the MTWM setup obviates the need for active stabilization against ambient noise. The intrinsic MTWM fiber array sensor can be used for process monitoring and bio-medical ultrasonic imaging, and for a number of NDE applications such as acoustic emission detection and health monitoring of "smart" structures. Example applications for acoustic emission detection in composite panels are presented.

Measurement of Air-coupled Transducers Characteristics for Ultrasonic Non-destructive Evaluation

---Christine Biateau and Bernard Hosten, Laboratoire de Mécanique Physique, Université Bordeaux 1, UMR C.N.R.S. 5469, 351, Cours de la Libération, 33405-TALENCE Cedex, France; Didier Roziere, Fogale Nanotech Parc Kennedy – Bat. 3, 285 Rue Gilles Roberval, 30900 Nimes, France

---During the last decade, there were many improvements in the design of air-coupled transducers and the associated electronic. Their use in ultrasonic non-destructive evaluation and control of materials, instead of immersion transducers, is now possible. There are many techniques to produce these transducers and the comparison is often difficult in the absence of absolute values of the efficiency at the emission and the sensitivity at the reception. This paper presents a simple method to measure the pressure in the acoustic field produced by air-coupled transducers. A metalized thin membrane is placed in the acoustic field and an optic probe measures the absolute value of the membrane velocity. Since the response versus the frequency of the membrane is know, the absolute value of the pressure is deduced easily. This technique is applied to compare the characteristic of capacitive air-coupled transducers made of a thin membrane placed on a back-plate roughen by sand blasting. The grain size is chosen in order to get various central frequencies and bandwidths. The method permits to compare the efficiency of these transducers and to predict the possibility to use them in the C-scan technique.

Development of a Fully Automated Knife Edge Inspection Using the Veridian Eddy Current Inspection System

---Joseph E. Ruthenberg, Systems Integration Group, Veridian Engineering, 2700 Indian Ripple Road, Dayton, OH 45440-3638; Kurt Oldson, Uniwest Corporation, Pasco, WA

---The knife-edge eddy-current probe was developed for the Veridian Eddy Current Inspection Station to fulfill the inspection requirements of the knife-edges on Pratt & Whitney F100-PW-220 compressor and turbine air seals on the Retirement for Cause (RFC) program. The flaw detection requirements were for through cracks, axially oriented, and propagating toward the center of the part. Previous attempts to inspect knife-edges on the ECIS used a standard differential reflection "D" pancake style probe, which rode along the top surface of the knife-edge while the part was rotated about a central axis. As the inspection requirement was for through cracks, only one side of the knife-edge needed to be inspected. Although this technique worked in laboratory conditions, it did not function well in a production environment, due to the presence of bent knife-edges, a rework procedure known as blending, in which small chips in the outer edge of the knife edge are removed through the careful application of abrasive stones, plasma coatings which wore the probe tip prematurely, and physical access limitations on the parts. A new probe and inspection technique were developed to overcome these deficiencies.

Detection of Discontinuity in the Reflector-Radiator Adhesive Layers Based on the Electromagnetically Induced Acoustic Signals Evaluation

---Yanis I. Bulbik[1] and Boris A. Belyaev[2], [1]Siberian Aerospace Academy, Krasnoyarsk 660014; [2]Institute of Physics, Siberian Division of Russian Academy of Sciences, Krasnoyarsk 660036

---As is known, the optical solar reflector–radiator (OSR-R) coatings are applied on spacecrafts for various science and communication missions since early stages of the satellite technology development. The OSR-R is a part of the satellite thermal control subsystem which external panels consist of plates, made of optical radiation-resistant glass, one side metalized by silver-nichrome reflective layer. These plates are connected by their metalized sides with a radiator surface by the thin adhesive layer of silicon-organic glue. The problem is to detect discontinuity as air bubbles into the adhesive layers due to incomplete gluing during the OSR-R fabrication. To enhance the conventional ultrasonics there was developed a new technique using electromagnetically induced acoustic signals. The time-dependent electromagnetic field of a miniature cylindrical coil placed on the external surface of the plate, interacts with eddy currents on its opposite side. Elastic wave intensity in the plate depends on adhesive layer quality that can be locally evaluated by acoustic signals from a built-in ultrasonics pickup. Details of this design and technique are presented.

Resonant Ultrasonic Vibration Detection Study

---Thomas C. Hale and Thomas J. Asaki, Measurement Technology Group-ESA, Los Alamos National Laboratory, Mail Stop C914, Los Alamos, NM 87545

---Contact and non-contact (optical) vibration detection methods, used in a resonant ultrasound spectroscopy application, are discussed in a comparative manner. The noise-floor for three different methods of vibration detection are quantitatively compared using a unique experimental configuration which employs spherical resonators. Spherical resonators, when resonating at their "breathing mode", have the special characteristic of vibrating uniformly in all directions with the same displacement. Noise-floor comparisons are made utilizing this unique mode of vibration to simultaneously measure vibration displacements for all three methods without changing the mechanical input coupling to the resonator. Among other things, in this application, we demonstrate that contact vibration detection systems do not necessarily perform better than optical methods in terms of noise-floor and cross-talk considerations.

Magnetic Field Gradient Measurement on Magnetic Cards with Magnetic Force Microscopy

---C. C. H. Lo and D. C. Jiles, Iowa State University, Center for NDE, Ames, IA 50011; J. Leib, Iowa State University, Department of Materials Science and Engineering, Ames, IA 50011; W. C. Chedister, Circle Systems, Inc., Hinckley, IL 60520

---Quantitative measurements of magnetic field gradient on magnetic cards have been made using a magnetic force microscope (MFM). The magnetic cards are being developed as a quantitative tool for classifying magnetic particles used in magnetic particle inspections (MPI). The sensitivity of magnetic particles to magnetic field is determined by spraying the particles to the card and finding the region of the lowest field gradient to which the particles adhere. In order to quantify the particles sensitivity for MPI, MFM was used to determine the magnetic field gradients above the surface of the magnetic cards. During the measurements a magnetic probe was moved towards the surface of the magnetic card and the magnetic force acting on the probe, which is proportional to the product of the magnetic field emanating from the card and the magnetic moment of the probe, was measured as a function of the probe-sample separation. The field gradient was determined from the slope of the force-distance curve. The results were found to agree well with the field gradients determined from the magnetizing field strength and frequency used in encoding the magnetic patterns in the cards.---This research was supported by the NSF Industry/University Cooperative Research Program of CNDE, and by DoE, BES under the contract number W-7405-Eng-82.

Requirements for Reproducible, High-Power, Short Rise-Time Pulser for Thick-Transducer Applications

---Paul M. Gammell, 6139 Pleasant Cove Dr., Exmore, VA 23350; Gerald R. Harris, Food and Drug Administration, Center for Devices and Radiological Health, Rockville, MD 20850

---Transiently-excited, thick ultrasonic source transducers have proved to be useful in a number of applications, including broadband measurements of attenuation and the directivity and frequency response of receiving transducers. "Thick" in this context means that the excitation pulse duration is small compared to the transit time of the acoustic wave through the transducer. The acoustic field is a plane wave over a time determined by the transducer dimensions, and the acoustic pressure is proportional to the electrical excitation voltage, providing certain constraints are observed. This pressure-voltage proportionality notwithstanding, it is still often desirable to a have known, analytically manageable driving waveform, such as an exponential or square wave. Other characteristics such as duration and rise time are important, as is adequate voltage amplitude, because the transducer is not operated in a resonant mode. High-power pulsers having characteristics tailored for specific applications have been commercially produced, but they are expensive and are not optimized for the load impedances presented by thick ultrasound sources. Thus, for purposes of calibration, laboratory research, and verification of data at distant sites or times, it is desirable to have a simple and reproducible pulser design. The design considerations and options for such a pulser are discussed.

Parametric Studies of Laser Ultrasonic Signals in Ablative Regime: Time and Frequency Domains

---Bao Mi and Charles Ume, Woodruff School of Mechanical Engineering, Georgia Institute of Technology, 801 Ferst Drive NW, Atlanta, GA 30332-0405

---A laser pulse incident on a material may generate ultrasound by means of two different phenomena: Thermoelastic effect at low power density and ablation effect at high power density. Ablative generation of ultrasound is necessary for some critical applications such as on-line welding monitoring in which strong signals are required to compensate the elevated temperature and the long path length. While the waveform in time domain has been discussed extensively in the literature, there is little knowledge about the frequency components of laser ultrasound although this information is necessary for practical applications. In this paper, analytical results from both thermoelastic and ablative regimes are reviewed. Laser ultrasonic signals generated by ablation are measured in a number of metal samples (2024 Al, 6061 Al, 7075 Al, mild steel, and copper) with a broadband laser interferometer, and the frequency spectra are analyzed and compared for different thicknesses (50.8mm, 25.4mm, 12.7mm, and 6.4mm), and for different power densities. Hanning windowing is applied to the longitudinal pulses in time domain before frequency analysis is performed. The experimental data match the theoretical predictions very well. The results show that the frequency spectrum extends from 0 to 15MHZ, with the center frequency occurring near 2MHz. The detailed distribution of the spectrum is dependent on the material, thickness, and laser power density.

CPC-48-A System for Non-Contact Film Build Measuring in Production

---Ken Paige, S&G Technologies, 1 Whitmore Road, Unit 18, Woodbridge ON L4L 8G4, Canada

--- S&G Technologies' CPC-48 is a non-contact, real-time, wet film, powder paint and slurry coating thickness gauge based on a patented X-ray technique. The system can measure traditional organic coatings as well as the specialized coating materials used in stealth technology. The gauge is a proprietary design that incorporates an array of Cadmium Zinc Teluride radiation detection crystals in a completely solid-state package ensuring a stable device not subject to variations in humidity, temperature, vibration and so on. Prediction of dry film thickness from wet or uncured powder or slurry measurements can be performed with consistency. The CPC-48 gauge has been incorporated into a complete turnkey system for use in a variety of applications including automotive and aerospace. The small, compact, lightweight, intrinsically safe gauge is affixed to an appropriately sized full-axis paint shop robot or other appropriate automation. The system uses off-the-shelf robot technology, such as line tracking, with system specific designs that control stand-off distance and employ distance compensation algorithms to ensure consistent, repeatable measurements. The CPC-48 is an enabling technology that will change the focus of coating applications from one of quality control to one of process control including automatic closed-loop thickness control. Greater film build control will significantly drive down costs while simultaneously improving quality.

Numerical Simulation of the Measurement Coils for Damage Detection in Large Metalic Corps

---Arkadiusz Lukjaniuk and A. Jordan, Institute of Electrical Engineering, Technical University of Bialystok, Grunwaldzka str. 11/15, 15-893 Bialystok, Poland

---This paper describes a numeric model of the system designated for damages detection in large metallic corps (nuclear reactor). Thee are two identical coils (N-1000 turns in each coil) in the infinitely long tube made of INCONEL 600, connected differentially and energized by an AC current with frequency f = 1, 10, 100 and 200 kHz. Calculations are done for two following variants: the tube surrounded an air and situated in a hole of ferromagnetic plate. The material defect, which is in the tube, is placed symmetrical according to plate edge. EMRC NISA/EMAG software is employed for calculations. The changes of impedance are computed and presented for different frequency of impressed current, mutual interval of coils, various placement of defect and in relationships of distance between coils and damage place. Also an influence of model simplifications for obtained results is analyzed.

The Implementation of a Flexible Bobbin Coil to Inspect Dovetail Slots

---Gabriel C. Upton, Systems Integration Group, Veridian Engineering, 2700 Indian Ripple Road, Dayton, OH 45440; Kurt Oldson, Uniwest Corporation, Pasco, WA; Shawna Pickering, Pratt & Whitney, Hartford, CT; Gary Taube, Aeronautical Systems Center/Propulsion Directorate, Wright-Patterson AFB, OH 45433

---A Uniwest flexible coil probe is now used to inspect dovetail slots on Pratt & Whitney F100-PW-229 jet engine disks with the Veridian Eddy Current Inspection System (ECIS). This work was completed by a combined effort from the USAF, Pratt & Whitney, Uniwest Corporation and Veridian Engineering under the USAF Retirement for Cause program. This type of probe offers wide zone coverage comparable to array probes but requires only a single drive and two receive elements for full compatibility to operate with the US500 eddyscope or it's older counterpart the NDT25. A series of "Flex" probes were implemented on several parts from the F100-PW-229 engine where previous inspection technique utilized the traditional split "D" differential reflection coils. Inspection times were significantly reduced. A range of 0.008-0.037" crack depth detection capability was demonstrated by full probability of detection (POD) study on both titanium and nickel engine alloys. Further capability has shown inspection coverage to extend to 0.05" of the slot edge. This paper presents the work done to implement the probe and inspection technique on the ECIS as well as POD supporting data.

Comparison of Different Measurement Configurations for Nondestructive Testing of Well-Conducting Materials

---Ryszard Sikora, Electrical Engineering Faculty, Technical University of Szczecin, Ul. Sikorskiego 37, 70-313-Szczecin, Poland; Ryszard Palka, Insitutut f. elektr. Maschinen, Technical University of Braunschweig, Braunschweig, Germany

---One of the most important properties of each measurement configuration for non-destructive testing is it's sensitivity. This paper proposes a fundamental configuration for finding cracks in well-conducting materials consisting of two identical coils connected differentially which move along the infinitely long tube. The coils are energized by an impressed high frequency AC current. The changes of the impedance of these coils depend on the position of the cracks in the tube. Optimization of all properties of this system (dimensions of the coils and their relative positions) in order to increase its sensitivity has been done by numerical calculations using finite element method. The application of this method requires a very fine finite (tuned) element grid, because of extremely small skin depth of electromagnetic field at high frequencies for well-conducting regions. Additionally some boundary transitions for electromagnetic field have to be defined. Numerical calculations have been done for four modifications of the main system by defining different properties of surrounding areas. Based on these results some requests are formulated for the developer of NDT-sensors.

The Interaction of Pulsed Eddy Current with Metal Surface Crack for Various Coils

---Hung-Chi Yang and Cheng-Chi Tai, Department of Electrical Engineering, National Cheng Kung University, 1 University Road, Tainan, Taiwan 701, China

---We study the interaction of pulsed eddy current (PEC) with metal surface cracks using various coils that have different geometrical sizes. In the previous work, we have showed that the PEC technique can be used to inspect electrical-discharge-machined (EDM) notches with depth from 0.5 mm to 9 mm. The results showed that the relationship between PEC signals and crack depth is obvious. In this work, we further try a series of coils with different radii, heights, turns and shapes. We will discuss the effects of these coil parameters on the PEC signal. Some other critical problems of PEC measurements such as signal drift that caused by heating effect of coil currents will be studied. We also show more experiments on fatigue cracks to demonstrate the capability of PEC technique for cracks inspection.

Detection of Surface Cracks of Arbitrary Shape in Metals Using an Open-ended Waveguide Probe

---Farhad Mazlumi, Seyed H. H. Sadeghi, and Rouzbeh Moini, Department of Electrical Engineering, Amirkabir University of Technology, 424 Hafez Avenue, Tehran 15914, Iran

---A new formulation is presented to model the problem of an open-ended waveguide probe radiating into a conducting metal with a surface-breaking crack of arbitrary shape. In this formulation, the crack is first modeled by an appropriate number of short rectangular waveguides. The mode-matching technique is then used to calculate the scattering matrix of the new segmented waveguide structure. The probe reflection coefficient of the dominant mode, TE10, is finally calculated for various positions of the crack in order to predict the probe output signal. Results obtained for a semi-circular crack will be presented, demonstrating the potential of the new formulation for handling real fatigue cracks.

Microwave Analysis of Accelerated Chloride Ingress in Type I/II, III and V Mortar

---T. Case, K. Donnell, D. Hughes, and R. Zoughi, Applied Microwave Nondestructive Testing Laboratory (amntl), Electrical and Computer Engineering Department, University of Missouri-Rolla, Rolla, MO 65409; K. E. Kurtis, School of Civil and Environmental Engineering, Georgia Institute of Technology, Atlanta, GA 30332-0355

---Because corrosion of steel in reinforced concrete structures can be induced by the presence of chloride ions near the steel/concrete interface, there is much interest in monitoring chloride ingress into cement-based materials. To this end, three 8"x8"x8" mortar specimens with *w/c* of 0.7 and *s/c* of 3.5 were prepared each with Portland cements of ASTM Types I/II, III, and V. Because of their different tricalcium aluminate contents, the different types of cement will possess varying potential for reacting with or binding ingressing chloride ions. After curing for more than a month, the mortars were soaked in water baths containing a 1% salinity for twenty hours. Subsequently, they were removed and left in room temperature while their microwave reflection properties were measured daily, for twenty days, at S- (3 GHz) and G-bands (5 GHz). To accelerate this diffusion of chloride ions in these specimens, six such cycles were repeated. After the last cycle, cores were removed from the specimens so that their dielectric properties, as a function of depth into the specimen, could be determined. The primary goal of this investigation was to determine the capability of these microwave measurements for determining the presence of chloride in these specimens, and whether different chloride reaction can be detected with each respective specimen. A complete discussion of the results will be presented in this paper.---Portion of the work conducted while at Colorado State University.

Microwave Detection of Delaminations Between Fiber Reinforced Polymer (FRP) Composites and Concrete Substrate

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---Fiber reinforced polymers (FRP) composites are becoming one of the material systems of preference for the rehabilitation and upgrade of the concrete infrastructure. These systems can be externally bonded to the concrete surface and provide additional tensile reinforcement or confinement depending on the strengthened member. In almost all applications, the quality of the bond is of paramount importance as it controls the mechanism of stress transfer. Delaminations may occur as the result of poor workmanship at the time of installation or unforeseen events such as gassing of the concrete. In the past few years, near-filed microwave nondestructive testing techniques have been extensively and effectively used to detect disbands and delaminations in layered composite structures. These techniques not only have demonstrated their ability to detect disbands but also the potential to determine the location of a disbond within a stratified composite structure. To this end the dielectric properties of FRP composites used for concrete structure rehabilitation were measured in a relatively wide range of microwave frequencies. Subsequently, a multi-layered electromagnetic formulation was used to simulate the presence of a disbond between a layer of FRP and a concrete backing. This electromagnetic simulation was conducted to determine near optimal measurement parameters such as the frequency of operation and standoff distance. A concrete specimen, wrapped with FRP, was also constructed possessing a known region of disbond between the concrete and the FRP. Using a microwave reflectometer microwave images of the disbanded region were obtained indicating the potential of this inspection technique. This paper presents the results of the microwave dielectric measurements of the FRP, electromagnetic simulations and the experimental results.

Multiplexed HTS rf SQUID Magnetometer Array for Eddy Current Testing of Aircraft Rivet Joints

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---Using three rf SQUID magnetometers, a multiplexed SQUID array was implemented. The SQUIDs are positioned in line with 7 mm spacing and operated using one feedback electronics with sequential read out demodulation at different rf frequencies. The cross-talk between SQUID channels was determined to be negligible. To show the performance of the SQUID array, eddy-current (EC) measurements of aluminum aircraft samples in conjunction with a differential (double-D) EC excitation and lock-in readout were carried out. With computer-controlled continuous switching of the SQUIDs during the scan, three EC signal traces of the sample are obtained simultaneously. We performed measurements with an EC excitation frequency of several hundred Hz to localize a crack of 40 mm length in an aluminum sheet with thickness of 0.6 mm. The crack was detected when covered with aluminum of up to 7 mm thickness. In addition, measurements with varying angles between scanning direction and crack orientation are presented.

Determination of the Effective Focal Characteristics of Bicylindrically Focused Ultrasonic Transducers

---F. J. Margetan, R. Roberts, C.-P. Chiou, and R. Bruce Thompson, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---Rotating jet engine components are commonly fabricated from sections of material cut from cylindrical billets. Prior to the forging process, the billets themselves are ultrasonically inspected for defects. One pulse/echo inspection scheme makes use of several ultrasonic transducers each designed to focus at a different depth in the billet. Such transducers are typically bi-cylindrically focused to compensate for the curved sound-entry surface of the billet. Prior to certifying transducers for service, it is useful to determine how accurately their actual focal characteristics match their design values. This presentation explores several methods for deducing effective probe diameters and focal lengths from ultrasonic data. The overall approach is the same in each case. Ultrasonic echoes (A-scans) from a reflector are measured and stored for different locations of the reflector relative to the transducer. The transducer is then modeled as an ideal bi-cylindrically focused piston probe with an elliptical element. The model transducer has four parameters that determine its radiation pattern at a given frequency: two element diameters (Dx and Dy); and two geometrical focal lengths (Fx and Fy). These parameters are adjusted to provide a best fit between the model predictions and the measured ultrasonic data. To speed the fitting process, predictions are made using a paraxial Multi-Gaussian beam model. The experiment methods considered are (1) reflection from a flat surface as a function of water path; (2) refection from a ball-target in water as a function of lateral position and water path; and (3) reflection from a flat-bottomed hole in a cylindrical billet as a function of lateral position and metal depth. The three methods are demonstrated for a typical case, and their relative merits and drawbacks are discussed.---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 Center for Aviation Systems Reliability program.

Ultrasonic Scattering Analysis of Flaws by Gauss-Hermite Beam Model and a Boundary Element Method

---Hyunjo Jeong, Division of Mechanical Engineering, Wonkwang University, Iksan, Chonbuk, Korea; Jin-Ho Kim, School of Mechanical Engineering, Pusan National University, Pusan, Korea

---Ultrasonic modeling plays an important role in many aspects of quantitative nondestructive evaluation. The ultimate goal of a model is to predict a testing system's response to a specific flaw in a material. Thus, a system model should include the transducer, its radiation pattern, the beam reflection and propagation, and scattering from defects. In this paper attention is focused on the beam and scattering models. The probe beam radiation and propagation is described by Gauss-Hermite beam model and the scattered fields from defects are modeled by an elastodynamic boundary element method. Flaw types addressed are void-like and crack-like flaws. When ultrasonic T-waves are obliquely incident on the flaw, the angular distribution of far-field scattered displacements are calculated and presented in the form of A-scan mode. The component signals obtained from each scattering problem are identified and their differences are addressed. The numerical results are also compared with those obtained by high frequency approximate solutions.

A Matrix Method for Numerical Computation of Field Radiated and Receipted by Acoustic Transducers

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---In the context of studying the acoustic material signature, a numerical method is developed for the computation of the diffraction field radiated and the electrical signal received by a focusing probe. This method takes no approximation and simplification conditions for Rayleigh-Sommerfeld field integration as often used in focusing field calculation. The formalism for field evaluation is based on a matrix method. The field at observing points are related to the vibration at source points by a simple matrix which depends only on the source-observer geometrical relation. From the reciprocal relation, the received signal reflected by an object can be obtained using the same matrix. This method can be applied to the calculation of field radiated by an acoustic source having arbitrary form. As for examples, the field patterns in the case of spherical and cylindrical lens and shell transducer, and rectangular and phased array transducers are given.

Inverse Scattering Analysis for a Defect in a Plate

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---A linearized inverse scattering method based on the Born approximation has been developed for reconstruction of a defect shape in an elastic solid. In order to fully recover the shape of the defect, the Born inversion approach requires that information must be measured at all frequencies and at all aspect-angles with respect to the scatterer. For a defect in a plate, however, data is not measurable at all directions. In this paper, the aspect-limited problem of the Born inversion is investigated for inverse scattering of antiplane waves. It is found that the illuminated portion of the defect can be reconstructed even using the limited data. The defect shape in a plate can, therefore, be recovered well utilizing the reflected waves at the bottom surface. Pulse echo ultrasonic experiments using SH probes are conducted for a cylindrical cavity in a steel block. The Born inversion is applied to the data directly back scattered by the cavity as well as the back scattered data with the reflection at the bottom of the steel block. It is shown that even with limited number of data, the Born inversion can produce much better image of the defect than the aperture synthetic approach.

Theoretical Stress Evaluation of Intact and Cracked Ellipsoidal Inhomogenity Using FEM

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---The transient response of an anisotropic layered plate under pulsed laser illumination is formulated by using Fourier and Laplace integral transform techniques and the Thompson transfer matrix method. Several numerical results are presented showing the normal surface displacements for the following configurations: a Silicon half-space, a homogeneous Silicon plate, TiN coating layer on a Silicon plate, and a three layered plate of Silicon/TiN/Silicon. The characteristics of the laser-generated transient signals and their dispersion phenomena are studied. The numerical inversion procedures that transfer the displacements from the Fourier and Laplace transform domains to the time-domain are demonstrated in some detail. Numerical results have been verified experimentally for a number of cases. The preliminary results show good agreement between simulations and measurements.

Estimating the Ultrasonic Reflectivity of Naturally Occurring Flaws

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---The ultrasonic echo amplitudes that are reflected by naturally occurring flaws are the primary factors controlling their detection and probability of detection. Natural flaws with numerically equivalent scattering cross sections (areas) can reflect significantly different signal amplitudes. Estimating the probability of detection for a set of flaws with equivalent cross sectional area is dependent on estimating the percentage of these signal amplitudes, that would fall above a detection threshold. The flaw signal distribution is, in turn, dependent on the flaw reflectivity distribution. In the definition of reflectivity that is proposed here, flaws of equal cross sectional area, and equal reflectivity, will reflect equal signal amplitudes. Such flaws would be termed to have the same Effective Reflectivity (Re). Historically, the effective reflectivity (Re) for a flaw has been calculated from the ratio of the effective flat bottomed hole area calculated from its reflected ultrasonic amplitude to the maximum area observed in serial metallographic sections of that flaw. This calculation has enjoyed relatively good success where the ultrasonic beams have significantly larger areas than the flaws. The introduction of focused ultrasonic beams, however, often presents situations where the beam is larger than the calibration target, but smaller than a flaw that reflects a significantly lower amplitude signal. This paper will present some relatively simple methods for estimating the reflectivity of flaws that are both larger and smaller than the ultrasonic beam.

Further Development of 3D Ultrasonic Ray Tracing in AutoCAD

---D. Reilly, NDTSoft, 47 Hazel Road, Abronhill, Cumbernauld, Glasgow, G67 3BN, Scotland; A. McNab, Centre for Ultrasonic Engineering, Department of Electronic and Electrical Engineering, University of Strathclyde, Glasgow, G1 1XW, Scotland

---This paper describes the further development of the ultrasonic 3D ray tracing add-on module for AutoCAD 2000 presented at QNDE 2000. The ray tracing entities created within the module are now fully interactive with AutoCAD. For instance, grip points allow the user to alter the ray path by clicking and dragging the mouse to either change the ray start position or the angle and skew; the ray properties, e.g. angle, skew, path, can be altered using the object property dialog; new ray paths can be created using AutoCAD commands COPY and ARRAY (rectangular and polar). The ray path calculation can be performed on components with multiple layers and materials, the parameters of which can be set using a command within the module. Furthermore, if the solid model database within AutoCAD is modified, e.g. the orientation of a solid (representing a defect) is changed, then the ray tracing updates automatically. Finally, a simulator for automated scanning manipulators comprised of two driven axes (linear, axial or circumferential) has been implemented. This enables the probe location and orientation on the component surface to be determined and subsequently the path of the probe beam. Thus coverage maps may be generated.

A Software Package for Simulating Ultrasonic Inspections In 3D CAD Geometry

---Mike Garton and Tim Gray, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---Software has been created at CNDE to model ultrasonic inspections. The software runs on Windows TM personal computers. Both immersion and contact inspections can be modeled. Detailed maps of beam amplitude can be shown as a function of position. Accurate signal amplitudes are output from known flaw shapes. The software will be demonstrated.---This material is based upon work supported by the Federal Aviation Administration under Grant Number 97-C-014 and performed at Iowa State University's Center for NDE as part of the Center for Aviation Systems Reliability program.

Recent Advances in CAD-Based UT Simulation in CIVA

---Pierre Calmon, Sylvain Chatillon, Laurent Le Ber, and Stéphane Le Berre, French Atomic Energy Comission, CEA/LIST, CEA-Saclay, bât. 611, 91191 Gif-sur-Yvette cedex, France

---In high-tech industries, NDT is progressively taken into consideration as early as at the design stage. Soon, components should be designed together with suitable NDT methods to examine them. Availability of tools for NDT simulation in virtual CAD environment is decisive to achieve this goal. As far as NDT is concerned, component CAD description must include their outer geometry and inner structure if need be (heterogeneous materials). CIVA is developed at CEA for imaging and processing experimental NDT data (UT, EC, X-rays), simulating them and deals with CAD descriptions. The paper illustrates recent advances of CIVA in CAD-based UT simulation. CAD descriptions from design office and major file formats are now considered. Alternatively, CIVA allows one to define generic components by a set of parameters (tubes, elbows, nozzles…), CAD-based routines doing all the rest. Examples requiring specific CAD-based modeling developments are presented: simulated or experimental data displayed in the component coordinate system superimposed with CAD for better insight into complex results; transformation of experimental data related to component shape as CAD files usable in simulation; positioning of contact probe on irregular surfaces; computation of delay laws for phased arrays scanning complex components to keep steady beam characteristics; beam prediction in heterogeneous materials, etc.

The Effect of Defect Depth, Axial, and Circumferential Extent on the Reflection of Extensional Guided Waves in Pipes

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---Guided wave screening of long lengths of pipework using low frequency guided waves is now in routine industrial application. The technique can be operated using either torsional (T(0,1)) or extensional (L(0,2)) waves. This paper reports a systematic study of the influence on the reflection coefficient of the extensional mode of the defect depth, circumferential extent and axial extent. The reflection coefficients of both the incident axially symmetric mode and mode-converted flexural modes are predicted as a function of frequency using finite element analysis and the results are verified experimentally. The behavior of the reflection coefficients as a function of defect size is discussed in terms of low and high frequency scattering regimes.

Flexural Mode Tuning in Pipe Inspection

---Zongqi Sun and Joseph L. Rose, Engineering Science and Mechanics Department, The Pennsylvania State University, State College, PA 16803; Mike Quarry and Diane Chinn, Lawrence Livermore National Laboratory, Livermore, CA 94550

---The ability to carry out a complete pipe inspection with limited access to 180 degree or less of the circumference is often necessary. Techniques are introduced to make this possible by flexural mode and focusing control via a four dimensional tuning process of adjusting circumferential loading length, position, phase and frequency. Defect interaction possibilities with radial and circumferential strain as well as radial and circumferential stress are discussed. A sample experiment is conducted to demonstrate the tuning process. Some potential inspection problems are also discussed.

A Study on the Strain Measurement of Butt Welded Zone by the Laser System

---Back-Sub Sung, Chang-Eun Park, and Ill-Soo Kim, Department of Mechanical Engineering, Mokpo National University, Muan-gun, Chonnam, 534-729, Korea; Yong-Hoon Cha, Department of Mechanical Engineering, Chosun University, Kwangju City, Korea

---Currently knowledge of strain in welds has mainly been obtained from strain gaging method; that is directly attaching most of the material to the gage. The very few non-contact method are still in the early stage. One of the non-contact methods is by the use of the laser that has high-level of the accuracy for the measurement, and this laser also has excellent characteristics on which many studies for its applications are focused throughout the many fields. The dissertation is on the measurement of the strain caused by the characteristics and the temperature changes of the TIG welded zone which is used with 3D ESPI system that is functionally modified through the laser ESPI system. This system employed the aluminum sheet-metal which are mainly used for the steel plate such as for the electronics, chemistry, food instrument and electronic appliances.

Ultrasonic Phased Arrays for Weld Inspections

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---Phased arrays offer significant technical advantages for weld inspections over conventional ultrasonics. The phased array beams can be steered, scanned, swept and focused electronically. Beam steering permits the selected beam angles to be optimized ultrasonically by orienting them perpendicular to the predicted defects, especially Lack of Fusion with automated welding. Electronic (linear) scanning permits very rapid coverage of the welds, typically much faster than a mechanical system. Beam steering (usually called sectorial or azimuthal scanning) can be used for mapping welds at different angles to optimize Probability of Detection of defects. Electronic focusing permits optimizing the beam shape and size at the expected defect location, and hence optimizing Probability of Detection. Due to their high flexibility, phased arrays can be used for innumerable inspections, and have been installed in a wide variety of industries, typically using linear scanning: nuclear, aerospace, petrochemical, steel. This paper describes the application of phased arrays for inspecting welds, particularly automated gas-metal arc welds in pipelines, electric resistance welds in pipe mills, and general weld inspections using “top, side, end” view displays. In each case, the practical advantages of phased arrays over conventional automated inspections will be noted.

High Temperature Monitoring of the Process of Sintering Using EMATs

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---Considerable attention has been given to the use of nondestructive evaluation (NDE) techniques to reduce the costs associated with the manufacture of powder metal (P/M) components. In-situ characterizations of green state part density and sintering state have long been desired in the powder metal community. Recent advances in non-contact electromagnetic acoustic transducer (EMAT) technology have enabled in-situ monitoring of acoustic amplitude and velocity as sintering proceeds. Samples were made from elemental powders of Al (99.99%), Al (99.7%), Ag (99.99%), Cu (99.99%) and Fe (99.9%). The powders were pressed in a uniaxial die and examined with acoustic waves for changes in velocity and amplitude during sintering for the samples containing Al, Ag, and Cu. The changes in acoustic properties were correlated with sample microstructures and mechanical properties. Evolution of a series of reverberating echoes during sintering is shown to provide information on the state of sintering, changes in sintering kinetics as well as having the potential for detection of interior flaws.---This work is funded by a laboratory directed research and development grant and by DOE-BES under Contract No. W-7405-ENG-82.

Evaluation of Cure Process of Damaged Ceramics with Surface Wave Dispersion

---Koichiro Kawashima, Toshiyuki Shima, and Takahiro Hayashi, Nagoya Institute of Technology, Nagoya, Japan; Shoji Uchimura, Hiroyuki Ishiguro, and Shinto V. Ceracs, Toyokawa, Aichi, Japan

---Dispersion of the leaky Rayleigh wave velocity, V_R, is found to be effective for characterizing cure process of ceramics which were subjected to aging at elevated temperature after shot peening. Ceramics samples of Si_3N_4 and Al_2O_3 were subjected to shot peening under various shot conditions. Thereafter the dispersion of V_R was measured by a line-focused transducer of 30 MHz. The samples were aged at 1200 and 1300? for a given period in air. Thereafter, the dispersion of V_R was measured again. The dispersion curves at a suitable aging condition show the highest phase velocity, while the shot-peened samples without aging show the lowest phase velocity. The difference in these velocities is about 100m/s, which is far greater than local velocity variation. This is explained by partial closure of minute cracks generated by peeing due to growth of oxyacid on the crack surfaces.

Mathematical Simulation as an Instrument for QNDE

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---An ever-increasing interest in Quantitative Nondestructive Evaluation (QNDE) of quality of manufacture of products, and/or the state of structural components at long-term service requires continuous improvements to the existing, and searches for new promising approaches and principles of QNDE. Among these of deserving special attenuation is mathematical simulation of physical processes in materials which could influence the quality of a structure (avoiding of discontinuities, ensuring adequate properties etc.) by means of continuous observation to the kinetics of such processes during different manufacture stages and by taking account of in-service loading conditions. The present report summarizes results on application of the mentioned approach in two typical problems in QNDE. The first one is assessment of quality of large ingots of Inconel-718 obtained by using electro-slag remelting. The quality here is specified by the defects of primary crystallization of a type of spot liquation, formation of Laves' phases etc. The modern small-scale production of such ingots is a rather time-consuming process (needs about 20 to 50 hours) which avoids maintaining a stability of technological parameters that could ensure avoidance of the above defects. Thus, a QNDE of a finished product is required here. An example of such evaluation is proposed in the present report based on the in-time registration of technological parameters of the remelting process and mathematical simulation to the process of primary crystallization of the ingot's material. The next problem consists in assessment of the material's state of a critical welded structure (a material's degradation degree) intended for long-time use that suffers a limited access to its "hot spots" but provides detailed registration data concerning the history of in-service temperatures and the loading conditions.

Accuracy of Measurement of Thickness of a 6061 Aluminum Sample at 1-mm Lift Off

---William F. Schmidt, Department of Mechanical Engineering, University of Arkansas, Fayetteville, AR 72701; Otto H. Zinke, International Validators, Inc., 817 North Jackson, Fayetteville, AR 72701

---The accuracy of measurement of a 0.51-mm thick, 6061 aluminum sample under lift-off variations of plus or minus 0.25 mm at 1.08 is shown to be plus or minus 5 percent by means of a complex-reluctance plane analysis. The analysis is shown to depend critically on the statistical accuracy of such measurements. Large lift-off measurements of aluminum thickness with large lift-off variations can be important for measurement of samples with radii of curvature such as aluminum cans, for measurements of sheets in rolling mills, and for reducing measurement problems in automatic scanning of aircraft skins where corrosion or spalling may have occurred.

Developments in Using Ultrasound for QNDE of Polymer Melts

---David C. Seto and Walter H. Weber, UTEX Scientific Instruments, Inc., 2319 Dunwin Drive, Unit #8, Mississauga, L5L 1A3, Ontario, Canada

---New applications using ultrasound for QNDE of polymer melts are emerging. Long used for NDE of composite structures, ultrasound is also a useful tool for on-line evaluation of polymer materials during manufacture or secondary processing. Ultrasonic monitoring of the polymer melt can improve quality, enhance process control, and enable new materials with specific properties to be produced. Ultrasonic analysis techniques have been demonstrated to accurately measure melt viscosity, filler content, and molecular weight, all on-line. Excellent correlation with traditional laboratory testing methods is obtained. Recent developments towards commercialization of this promising new technology will be discussed.

Tuesday, July 31, 2001

SESSION 12
BIOLOGICAL APPLICATIONS OF NDE
B. Audoin, Chairperson
Sills 117

3:30 PM **Characterization of Eddy Current Distortion Effects on Magnetic Resonance Axonography of Human Brain**
---I. Elshafiey and P. A. Narayana, University of Texas-Houston Medical School, Department of Radiology, 6431 Fannin, MSB 6.172, Houston, TX 77030

3:50 PM **In Vivo Magnetic Resonance Imaging of Spinal Cord at 7T**
---I. Elshafiey and P. A. Narayana, University of Texas-Houston Medical School, Department of Radiology, 6431 Fannin, MSB 6.172, Houston, TX 77030

4:10 PM **Thermal Wave Lock-In Imaging of Subsurface Chromophores in Biomaterials**
---S. A. Telenkov and T. E. Milner, University of Texas at Austin, Biomedical Engineering Program, Austin, TX 78712; J. S. Nelson, University of California, Beckman Laser Institute and Medical Clinic, Irvine, CA 92612

4:30 PM **Automated Segmentation and Quantitative Characterization of Radiodense Tissue in Digitized Mammograms**
---J. Neyhart, M. Kirlakovsky, and S. Mandayam, Rowan University, Electrical and Computer Engineering, Glassboro, NJ 08028; M. Tseng, Fox Chase Cancer Center, Philadelphia, PA 19111

4:50 PM **Biological Effects of Low-Power Ultrasonics**
---R. Buhbinder[1] and P. Dickstein[1,2], [1]Technion-Israel Institute of Technology, Quality Assurance and Reliability, Haifa, Israel 32000; [2]Soreq Nuclear Research Center, Yavne, Israel 81800

5:10 PM **Clinical Results with an UltraSonographic Periodontal Probe**
---M. K. Hinders and J. E. Lynch, College of William and Mary, Department of Applied Science, Williamsburg, VA 23187; G. B. McCombs, Old Dominion University, Department of Dental Hygiene, Norfolk, VA 23606

Characterization of Eddy Current Distortion Effects on Magnetic Resonance Axonography of Human Brain

---I. Elshafiey and P. A. Narayana, University of Texas-Houston Medical School, Department of Radiology, 6431 Fannin, MSB 6.172, Houston, TX 77030

---Axonography of human brain, based on Diffusion Tensor Magnetic Resonance Imaging (DT-MRI) is becoming essential in understanding the organization of human nervous system and also in monitoring progression of therapeutic trials for diseases such as multiple sclerosis. The technique depends on increasing the sensitivity of MRI to random water diffusion in tissues, by adding diffusion gradient pulses to the imaging sequence. Increase of diffusion weighting is achieved by increasing the magnitude of diffusion pulses, which alleviates the problem of eddy current induction in the scanner cryostat. Induced eddy current results in distortion of the acquired magnetic resonance images. The purpose of this study is to characterize the effect of eddy current on images obtained using the DT-MRI technique when scanning the human brain. Characterization of eddy current effects is essential in optimizing the scanning parameters and improving image qualities. All MRI studies were performed on 1.5-T GE scanner operating at 8.3M5. Single shot diffusion weighed echo planar images with cardiac gating were acquired with the following parameters: 5 mm slice thickness, 240 mm FOV, total of 8 slices, 128 x 128 matrix. Diffusion gradient space was explored using a set of 62 directions along the two poles, and 60 other directions. Sequence timing was adjusted to obtain recovery time of 3 RR periods, echo time of 69 ms, and diffusion gradient pulse duration of 22 ms. Total scan time was less than three minutes. The exploration of the diffusion-space helps quantify the relationship between diffusion orientation and eddy current level. Experimental results demonstrate that certain directions suffer more in terms of eddy current distortion effects. Determining the optimum gradient directions should present a powerful technique for reducing eddy current distortion, and thus enhance the use of MRI as an axonography noninvasive assessment tool of human brain.

In Vivo Magnetic Resonance Imaging of Spinal Cord at 7T

---I. Elshafiey and P. A. Narayana, University of Texas-Houston Medical School, Department of Radiology, 6431 Fannin, MSB 6.172, Houston, TX 77030

---Research on spinal cord injury is crucial for bringing hope to hundreds of thousands of affected patients. Magnetic resonance imaging (MRI) is a promising noninvasive evaluation tool for the spinal cord. This paper introduces in vivo study of spinal cord plasticity after injury. An axonography imaging technique: Diffusion Tensor Magnetic Resonance Imaging (DT-MRI) is implemented. The technique is based on monitoring random diffusion of water molecules in spinal cord tissues. MRI images are acquired for normal and injured rats using a 7 Tesla scanner. Multi-shot echo-planar imaging sequence is implemented with the following parameters: slice thickness=1 mm, field of view=25 mm, image matrix=128 x 128, number of averages=4. Signal to noise ratio is increase by the use of an implanted RF coil. In order to minimize motion artifacts, images are acquired by gating on every other respiratory cycle. Diffusion gradients were applied along seven different orientations, and diffusion gradient pulse width was chosen to be 12 ms, resulting in relatively high diffusion weighting. Fitting of diffusion-weighted images demonstrated biexponential decay of the acquired signal, suggesting the presence of two components of water diffusion: fast diffusion and slow diffusion components. The biexponential nature of the diffusion signal can be correlated with the existence of two compartments in the tissues, namely the intracellular and extracellular spaces. Rotationally invariant measures of anisotropy indices are calculated and presented for each of the two diffusion components. DT-MRI of rat spinal cord demonstrates encouraging results for the possibility of adapting the technique for axonography of spinal cord in patients. Axonography of spinal cord would help detect the survival of injured neurons and assess the growth of new axons after injury. This should present a powerful tool for future clinical therapeutic trials of spinal cord injury.

Thermal Wave Lock-in Imaging of Subsurface Chromophores in Biomaterials

---Sergey A. Telenkov and Thomas E. Milner, Biomedical Engineering Program, University of Texas at Austin, Austin, TX 78712; J. Stuart Nelson, Beckman Laser Institute and Medical Clinic, University of California, Irvine, CA 92612

---Thermal wave imaging of discrete chromophores in biomaterials is reported using phase sensitive coherent detection technique applied to recorded infrared (IR) images. We demonstrate that utilization of a periodically modulated laser source for thermal wave excitation and coherent detection applied to each pixel maybe used to compute images of the thermal wave amplitude and phase at laser modulation frequency. The narrow-band band detection technique significantly improves quality of thermal wave amplitude images. Additionally, the technique provides phase information, which may be used to assess chromophore depth in tissue. We present a theoretical analysis and computer simulations of the thermal wave imaging in biological specimens. Effect of tissue optical properties on radiometric signal is discussed. Experimental application of the technique is demonstrated using tissue phantoms and an in-vivo biological model.

Automated Segmentation and Quantitative Characterization of Radiodense Tissue in Digitized Mammograms

---Jeremy Neyhart, Magdalena Kirlakovsky, and Shreekanth Mandayam, Electrical & Computer Engineering, Rowan University, Glassboro, NJ 08028; Marilyn Tseng, Fox Chase Cancer Center, Philadelphia, PA 19111

---Mammography has emerged as a reliable noninvasive technique for the early detection of breast cancer - the second leading cause of cancer-related mortality among American women. The radiographic appearance of the female breast consists of radiolucent (dark) regions due to fat and radiodense (light) regions due to connective and epithelial tissue. The amount of radiodense tissue can be used as a marker for predicting breast cancer risk. This paper presents the development of an image processing algorithm for estimating the percentage and amount of radiodense tissue in a digitized mammogram. The technique involves determining a dynamic threshold for segmenting radiodense indications in mammograms. Both the mammographic image and the threshold are modeled as Gaussian random variables. This work is intended to support a concurrent study being conducted at Fox Chase Cancer Center (FCCC) exploring the association between dietary patterns and breast cancer risk. Mammograms have been obtained from an existing cohort of women enrolled in the Family Risk Analysis Program at FCCC; preliminary segmentation results are presented.---This work is sponsored by the American Institute for Cancer Research and the American Cancer Society.

Biological Effects of Low-Power Ultrasonics

---Rena Buhbinder[1] and Phineas Dickstein[1,2], [1]Quality Assurance and Reliability, Technion-Israel Institute of Technology, Haifa, Israel 32000; [2]Soreq Nuclear Research Center, Yavne, Israel 81800

---Ultrasonics is wildly used in medical diagnosis. The mechanical nature of ultrasonic, vibrations within the media, have impacts on biological systems. Several experiments on animals exposed to ultrasonics, and some experience with humans, revealed potential biological effects. These effects depend on both the radiation features (frequency, power, duration of exposure) as well as on biological parameters of the media. At certain conditions, the biological effects may become a hazard. We conducted a critical survey of the experimental data related to biological effects of ultrasonics. The existing data have considerable limitations, mainly because most of the reported biological effects cannot be accepted as statistically significant. Another difficulty, regarding potential hazards to humans, is that biological effects revealed in certain animals cannot be simply related to humans as well. In spite of these difficulties, an attempt is made to decipher the dominant and most probable biological effects on humans exposed to ultrasonics, and to examine, subsequently, the suitability of the current safety standards.

Clinical Results with an UltraSonographic Periodontal Probe

---Mark K. Hinders and John E. Lynch, Department of Applied Science, College of William & Mary, Williamsburg, VA 23187; Gayle B. McCombs, Department of Dental Hygiene, Old Dominion University, Norfolk, VA 23606

---A new ultrasonographic periodontal probe has been developed that offers the potential for earlier detection of periodontal disease activity, non-invasive diagnosis, and greater reliability of measurement. A comparison study of the ultrasonographic probe to both a manual probe, and a controlled-force probe was conducted to evaluate its clinical effectiveness. Twelve patients enrolled into this study. Two half-month examinations were conducted on each patient, scheduled one hour apart. A one-way analysis of variance was performed to compare the results for the three sets of probing depth measurements, followed by a repeated measures analysis to assess the reproducibility of the different probing techniques. These preliminary findings indicate that manual and ultrasonographic probing measure different features of the pocket. Therefore, it is not obvious how the two depth measurements correspond to each other. However, both methods exhibited a similar tendency toward increasing pocket depths as Gingival Index scores increased. Based on the small sample size, further studies are being conducted using a larger population of patients exhibiting a wider range of disease activity. In addition, studies that allow histological examination of the pocket after probing will help further evaluate the clinical effectiveness of the ultrasonographic probe. Future studies will also aid in the development of more effective automated feature recognition algorithms that convert the ultrasonographic echoes into pocket depth readings.

Tuesday, July 31, 2001

SESSION 13
NDE FOR RAIL DEFECTS
S.-C. Wooh and S. Singh, Co-Chairpersons
Druckenmiller 016

3:30 PM **Ultrasonic Characterization of Transverse Defects in Rail Heads**
---S. Singh and R. Clark, Sperry Rail Service, 46 Sheltor Rock Road, Danbury, CT 06810

3:50 PM **Elastic Wave Analysis for Broken Rail Detection**
---J. L. Rose, The Pennsylvania State University, Engineering Science & Mechanics Department, University Park, PA 16802; M. J. Avioli, Jr., FBS, Inc., State College, PA 16801; Y. Cho, Inje University, School of Mechanical and Automotive Engineering, Kimhae Kyongsangnam-do, 621-749, Korea

4:10 PM **Exploring Enhanced Rail Flaw Detection Using Ultrasonic Phased Array Inspection**
---D. Utrata, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

4:30 PM **Laser Ultrasonic Detection of Rail Defects**
---S.-C. Wooh and J. Wang, Massachusetts Institute of Technology, Department of Civil and Environmental Engineering, 77 Massachusetts Avenue, Cambridge, MA 02139

4:50 PM **Hybrid Ultrasonic Array Transducer for the Characterization of Rail Head Defects**
---S.-C. Wooh and J. Wang, Massachusetts Institute of Technology, Department of Civil and Environmental Engineering, 77 Massachusetts Avenue, Cambridge, MA 02139

5:10 PM **Finite Element Modeling of Waves in a Rail**
---W.-Y. Lu and J. Dike, Sandia National Laboratories, MS 9042, 7011 East Avenue, Livermore, CA 94551-0969; A. Modjtahedzadeh, Bay Area Rapid Transit, MS 1KB-6, 1000 Broadway, Oakland, CA 94607

5:30 PM **NDE of Rail Trackbed Using GPR and Infrared Thermography**
---M. Clark, D. M. McCann, and M. C. Forde, University of Edinburgh, The Kings Building, Edinburgh EH9 3JN, Scotland, United Kingdom

Ultrasonic Characterization of Transverse Defects in Rail Heads

---Surendra Singh and Robin Clark, Sperry Rail Service, 46 Sheltor Rock Road, Danbury, CT 06810

---Knowledge of sound fields in 70^o refracted shear waves as well as their interactions with defects is important to optimize ultrasonic rail inspections. Various techniques, such as photoelastic visualization and Schlieren optics have been used to study the wave-propagations in materials. These techniques, however, have limitations; for example, Schlieren method is used only in transparent media. In this work, we studied the sound fields in 70^o refracted shear waves and their interactions with defects in transverse planes in four rail specimens. The first and the second specimens had side-drilled holes (SDHs) and were used to study the sound fields in the transverse (y-z) plane. The results showed that the field 70^o transducers (front and rear) had a higher sensitivity than the gage 70^o transducers. The third and the forth specimens having EDM notches (simulating kidney-shaped defects known as Detailed Fracture "DF") were used to study the effect of size and orientation of EDM notches on the amplitude of echoes. These results showed that the amplitude of waves reflected from EDM notches was highest for the notch oriented at 20^o and decreased for other notches oriented at 5^o, 10?, 15?, 25?, 30?, and 35^o. In addition, the amplitude of echoes was dependent on the size of the notches.

Elastic Wave Analysis for Broken Rail Detection

---Joseph L. Rose, The Pennsylvania State University, Engineering Science & Mechanics Department, University Park, PA 16802; Michael J. Avioli, Jr., FBS, Inc., State College, PA 16801; Y. Cho, Inje University, School of Mechanical and Automotive Engineering, Kimhae Kyongsangnam-do, 621-749, Korea

---Signal processing and data analysis concepts are presented to identify broken rail as a result of guided wave propagation over distances from 0 on up to 10 Km. Two major techniques are presented, one for the detection of broken rail utilizing an impact device and one from energy propagating from the train wheel contact with the rail itself. Receivers can be mounted on the track itself or mounted directly onto the moving train. Progress on receiver techniques will be discussed. In principle, elastic guided wave energy propagates along the track until a broken rail is encountered. Pulse echo reflection is then used to identify broken rail. Sonic and ultrasonic wave packets are considered. As the train gets closer to a broken rail the elastic wave energy gets stronger and the subsequent reflection also gets stronger. This leads to an exponential decrease in penetration power from a source as a function of distance. Natural energy filtering mechanisms of a rail are discussed along with a model of guided wave propagation in rail. Sample experiments will be reported.

Exploring Enhanced Rail Flaw Detection Using Ultrasonic Phased Array Inspection
---Dave Utrata, Center for NDE, Iowa State University, 1915 Scholl Road, Ames, IA 50011

---In previous work, an apparent increase in detectability of rail flaws was noted when fluid-filled wheel probes or immersion ultrasonic probes were oriented in a non-traditional manner. It was found that transverse defects in various rails produced significantly larger high-amplitude regions in C-scans when the plane of refracted inspection beams was about 10 degrees off from parallel to the longitudinal axis of the rail. Using a linear phased array transducer, this angular dependency of detected flaw signal was more closely examined. Three rails having different profiles but nominally the same size transverse defect were scanned while electronically sweeping a refracted 70^{o} shear beam from parallel to the longitudinal axis of the rail to either rail side in 2.5 degree increments. Irrespective of rail profile, the aforementioned increase in high-amplitude regions on the resultant C-scans was found for all flaws when the incident beam was aimed a nominal 10-15 degrees to the field side of the rail. This suggests increased inspection sensitivity if a decidedly unconventional beam alignment were to be used. Challenges and cautions in making this conclusion are discussed, along with some corrections used for miscalculated steered-beam trajectories.---The author wishes to thank Krautkramer and Sperry Rail Service for their support of this research.

Laser Ultrasonic Detection of Rail Defects
---Shi-Chang Wooh and Jiyong Wang, Department of Civil and Environmental Engineering, Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, MA 02139

---The objective of this study is to investigate laser-ultrasonic methods for non-contact detection and characterization of rail defects. Theoretical studies reveal that the most effective wave mode for detecting transverse defects is the shear wave propagating at high angles. Accordingly, a laser ultrasonic detection scheme based on the principle of ultrasonic shadowing is presented and its optimal configuration is studied. The feasibility of this approach is evidenced by the proof-of-concept tests showing the capability of generating and detecting ultrasonic signals for rail specimens with transverse head defects. In addition, a scheme for sizing and locating the flaw is presented. The outcome of the feasibility tests looks promising; the laser method may be implemented as a non-contact NDE method for detecting such flaws as transverse defects masked by longitudinal shells, which are blind to traditional ultrasonic techniques.

Hybrid Ultrasonic Array Transducer for the Characterization of Rail Head Defects

---Shi-Chang Wooh and Jiyong Wang, Massachusetts Institute of Technology, Department of Civil and Environmental Engineering, 77 Massachusetts Avenue, Cambridge, MA 02139

---A concept of an ultrasonic defect detection system is introduced. Based on the principles of dynamic beam steering and ultrasonic shadowing, the transducer system consists of two sub-arrays: an assembly of a linear phased array for directing and steering an ultrasonic beam in a test specimen, and a static array for sensing the boundaries of the near and far shadows of a defect from the reflected beam. Using a dynamic pitch-catch configuration, the transducer is capable of determining the location, size and orientation of a planar defect without any mechanical scanning or relocating the transducer. A theoretical shadow analysis carried out in this study allows for developing a scheme for characterizing a defect. To demonstrate the feasibility of the technique, a rail specimen with real defect has been assessed. This scheme proves to be a viable approach for characterizing transverse defects with good accuracy.

Finite Element Modeling of Waves in a Rail

---Wei-yang Lu and Jay Dike, Sandia National Laboratories, MS 9042, 7011 East Avenue, Livermore, CA 94551-0969; Ali Modjtahedzadeh, Bay Area Rapid Transit, MS-1KB-6, 1000 Broadway, Oakland, CA 94607

---Using a rail as an acoustic waveguide is being considered as a potential technique for broken rail detection. Due to its complicated geometry, the modes and propagation of guided waves in a rail are not well understood. Finite element (FE) modeling may provide understanding of guided wave characteristics and information about waveguide scattering from cracks, welds, joints, etc. This study concentrates on developing a FE model to obtain the modes of deformation and wave velocities in a 119RE rail. Modal and transient analyses of a rail with 30 inch tie-downs are considered. Simple and ideal conditions are considered for the rail system? that is the rail material is elastic and the tie-downs are rigid. A representative short rail, about 180 in long, is used in the modeling. In transient analyses, impact or wavelet-type excitations are applied in the web section. Simulated resonant mode shapes, frequencies, waveforms, velocities, etc. are reported.

NDE of Rail Trackbed Using GPR & Infra-red Thermography

---M. Clark, D. M. McCann, and M. C. Forde, University of Edinburgh, The Kings Buildings, Edinburgh EH9 3JN, Scotland, United Kingdom

---The role of ballast is to provide a stable platform for the sleepers (or ties) which support the rails. Approximately thirty percent of deformation problems with the rail may be attributed to deformation of the ballast. This paper will report on laboratory research to characterize the electrical permittivity of ballast material. This data was then used for the radar (GPR) field trials on both a pilot scale track and on live track. It was demonstrated that it is possible to discriminate between: clean dry, clean wet, spent and wet spent ballast. A complementary approach was to use infrared thermography to identify defects in ballast. It was found that infrared thermography was effective in identifying wet areas. Results will be given from full-scale field trials of infrared thermography alongside the GPR work. Considerable scope exists for extending this work to high speed rail monitoring.

SESSION 14
MICROWAVE NDE
H. Martz, Chairperson
Smith Auditorium (Sills)

3:30 PM **Investigation of Potential Use of Combined Microwave Near-Field and Modulated Scattering Techniques (MST) for Detection of Delaminating Due to Impact Damage in Multi-Layered Glass Fiber Reinforced Polymer Composite Structures**
---D. Hughes, C. Behrens, and R. Zoughi, University of Missouri-Rolla, Applied Microwave Nondestructive Testing Laboratory (*amntl*), Electrical and Computer Engineering Department, Rolla, MO 65409

3:50 PM **Microwave Imaging of Delaminations in IC Packages**
---Y. Ju[1], M. Saka[1], and H. Abé[2], [1]Tohoku University, Department of Mechanical Engineering, Aoba 01, Aramaki, Aoba-ku, Sendai 980-8579, Japan; [2]Tohoku University, 2-1-1 Katahira, Aoba-ku, Sendai 980-8577, Japan

4:10 PM **NDE of Small 3D Surface Fatigue Cracks in Metals by Microwaves**
---M. Saka[1], Y. Ju[1], Y. Uchimura[1], and H. Abé[2], [1]Tohoku University, Department of Mechanical Engineering, Aoba 01, Aramaki, Aoba-ku, Sendai 980-8579, Japan; [2]Tohoku University, 2-1-1 Katahira, Aoba-ku, Sendai 980-8577, Japan

4:30 PM **Interaction of Lateral Electromagnetic Waves with Metallic Surfaces**
---J. Yotsuji and J. B. Spicer, The Johns Hopkins University, Materials Science and Engineering, 3400 N. Charles Street, Baltimore, MD 21218

4:50 PM **Finite-Difference Time-Domain Modeling of Wave Propagation for Simulation of Radar Measurements of Concrete**
---H. C. Rhim, Yonsei University, Nondestructive Evaluation and Structures Laboratory, Department of Architectural Engineering, Seoul 120-749, Korea

Investigation of Potential Use of Combined Microwave Near-Field and Modulated Scattering Techniques (MST) for Detection of Delaminating Due to Impact Damage in Multi-Layered Glass Fiber Reinforced Polymer Composite Structures

---D. Hughes, C. Behrens, and R. Zoughi, Applied Microwave Nondestructive Testing Laboratory (amntl), Electrical and Computer Engineering Department, University of Missouri-Rolla, Rolla, MO 65409

---Impact damage in glass fiber reinforced polymer composites can result in delamination in between various fiber layers. In critical environments in which thick composite structures are utilized in a nondestructive method capable of detecting this type of damage is needed. Near-field microwave nondestructive techniques have shown great potential for detecting thin delaminations in thick and multi-layered composites. In this paper, application of modulated scattering techniques (MST), using embedded modulated PIN diode-loaded dipole probes, combined with near-field microwave NDT techniques, for the purpose of detecting delamination in composite structures is investigated. The addition of a modulated dipole probe increases the sensitivity of the measurements, as well as providing local material characterization around the probe. For this investigation, a composite panel was manufactured using 16 plies of 30-cm square woven glass fabric, and 8810/TEDA epoxy, resulting in an overall thickness of 9.05 mm. Three modulated dipole probes were embedded under the fifth, the eighth and the eleventh plies. This sample was then subjected to several drop-weight impact cycles near the location of the modulated dipole probes, using a 0.162-kg, 5.655-cm diameter spherical mass. Subsequently, the effect of the impact(s) is investigated through measuring the dynamic reflection properties (reflection from the modulated dipole probe) of the composite specimen. This paper presents the results of this investigation in addition to a discussion of future work.

Microwave Imaging of Delaminations in IC Packages

---Yang Ju[1], Masumi Saka[1], and H. Abé[2], [1]Department of Mechanical Engineering, Tohoku University, Aoba 01, Aramaki, Aoba-ku, Sendai 980-8579, Japan; [2]Tohoku University, 2-1-1 Katahira, Aoba-ku, Sendai 980-8577, Japan

---The delamination that may occur in IC packages has become more and more an important factor regarding the reliability of the package, because the plastic encapsulant is required to be made as thin and small as possible in order to raise the density of surface mount. Therefore, the inspection of such delamination is a very important issue for either the design of IC packages or the development of encapsulant materials. In the present paper, delaminations, which may occur between the chip pad and the encapsulant resin in IC packages, are inspected by microwave imaging technique. An open-ended coaxial line sensor is used to increase the spatial resolution of the measurement. The microwave images are generated using the measured amplitude and phase of the reflection coefficient. The full and part delaminations are detected successfully. The results are also compared with those obtained by scanning acoustic tomography. The good inspection capability and no necessity of any coupling medium of this technique offer a new approach for the integrity assessment of IC packages.

NDE of Small 3D Surface Fatigue Cracks in Metals by Microwaves

---Masumi Saka[1], Yang Ju[1], Yasuhiro Uchimura[1], and H. Abé[2], [1]Department of Mechanical Engineering, Tohoku University, Aoba 01, Aramaki, Aoba-ku, Sendai 980-8579, Japan; [2]Tohoku University, 2-1-1 Katahira, Aoba-ku, Sendai 980-8577, Japan

---Fatigue cracking often initiates from the surface, since the surface stress is often higher than the stress of inside when a metal is under load. Hence, the evaluation of the surface connected cracks in practical structures has greater significance than that of comparable cracks within the materials. In this paper, small 3D surface fatigue cracks in metals are evaluated quantitatively by using microwaves under a condition of no contact and without any coupling medium. So far, nondestructive evaluation of slits by using microwaves has been reported. However, it has not been successful to detect and evaluate such cracks due to the lack of the spatial resolution of usual microwave techniques. In this study, an open-ended coaxial line sensor is used to increase the spatial resolution and the ratio of signal to noise. Small 3D fatigue cracks including closed cracks are detected successfully, where a W-shaped characteristic signal is obtained. Then, a dual frequency technique is proposed to evaluate the depth of small 3D fatigue cracks, of which situation regarding crack closure is unknown. The evaluated results are shown to agree well with the actual values observed on the fractured surface obtained after finishing the microwave testing. The promising new technique indicates a great significance for the integrity assessment of metallic structures.

Interaction of Lateral Electromagnetic Waves with Metallic Surfaces

---Junichi Yotsuji and James B. Spicer, Materials Science and Engineering, The Johns Hopkins University, 3400 N. Charles St., Baltimore, MD 21218

---Electromagnetic wave techniques have been used extensively for materials characterization. Microwaves have been used for the measurement of degree of cure in composite materials, eddy current methods have been used for the detection of surface breaking cracks in metal alloys and radio waves have been used as a probe of the earth's crust . For techniques that use propagating waves, there are actually three modes for electromagnetic wave transmission from the source to the receiver: direct waves, reflected waves and lateral waves (also known as surface waves). An interesting characteristic of lateral waves is that they propagate along the boundary between two different materials with the interaction being confined to the boundary region. In this work, the use of lateral waves for remote and noncontacting sensing is considered with an emphasis on characterization of metallic surfaces. The interaction of these waves with near surface microstructural features such as cracks, voids and inclusions is considered showing that lateral waves can be used to detect these features using microwave-based techniques. While the lateral field strength is small compared to other modes, it is shown that this field is sufficiently large to be useful for crack detection purposes.

Finite-Difference Time-Domain Modeling of Wave Propagation for Simulation of Radar Measurements of Concrete

---Hong C. Rhim, Nondestructive Evaluation and Structures Laboratory, Department of Architectural Engineering, Yonsei University, Seoul 120-749, Korea

---Finite difference-time domain (FD-TD) modeling method has been applied to study the interaction of concrete with electromagnetic waves. The purpose is to visualize the propagation of the electromagnetic fields in a dielectric medium of concrete in an effort to obtain one-dimensional imagery of a concrete target for nondestructive testing purposes. A Gaussian pulse plane wave and a sinusoidal wave are directed to laboratory size concrete specimens as excitation sources. Snap shots of computer simulation are shown to display wave propagation and scattering through and by the concrete specimens. Geometry of the targets is varied with different dimensions, and with or without an inclusion. The use of electromagnetic wave scattering to image the interior configurations of concrete structures is a powerful tool for nondestructive remote sensing. The method involves the study of electromagnetic wave interaction with various concrete targets and a numerical technique, which can simulate wave scattering by a dielectric medium such as concrete to examine numerous electromagnetic phenomena on a computer. Interpretation of echograms from radar measurements for nondestructive testing (NDT) of concrete structures hinges on an understanding of how electromagnetic waves propagate in concrete. In that respect, the study of forward modeling with known material and geometric parameters of concrete can provide valuable information as to how the wave propagates through and scatters by a concrete target. A candidate numerical modeling approach for this purpose is the finite difference-time domain (FD-TD) solution of Maxwell's curl equations, which are the governing equations of the electromagnetic fields. The FD-TD is a marching-in-time procedure, which can simulate continuous wave propagation in concrete. The technique is flexible in simulating objects with different geometry and wave sources. The method is especially suited for visualizing the electromagnetic phenomena, since electric and magnetic fields are calculated everywhere within a computational domain as a function of time. The FD-TD numerical modeling technique is applied to selected laboratory size concrete specimens. Electromagnetic wave scattering phenomena by three different types of concrete specimens using the FD-TD method are presented. One-dimensional images of the specimens, which represent the interior configurations of the targets, are obtained from the numerical study. The outside dimensions of the specimens are varied to examine the effect of target sizes on the wave propagation and scattering. The specimens are modeled with or without an inclusion to study the detectability of the inclusion. The issues involved in the use of the FD-TD method on concrete specimens for NDT purposes are also discussed.

SESSION 15

WAVE PROPAGATION IN ANISOTROPIC AND INHOMOGENEOUS MEDIA

M. B. Spies, Chairperson
Cleaveland 151 (Druckenmiller)

3:30 PM **An Efficient Stable Recursive Algorithm for Elastic Wave Propagation in Layered Anisotropic Media**
---L. Wang and S. I. Rokhlin, The Ohio State University, Nondestructive Evaluation Program, Edison Joining Technology Center, 1248 Arthur E. Adams Drive, Columbus, OH 43221

3:50 PM **Modeling of Point-Source and Transducer Wavefields in a Transversely Isotropic Half-Space**
---D. Gridin and L. J. Fradkin, South Bank University, Center for Waves and Fields, School of Electrical, Electronic, and Information Engineering, 103 Borough Road, London SE1 0AA, United Kingdom

4:10 PM **Gaussian Beam Propagation in Anisotropic Inhomogeneous Elastic Media**
---L. W. Schmerr, Jr., Iowa State University, Center for NDE and Department of Aerospace Engineering and Engineering Mechanics, Ames, IA 50011; A. Sedov, Lakehead University, Department of Mechanical Engineering, Thunder Bay, Ontario, Canada P7B 5E1

4:30 PM **Combined Effects of Material Heterogeneity and Anisotropy on Wideband Radiation of Ultrasonic Beams**
---N. Gengembre and A. Lhémery, French Atomic Energy Commission, CEA/LIST, CEA-Saclay, bât. 611, 91191 Gif-sur-Yvette, Cedex, France

4:50 PM **Influence of Forward Scattering on Ultrasonic Measurements**
---A. Li, R. Roberts, F. J. Margetan, and R. B. Thompson, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

5:10 PM **Numerical and Experimental Studies of the Angular Deviation of Lamb Waves in an Anisotropic Plate When Excited by a Bounded Beam**
---S. Baly, C. Potel, and J.-F. de Belleval, Laboratoire Roberval, UMR CNRS 6066, Université de Technologies de Compiegne, Compiegne, France; M. J. S. Lowe, Imperial College, Department of Mechanical Engineering, London SW7 2BX, United Kingdom

An Efficient Stable Recursive Algorithm for Elastic Wave Propagation in Layered Anisotropic Media

---L. Wang and S. I. Rokhlin, The Ohio State University, Nondestructive Evaluation Program, Edison Joining Technology Center, 1248 Arthur E. Adams Drive, Columbus, OH 43221

---An efficient recursive algorithm, the stiffness matrix method, has been developed for wave propagation in multilayered generally-anisotropic media. This algorithm has the computational efficiency and simplicity of the standard transfer matrix method and is unconditionally computationally stable for high frequency and layer thickness. In this algorithm, the stiffness (compliance) matrix is calculated for each layer and recursively applied to generate a stiffness (compliance) matrix for the layered system. Next, reflection and transmission coefficients are calculated for the layered media bounded by liquid or solid semispaces. Results show that the method is stable for arbitrary number and thickness of layers and the computation time is proportional to the number of layers. It is shown both numerically and analytically that for a thick structure, the solution approaches the solution for a semispace. This algorithm is easily adoptable for laminates with periodicity, such as multi-angle lay-up composites. The repetition and symmetry of the unit cell are naturally incorporated in the recursive scheme. Based on this method, characteristic equations for Lamb waves and Floquet waves in periodic media have also been determined.---This work was partially sponsored by the Federal Aviation Administration under Contract #DTFA03-98-D-00008 and performed at The Nondestructive Evaluation Program at The Ohio State University as part of the Center for Aviation Systems Reliability program through the Airworthiness Assurance Center of Excellence.

Modeling of Point-Source and Transducer Wavefields in a Transversely Isotropic Half-Space

---Dmitri Gridin and Larissa J. Fradkin, Centre for Waves and Fields, School of Electrical, Electronic and Information Engineering, South Bank University, 103 Borough Road, London SE1 0AA, United Kingdom

---The elastic wavefields generated by surface loads acting on a transversely isotropic (TI) half-space are studied. The symmetry axis of the solid is oriented arbitrarily with respect to the surface of the half-space. We start by considering the field of a point source, that is, Green's tensor of Lamb's problem for a TI solid. First, the integral representation of the time-harmonic Green's tensor is given. Then, the complete far-field asymptotic approximation of a quasi-longitudinal (qP) and two quasi-shear (qSH and qSV) waves is derived. The qP wave is described by the leading term of the ray series, since there is only one arrival of this wave. The qSH wave is treated similarly everywhere apart from the so-called kissing-point boundary layer where the qSH and qSV wave-fronts are tangentially close to each other. A special asymptotic formula is obtained for this case. The qSV sheet of the wave surface is allowd to have conical points and cuspidal edges. Thus, the far-field approximation of the qSV wave involves ray-asymptotic expressions while inside the geometrical regions (where either one or three qSV arrivals exist), or else boundary-layer asymptotics inside conical-point, cuspidal-edge and kissing-point boundary layers. Then, we present numerical results of the simulation of pulse propagation. A good agreement between the asymptotic and direct numerical codes is achieved but the former is orders of magnitude faster. We finish our presentation by considering the radiating near field of a circular ultrasonic transducer acting on the surface of a TI half-space.

Gaussian Beam Propagation in Anisotropic, Inhomogeneous Elastic Media

---Lester W. Schmerr, Jr., Center for NDE and Department of Aerospace Engineering and Engineering Mechanics, Iowa State University, Ames, IA 50011; Alexander Sedov, Department of Mechanical Engineering, Lakehead University, Thunder Bay, Ontario, Canada P7B 5E1

---In the ultrasonic NDE of welds and composite materials, one can encounter inspection problems where the underlying material may be both anisotropic and inhomogeneous. In such situations, the sound beam from the ultrasonic transducer may be "steered" and distorted, making such inspections very difficult to understand and use. Models can help to predict these effects but modeling the propagation of ultrasonic waves in such complex media is a very challenging task. Recently, we have begun modeling efforts aimed at simulating the wave field of a transducer in general anisotropic, inhomogeneous materials. In simpler homogeneous medium simulations, Gaussian beams have proven to be very useful as basis functions for synthesizing more general transducer fields. Thus, initially, we are considering the effects of anisotropy and inhomogeneity on the propagation of a single Gaussian beam. There are two parts to determining how a Gaussian beam behaves in such complex media. First, one needs to find the path the Gaussian follows. Second, one needs to determine the amplitude and phase variations that occur in the Gaussian along this path. The first problem is governed by a classical system of ray tracing equations, while the second problem can be described in terms of a set of so-called dynamic ray tracing equations. While it is possible to formally define both these systems of equations for general media, current formulations are plagued by "singularities" that arise whenever the slowness surfaces touch or intersect, a common occurrence in many anisotropic media of interest. Here, we will show that it possible to remove these singularities in a simple, direct manner through the use of a special set of moving ray coordinates and paraxial expansions of the slowness surface(s) in those coordinates. This approach results in a completely general and non-degenerate formulation for the propagation of the Gaussian beam, a formulation that we employ in future efforts to simulate NDE inspections.---This work was supported by the NSF Industry/University Cooperative Research program.

Combined Effects of Material Heterogeneity and Anisotropy on Wideband Radiation of Ultrasonic Beams

---Nicolas Gengembre and Alain Lhémery, French Atomic Energy Commission, CEA/LIST, CEA-Saclay, bât. 611, 91191 Gif-sur-Yvette cedex, France

---In previous issues of this conference, a model developed at CEA for predicting ultrasonic fields radiated by refraction (immersed, contact transducers) in materials has been progressively extended from the case of components made of isotropic material to those of components made of anisotropic, then isotropic and heterogeneous and eventually anisotropic and heterogeneous materials. The present paper aims at showing and discussing examples of application of the model to practical cases when prediction of beam radiation is required to study performances of a NDT method. These cases are concerned with components which constituting material exhibits both heterogeneous and anisotropic properties. In such components, accurate computations are required since having an intuitive understanding of what happens is almost impossible. On the other hand, a posteriori understanding of accurately predicted results can help solving for example the problem of determining what is the most suitable probe for a given task. The paper will outline the main stages in deriving the model. Then, examples will be given and discussed showing combined effects of heterogeneities and anisotropy on radiated fields. For this, various tools for imaging field characteristics will be used to have the best possible insight into what happens in rather complex testing configurations.

Influence of Forward Scattering on Ultrasonic Measurements

---A. Li, R. Roberts, F. Margetan, and R. Bruce Thompson, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---The elastic inhomogeneity of a granular microstructure introduces scattering noise in ultrasonic measurements. Backscattering at grain boundaries produces the familiar noise floor seen nearly universally in ultrasonic measurements. Scattering in the forward direction also introduces a type of noise. Forward scattering noise is not observed directly on the oscilloscope, as with backscattered noise, but rather is seen in its influence on signals generated by other scattering events, such as scattering by flaws, or back-wall reflections. Experimental examination of the effects of forward scattering noise has revealed puzzling behaviors, such as an apparent ultrasonic attenuation that depends on beam geometry, or a beam geometry-dependent flaw signal variance. While models for backscattering have undergone extensive development, relatively little development has occurred on the study of forward scattering in the context at hand. In this paper, we report on an ongoing computational study of the effects of forward scattering on ultrasonic measurement. The study uses a volume integral formulation of the scattering problem, which is solved by an efficient FFT-based Neumann iteration. The talk will summarize the computational procedure, and then discuss its application in explaining various experimentally observed forward scattering phenomena.---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 Center for Aviation Systems Reliability program.

Numerical and Experimental Studies of the Angular Deviation of Lamb Waves in an Anisotropic Plate when Excited by a Bounded Beam

---Stéphane Baly, Catherine Potel, Jean-Francois de Belleval, Laboratoire Roberval, UMR CNRS 6066, Université de Technologies de Compiegne, Compiegne, France; Mike Lowe, Department of Mechanical Engineering, Imperial College, London SW7 2BX United Kingdom

---The interaction of an incident monochromatic bounded beam with an anisotropic multilayered plate immersed in a fluid has been modeled, using the method of decomposition into plane waves, in a 3D configuration. This model permits the pressure of the reflected and/or transmitted field in the fluid to be predicted, notably at any position in a plane parallel to the plate. It is thus possible to study the specularly reflected near-field as well as the leakage of Lamb waves in the far field. The model allows arbitrary orientation of the incident beam in 3D with respect to the plate. For some ultrasonic testing configurations, a monochromatic Lamb wave beam can be locally excited in the structure by the emitting transducer immersed in the fluid : since the incident field is a bounded beam, a Lamb wave beam is generated in the structure. Due to the anisotropy of the media constituting the structure, the most energetic part of the Lamb wave beam is deviated with respect to the sagittal plane of the incident bounded beam, in a direction normal to the Lamb slowness curve. This phenomenon is illustrated both numerically and experimentally in the case of a single layer of unidirectional carbon/epoxy plate, the fibers of which are not necessarily parallel to the sagittal plane. According to the chosen Lamb mode, the deviation of the Lamb wave beam can occur in a direction very close to that of the fibers.

SESSION 16
UT MODELING
L. Fradkin and M. Kitahara, Co-Chairpersons
Smith Auditorium (Sills)

8:30 AM **Elastic Wave Modeling by a Chebyshev Collocation Method**
---S. A. Nielsen, Mechatronics and Sensor Technology, Force Institute, Park Allé 345, DK-2650, Brondby, Denmark

8:50 AM **A 3D Simulation of Ultrasonic Scattering in a Fluid-Loaded Elastic Half Space**
---K. Kimoto and S. Hirose, Tokyo Institute of Technology, Department of Mechanical and Environmental Informatics, O-okayama, Meguro-ku, Tokyo, Japan

9:10 AM **A Visualization Technique for Interaction of Circumferential Creeping Waves with Cracks**
---M. Kitahara, K. Nakahata, and T. Ichino, Tohoku University, Department of Civil Engineering, Graduate School of Engineering, Aoba-yama 06, Sendai, Miyagi, 980-8579, Japan

9:30 AM **Mathematical Modeling of Ultrasonic Inspection of Tilted Surface-Breaking Cracks**
---V. M. Babich and V. Kamotski, Steklov Institute of Mathematics, St. Petersburg, Russia; V. A. Borovikov, Department of Physical and Mathematical Sciences, Autonomous University of Puebla, Puebla, Mexico; L. J. Fradkin and D. Gridin, School of Electrical, Electronic and Information Engineering, South Bank University, London, U.K; B. A. Samokish, Department of Mathematics and Mechanics, St. Petersburg State University, St. Petersburg, Russia; V. P. Smyshlyaev, Department of Mathematical Sciences, University of Bath, Bath, United Kingdom

9:50 AM **Scattering of High Frequency Ultrasound from the Interface Between Two Rough Surfaces**
---A. M. Quinn[1], B. W. Drinkwater[1], and R. S. Dwyer-Joyce[2], [1]University of Bristol, Department of Mechanical Engineering, Queen's Building, University Walk, Clifton, Bristol, BS6 5PW, United Kingdom; [2]University of Sheffield, Department of Mechanical Engineering, Mappin Street, Sheffield, S1 3JD, United Kingdom

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

10:30 AM **Improvement of the Mass-Spring Lattice Model for Quantitatively Accurate Simulation of Ultrasonic Testing**
---H. Yim and C.-J. Lee, Hong-ik University, Department of Mechanical Engineering, 72-1 Sangsoo Dong, Mapo Ku, Seoul, 121-791 Korea

10:50 AM **Modeling Transient Radiation of Ultrasonic Transducers in Anisotropic Materials Including Wave Attenuation**
---M. Spies, Fraunhofer-Institute for Nondestructive Testing, IZFP, University Building 37, 66123, Saarbrucken, Germany

11:10 AM **Validation of Time Domain Theories for the Reflection of Ultrasonic Waves from Periodically Rough Surfaces**
---Y. Guo, R. B. Thompson, and F. J. Margetan, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

11:30 AM **Using DGS Diagrams to Validate Sound Field Simulations**
---A. Schumm, Electricité de France, R&D MTI/MMN, F-92141 Clamart, France

11:50 AM **Shape Reconstruction of Defects in Inhomogeneous Material**
---K. Nakahata and M. Kitahara, Tohoku University, Department of Civil Engineering, Graduate School of Engineering, Japan

12:10 PM ***Lunch***

Elastic Wave Modeling by a Chebyshev Collocation Method

---Steen Arnfred Nielsen, Mechatronics and Sensor Technology, Force Institute, Park Allé 345, DK-2650 Brondby, Denmark

---An accurate numerical simulation of the elastic field is needed in order to predict material parameters in materials with complex geometries. In this paper we present an approach for solving the elastic wave equation in discontinuous layered materials with complex geometries. The approach is based on a pseudospectral elastodynamic (PSE) formulation. The PSE-formulation gives a direct solution of the time-domain elastodynamic equations in a multi-domain setting. A typical calculation is performed by decomposing the global computational domain into a number of subdomains. Every subdomain is then mapped on a unit square using transfinite blending functions and spatial derivatives are calculated efficiently by a Chebyshev collocation scheme. With this curvilinear mapping the elastodynamic equations can be solved within spectral accuracy, and furthermore, complex interfaces can be approximated smoothly, avoiding staircasing. A global solution is constructed from the local solutions by means of characteristic variables. Each subdomain has either open, physical or stress free boundary conditions. Finally, the global solution is advanced in time using a fourth order Runge-Kutta scheme. Examples of field prediction in discontinuous solids with complex geometries are given and related to ultrasonic NDE.

A 3D Simulation of Ultrasonic Scattering in a Fluid-Loaded Elastic Half Space

---Kazushi Kimoto and Sohichi Hirose, Department of Mechanical and Environmental Informatics, Tokyo Institute of Technology, O-okayama, Meguro-ku, Tokyo, Japan

---Numerical simulations of an immersion ultrasonic testing by full numerical method such as FEM or BEM are often intractable or at least time consuming. Therefore, many problems of practical importance have been solved employing concept of the ray method. The ray method greatly simplifies the analysis and numerical implementations but give good solution as long as the field is dominated by the specularly reflected waves. However, strong diffracted waves sometimes appear depending on the shape of the scatterer. In such cases, the approximation becomes very poor and so does the simulation result. In this study, therefore, a boundary element method for simulations of an immersion ultrasonic testing is developed employing a fluid-loaded elastic half space as a numerical model. For computational efficiency, the incident field is calculated first by an approximate Green's function that satisfies the fluid-solid interface conditions. Then the remaining scattered field is obtained by the BEM. Since the scattered waves distribute only in the neighborhood of scattering obstacles, the BEM used here doesn't need as many elements as the ordinary BEM to achieve the desired accuracy. This can be the advantage of our method over the conventional BEM. In the numerical examples, therefore, simulations of an immersion ultrasonic testing are carried out changing source-receiver configuration and the efficiency of our method is examined.

A Visualization Technique for Interaction of Circumferential Creeping Waves with Cracks
---Michihiro Kitahara, Kazuyuki Nakahata, and Taisuke Ichino, Department of Civil Engineering, Graduate School of Engineering, Tohoku University, Aoba-yama 06, Sendai, Miyagi, 980-8579, Japan

---For the ultrasonic nondestructive evaluation, it is of primary importance to understand the wave propagation process from defects. In this study, the scattered waves from a cavity with the sub-surface inner cracks are calculated by the boundary element method. The scattered wave motion in the vicinity of the cavity is visualized in order to see the interaction process of the circumferential creeping wave with cracks. The backscattered waveforms at the transducer position is then calculated by using the far-field integral representation of the scattered wave. The effect of the sub-surface cracks to the backscattered receiving signal is investigated from both results of near-field visualizations and far-field waveforms.

Mathematical Modeling of Ultrasonic Inspection of Tilted Surface-Breaking Cracks
---Vassili M. Babich and Vladimir Kamotski, Steklov Institute of Mathematics, St. Petersburg, Russia; Vladimir A. Borovikov, Dept of Physical and Mathematical Sciences, Autonomous University of Puebla, Puebla, Mexico; Larissa Ju. Fradkin and Dmitri Gridin, School of Electrical, Electronic and Information Engineering, South Bank University, London, United Kingdom; Boris A. Samokish, Department of Mathematics and Mechanics, St. Petersburg State University, St. Petersburg, Russia; Valery P. Smyshlyaev, Dept of Mathematical Sciences, University of Bath, Bath, United Kingdom

---The Geometrical Theory of Diffraction (GTD) is a powerful means of modeling the ultrasonic inspection of smooth cracks in ferritic steel. Theoretically computed ``diffraction coefficients'' are used to quantify the amplitudes of the echoes diffracted from the tips or edges of the embedded misoriented cracks. For direct pulse-echo inspection of such cracks, a modeling code which uses GTD, has been extensively validated against experiment and is widely used in industry as a tool for establishing inspection capability. However, many cracks of practical interest are surface-breaking. In order to model this case with GTD, the diffraction coefficients for the two corners between the crack and the surface need to be calculated. In their recent papers Budaev and Bogy have developed a semi-analytical semi-numerical technique which may be used to solve the relevant problem of diffraction by an elastic wedge. We have performed work aimed at providing a better theoretical justification of Budaev and Bogy's approach and have come up with a somewhat different method for solving the resulting singular integral equation. It appears to be successful when dealing with wedge angles less than 180 degrees.---The authors would like to thank the Industry Management Committee of the United Kingdom nuclear licensees and EPSRC for funding this work.

Scattering of High Frequency Ultrasound from the Interface Between Two Rough Surfaces

---A. M. Quinn[1], B. W. Drinkwater[1], and R. S. Dwyer-Joyce[2], [1]University of Bristol, Department of Mechanical Engineering, Queen's Building, University Walk, Clifton, Bristol, BS6 5PW, United Kingdom; [2]University of Sheffield, Department of Mechanical Engineering, Mappin Street, Sheffield, S1 3JD, United Kingdom

---The use of ultrasound as a tool to characterize the contact between components in machine elements has been developed. Machine elements are rough on a microscopic scale, and so contact will occur initially at the roughness peaks of these surfaces. Ultrasonic reflection coefficients from the interface between contacts yield information as to their size and pressure distribution. There is a drive to use higher frequencies and to generate small focal spots at the interface in order to enhance the spatial resolution. As the frequency of ultrasound increases, the ultrasonic wavelength becomes comparable to the size of scatterers (gaps) at the interface. When this happens the well-known quasi-static spring model becomes invalid. A new model is described, which accounts for this high frequency scattering and allows measurement of contact phenomena from solid-solid interfaces beyond the low-frequency regime. A numerical elastic-plastic contact model is used to predict the geometry at the solid-solid interface. Finite Element Analysis is then used to predict the interaction of high frequency ultrasound with the resultant scatterers. This model has been validated against simple analytical scattering models and experiment. Comparisons are also made with the quasi-static spring model and the limits of applicability of this model discussed.

Improvement of the Mass-Spring Lattice Model for Quantitatively Accurate Simulation of Ultrasonic Testing

---Hyunjune Yim and Choon-Jae Lee, Department of Mechanical Engineering, Hong-ik University, 72-1 Sangsoo Dong, Mapo Ku, Seoul, 121-791 Korea

---The mass-spring lattice model has exhibited its excellent qualitative capability to predict various ultrasonic wave behaviors such as propagation, reflection, refraction, and diffraction in both isotropic and transversely isotropic elastic media. If the model is to be used for actual ultrasonic testing practices, however, the capability for quantitatively (as well as qualitatively) accurate predictions is prerequisite. This paper analyzes the quantitative accuracy of the mass-spring lattice model, and suggests modifications and further developments of the model for improved quantitative accuracy. The focus of the study lies in the reflection of ultrasonic waves at free surfaces and in the diffraction at crack tips, as these two problems are essential in simulating ultrasonic tests of embedded cracks having two stress-free faces. Besides, generation of wavefield from a simulated transducer and refraction through material interfaces are also dealt with. As the reference solutions for the accuracy evaluation of the numerical model, analytical solutions for the canonical problems corresponding to those listed above are used. Steps taken for the model improvement include the use of finer meshes, new modeling methods for free surfaces and material interfaces, and use of hybrid models. This work is expected to contribute significantly to the quantitative ultrasonic nondestructive evaluation.

Modeling Transient Radiation of Ultrasonic Transducers in Anisotropic Materials Including Wave Attenuation

---Martin Spies, Fraunhofer-Institute for Nondestructive Testing, IZFP, University Bldg. 37, 66123, Saarbrucken, Germany

---The use of anisotropic materials such as fiber-reinforced composites and columnar-grained stainless steels as primary structural components has resulted in a critical need for reliable and effective NDE techniques. In interpreting the wave amplitudes recorded in ultrasonic NDE experiments, the complicated nature of wave propagation in these media as well as wave attenuation have to be considered. Modeling will reveal the quantitative features of these phenomena and thus help in the optimization of conventional and in the development of new NDE techniques. In this contribution, a point source superposition technique is applied to model transducer-radiated transient wavefields assuming anisotropic material and attenuation symmetry. The presented formulation involves characteristic quantities obtained from plane wave theory and the respective point source directivities. For composite materials, the viscoelasticity is taken into consideration thru a complex, frequency-dependent stiffness tensor. For obtaining the pulsed solutions, the harmonic radiation is calculated at many frequencies and then this data is numerically Fourier transformed into the time domain. Two problems are addressed in detail: (i) the generation and propagation of quasi-shear vertical waves using commercial angle beam probes is considered for transversely isotropic weld metal specimens. The calculated wavefronts are employed to determine the transducer directivity patterns as a function of the grain alignment. (ii) For a unidirectional composite exhibiting orthotropic material symmetry, the effect of viscoelasticity on the propagating quasi-longitudinal waves is examined for various insonification directions.

Validation of Time Domain Theories for the Reflection of Ultrasonic Waves from Periodically Rough Surfaces

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

---In an ultrasonic pulse/echo immersion test, a periodically rough entry surface can cause a decaying tail signal following the direct reflected front wall echo. In ultrasonic NDE, these tail signals act as backscattered noise. They can obscure flaw signals and place a fundamental limitation on the ability to detect flaws. In addition, noise backscattered from microstructure can be used to characterize a material. Surface roughness can also lead to ultrasonic noise that can interfere with this ability. To quantitatively understand the effects of periodic surface roughness on ultrasonic backscattered noise, a theory that can predict roughness induced noise in the time domain for a real ultrasonic pulse/echo immersion test has been developed and reported in a previous QNDE meeting. In the present paper, we discuss the validation of that theory. A series of comparisons between measured noise and predicted noise for a few samples are presented. Good agreement between the theory and the experiment is observed in most cases. The effects of material properties on noise amplitudes are also investigated. Finally, we discuss the effects of oblique incidence on the generation of backscattered noise.---This work was supported by the NSF Industry/University Cooperative Research program.

Using DGS Diagrams to Validate Sound Field Simulations

---Andreas Schumm, Electricité de France, R&D MTI/MMN, F-92141 Clamart, France

---In ultrasonic modeling, one is always faced with the question of how to validate a simulation's result. The transient sound field amplitude at a given location, as obtained from common approximate models, is usually not accessible experimentally. Through-transmission experiments, on the other hand, are less convincing, as they provide only partial information. In this situation, DGS (distance-gain-size) diagrams turn out to be an excellent alternative to experimental validation. DGS diagrams relate distance and size of a planar disc shaped to the received echo amplitude. The 0dB reference echo is obtained from an infinite reflector using the back-wall. As opposed to DAC diagrams (distance amplitude curves), DGS diagrams take the reflector size into account, thus allowing to determine the size of an equivalent perpendicularly oriented disc shaped reflector. DGS diagrams have a number of interesting properties when used to validate a sound field simulation. They cover the entire sound beam, do rely on a straightforward sound/reflector interaction, and are close to a real inspection situation. As another advantage, DGS diagrams are easily available from probe manufacturers. We discuss approaches to calculate DGS diagrams in a post-processing step from transient sound field data obtained by an approximate model. Stephanishen's piston model can be used to estimate the reflector's impulse response approximately. Convolution with the transducer's impulse response then gives the system's total response. Since this approach supposes uniform excitation of the reflector, it becomes inaccurate for large reflector sizes. A more elaborate approach consists in a generalization of Stephanishen's piston model for arbitrary excitation. Both models neglect the effect of the preliminary sound path in the transducer to the reception process, and more elaborate techniques are required for immersed transducers.

Shape Reconstruction of Defects in Inhomogeneous Material

---Kazuyuki Nakahata and Michihiro Kitahara, Tohoku University, Department of Civil Engineering, Graduate School of Engineering, Aoba-yama 06, Sendai 980-8579, Japan

---A shape reconstruction method of the macroscopic defect in microscopically inhomogeneous material such as the composites containing inclusion is proposed by considering the order of scales between the macroscopic defect and inclusion. Here, the dilute distribution of inclusion is assumed and the linearized inverse scattering methods based on Born and Kirchhoff inversions are applied to reconstruct the defect shape from the backscattered waveforms. In this inversion process, it is necessary to introduce the frequency dependence of phase velocity to the inversion algorithm. The frequency characteristics of the phase velocity in inhomogeneous material are investigated first, and then the linearized inverse scattering methods are formulated. A specimen which has the macro-cavity in composite material is prepared and the ultrasonic measurement is performed by pulse-echo method. The result shows the capability of the method to reconstruct the macroscopic defect in inhomogeneous material.

SESSION 17
NDE FOR CONCRETE STRUCTURES
L. Jacobs, Chairperson
Druckenmiller 016

8:30 AM **Determination of Pavement Thickness Using a Time Domain Approach**
---A. Gibson and J. Popovics, Drexel University, Department of Civil and Architectural Engineering, 3141 Chestnut Street, Philadelphia, PA 19104

8:50 AM **Lamb Wave Technique to Characterize Repaired Concrete**
---K. Luangvilai, W. Punurai, and L. J. Jacobs, Georgia Institute of Technology, Civil and Environmental Engineering, Atlanta, GA 30332-0355

9:10 AM **Multiple Layer Visualization of Inductively Scanned Image of Reinforcing Bar Mesh Using a Polynomial-Based Separation Algorithm**
---S. Quek, B. Fernandes, P. Gaydecki, and G. Miller, UMIST, Department of Instrumentation and Analytical Science, Sackville Street, P. O. Box 88, Manchester M60 1QD United Kingdom

9:30 AM **Damage and Corrosion Visualization of Reinforcing Bars Embedded in Concrete Using a New Solid-State Inductive Scanning Sensor**
---B. Fernandes, G. Miller, P. Gaydecki, and S. Quek, UMIST, Department of Instrumentation and Analytical Science, Sackville Street, P. O. Box 88, Manchester M60 1QD United Kingdom

9:50 AM **Statistical Analysis of Ultrasonic Measurements in Concrete**
---C.-H. Chiang and P.-C. Chen, Chaoyang University of Technology, Department of Construction Engineering, Gifeng E. Road, No. 168, Wufeng, Taichung 413, Taiwan, China

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

10:30 AM **Ultrasonic Imaging of Defects in Concrete Pipelines**
---M. Ciocco, J. Neyhart, and S. Mandayam, Rowan University, Electrical and Computer Engineering, Glassboro, NJ 08028; D. B. Cleary and K. Jahan, Rowan University, Civil and Environmental Engineering, Glassboro, NJ 08028

10:50 AM **Noncontact Detection of Surface Waves in Concrete Using an Air-Coupled Sensor**
---J. Zhu and J. Popovics, Drexel University, Department of Civil and Architectural Engineering, 3141 Chestnut Street, Philadelphia, PA 19104

11:10 AM **Investigation of Microwave Reflection Properties of Mortar Exposed to Wet-Dry Cycles of Tap Water and Chloride Bath**
---T. Case, S. Peer, K. Donnell, D. Hughes, R. Zoughi, and K. E. Kurtis[1], University of Missouri-Rolla, Applied Microwave Nondestructive Testing Laboratory (*amntl*), Electrical and Computer Engineering Department, Rolla, MO 65409; [1]School of Civil and Environmental Engineering, Georgia Institute of Technology, Atlanta, GA 30332-0355

11:30 AM **Two-Dimensional Measurements of Concrete Specimens Using Inverse Synthetic Aperture Radar**
---H. C. Rhim, Yonsei University, Nondestructive Evaluation and Structures Laboratory, Department of Architectural Engineering, Seoul 120-749, Korea

11:50 AM **Imaging of Concrete Specimens Using Ground Penetrating Radar**
---H. C. Rhim, Yonsei University, Nondestructive Evaluation and Structures Laboratory, Department of Architectural Engineering, Seoul 120-749, Korea

12:10 PM ***Lunch***

Determination of Pavement Thickness Using a Time Domain Approach

---Alexander Gibson and John S. Popovics, Drexel University, Department of Civil and Architectural Engineering, 3141 Chestnut Street, Philadelphia, PA 19104

---A non-destructive method is proposed to accurately determine the thickness of a concrete pavement layer, based on reflected P-waves generated by an impact event on the surface. In contrast to the conventional Impact Echo method, the analysis is carried out in the time domain. The Impact Echo method is a commonly-used approach, but with certain limitations associated with frequency resolution and geometrical correction factors. More significantly prior knowledge of P-wave velocity (Vp) is required, which when measured at the surface may not accurately reflect properties throughout the pavement depth. In the test method proposed here, due to the geometrical configuration, prior knowledge of Vp and correction factors are not required. Using a Finite Element Model to simulate wave propagation in the pavement, potential testing configurations to measure the dynamic surface response are investigated. In this paper, the proposed approach is described and a simple test procedure is recommended based on the numerical results. The accuracy of the proposed approach is established, and recommendations for practical implementation are given.

Lamb Wave Technique to Characterize Repaired Concrete

---Kritsakorn Luangvilai, Wonsiri Punurai, and Laurence J. Jacobs, Civil and Environmental Engineering, Georgia Institute of Technology, Atlanta, GA 30332-0355

---A popular repair method for reinforced concrete involves externally bonding fiber reinforced plastic (FRP) patches on to the tension face of a beam, thus increasing the beam's flexural stiffness and loading capacity. The usage of FRP patches in these applications has created the requirement for reliable nondestructive evaluation (NDE) techniques capable of characterizing these bonded patches; this research proposes using guided Lamb waves for this purpose. The primary advantage of using guided Lamb waves in this application is that they are capable of interrogating large, inaccessible components in a time-efficient manner. This research combines laser ultrasonic techniques with digital signal processing techniques (time-frequency representations (TFR) and the two-dimensional Fourier transform (2D-FFT)) to characterize the material properties of this adhesive layer. The experimental procedure consists of measuring transient Lamb waves in FRP repaired concrete components. The frequency spectrum (dispersion curves) for each specimen are obtained by operating on these transient waveforms with either a TFR or the 2D-FFT. This study quantifies the effect of an adhesive bond's properties on these measured dispersion curves. Finally, these experimental results are interpreted in terms of an analytical, 2-layer guided wave model.

Multiple Layer Visualization of Inductively Scanned Image of Reinforcing Bar Mesh Using a Polynomial-Based Separation Algorithm

---Sung Quek, Bosco Fernandes, Patrick Gaydecki, and G. Miller, Department of Instrumentation and Analytical Science, UMIST, Sackville Street, P. O. Box 88, Manchester M60 1QD

---Inductive systems for imaging steel reinforcing bar mesh within concrete have been developed and reported by the authors in several publications. This system depicts the horizontal and vertical layers of the mesh as a composite grey scale image. Consequently, deeper bars appear as much fainter structures than those closer to the surface because the signals they generate are weaker and the image is linearly normalized with respect to the much stronger signals returned from the upper bars. Here, we describe a new suite of image processing algorithms that enables the original image to be visualized as multiple images representing the various bar layers. This is termed Polynomial-Based Layer Separation (PBLS). This technique also makes it possible to perform brightness-compensation of the lower bars and extract spatial and dimensional information regarding the diameters, orientations and depths of the bars. This information is critical for civil structures inspection teams. The technique is adaptive since it performs prior examination of the data. Knowing the spatial location of the bar peak widths in one layer, curve fitting is applied to calculate the baselines of the bars in other layers of the image. For a two-layer image, the peaks in the lower layer are removed leaving an image of the top bars, and vice versa for the bottom bars. Bars in the separated images are further resolved into individual images using Lorentzian and Gaussian peak fitting algorithms. Images of steel bar mesh processed using this PBLS system offer significant enhancements of the qualitative and quantitative properties of the original image data.

Damage and Corrosion Visualization of Reinforcing Bars Embedded in Concrete Using a New Solid-State Inductive Scanning Sensor

---Bosco Fernandes, G. Miller, Patrick Gaydecki, and Sung Quek, Department of Instrumentation and Analytical Science, UMIST, P. O. Box 88, Sackville Street, Manchester M60 1QD, United Kingdom

---This paper describes the modelling, design and use of novel high-density, multiple plane inductive coils etched on a printed circuit board (PCB) surface, for the imaging and assessment of steel reinforcing bars embedded in concrete. The work is a continuation of successful preliminary systems based on inductive scan principles developed by the authors. PCB coils are used because they can be quickly fabricated to high tolerances and are easy replicable, facilitating their incorporation into array designs. Also, being flat, they occupy less space, enabling portable, lightweight and ergonomic instrumentation to be realized. The results show that this sensor can both image the bars and detect extremely small losses of section due to corrosion. This is possible by exploiting, through a highly sensitive electronic system, both the phase and amplitude information present in the returned signal. The initial PCB sensors are limited to a short penetration depth, up to 15 mm below the concrete surface. However, improved versions are being investigated to extend the sensing distance. At present, three designs are being evaluated. The first uses a large rectangular excitation coil with a PCB coil in the center as the receiver. The second consists of two concentric coils, the outer one being the excitation. The third is a balanced coil, with the receiver coil wound in anti-phase on both sides of the excitation coil. All three designs can distinguish between corroded and good sections, but the latter has the greatest depth penetration.

Statistical Analysis of Ultrasonic Measurements in Concrete

---Chih-Hung Chiang and Po-Chih Chen, Department of Construction Engineering, Chaoyang University of Technology, Gifeng E. Rd. No. 168, Wufeng, Taichung 413, Taiwan, China

---The quality control is usually measured by the strength test, according to the report of American Concrete Institute 214.3R-88. Statistical analysis is successfully applied to large concrete project to ensure the load capacity, resistance of deterioration, and dimensional stability of concrete. During the first half year after the Chi-Chi earthquake in Taiwan, the condition assessment of existing concrete building raised a lot of public attention. Nondestructive testing based on stress techniques such as ultrasonic pulse velocity through concrete is often used for in situ measurements and provides quick results for further condition assessment. The purpose of current study is to examine the correlation between pulse velocity and strength estimation. Examples will be given to illustrate the variability of measurement results for both precast specimens in laboratory and concrete components in existing buildings.

Ultrasonic Imaging of Defects in Concrete Pipelines

---Michael Ciocco, Jeremy Neyhart, and Shreekanth Mandayam, Electrical & Computer Engineering, Rowan University, Glassboro, NJ 08028; Douglas B. Cleary and Kauser Jahan, Civil & Environmental Engineering, Rowan University, Glassboro, NJ 08028

---This paper describes the first stage of a research project to develop an automated vehicle for inspecting the structural integrity of concrete sewer pipelines. We have developed an innovative interrogation and signal processing algorithm for detecting and sizing defects in concrete media, irrespective of the composition of the concrete - a crucial factor for realizing an in-line inspection process for concrete pipes. We have simulated concrete pipeline inspection by fabricating concrete specimens of diverse compositions embedded with rectangular defects of varying depths immersed in synthetic wastewater of varying density. We present ultrasonic C-scans and their corresponding defect characterization profiles.---This work is supported by the Water Environment Research Foundation, Alexandria, VA.

Noncontact Detection of Surface Waves in Concrete Using an Air-Coupled Sensor

---Jinying Zhu and John Popovics, Drexel University, Department of Civil and Architectural Engineering, 3141 Chestnut Street, Philadelphia, PA 19104

---This research determines the utility of air-coupled sensors to be used in non-contact NDT for concrete structures. An air-coupled sensor detects propagating leaky surface waves generated by an impact event applied at a point on the surface. No special preparation to the concrete surface is needed to carry out the tests. Compared to conventional body waves, the leaky surface waves can be easily detected by the sensor due to the large out-of-plane motion of the waves. A highly directional detector (microphone) is used to detect leaky surface waves propagating in concrete with minimal disruption from the direct acoustic wave and ambient noise. The collected signals show high signal-to-noise ratio. Test results from a thin (80mm) concrete slab and a very thick concrete wall (915mm) are presented. In both cases, signals from 3 different distances between sensor and test surface and a series of impact-receiver spacing are presented. The arrival times of the sensed leaky waves indicate the nature of the wave: Rayleigh surface waves are generated in the thick wall and plate waves in the thin slab. The study shows the potential of this sensing method for rapid inspection of concrete structures.

Investigation of Microwave Reflection Properties of Mortar Exposed to Wet-Dry Cycles of Tap Water and Chloride Bath

---T. Case, S. Peer, K. Donnell, D. Hughes, R. Zoughi, and K. E. Kurtis[1], Applied Microwave Nondestructive Testing Laboratory (*amntl*), Electrical and Computer Engineering Department, University of Missouri-Rolla, Rolla, MO 65409; [1]School of Civil and Environmental Engineering, Georgia Institute of Technology, Atlanta, GA 30332-0355

---Corrosion of steel in reinforced concrete structures can be induced by the presence of chloride ions near the steel/concrete interface. To determine the influence of chloride ingress in mortar two 8" x 8" x 8" mortar specimens with *w/c* of 0.6 and *s/c* of 1.5 were prepared using portland cement type I/II. After curing for more than a month, one was soaked in a bath of tap water while the other was soaked in water with 1% salinity for twenty hours. Subsequently, they were removed and left in room temperature while their microwave reflection properties were measured daily at S- (3 GHz) and X-bands (10 GHz) until no appreciable change in the measurements was detected. To accelerate the diffusion of chloride ions in these specimens three such cycles were repeated encompassing 180 days. The primary goal of this investigation was to determine the major differences between the microwave behavior of these two specimens. In particular we were looking to evaluate the influence of cyclical chloride ingress in one specimen when compared with a an identical specimen without any external chloride influence. An electromagnetic multi-layer code as well as a dielectric mixing model is used to evaluate the properties of these specimens as a function of time within the cycles. A complete discussion of the results will be presented in this paper.--- Portion of the work conducted while at Colorado State University.

Two-Dimensional Measurements of Concrete Specimens Using Inverse Synthetic Aperture Radar

---Hong C. Rhim, Nondestructive Evaluation and Structures Laboratory, Department of Architectural Engineering, Yonsei University, Seoul 120-749, Korea

---Radar Measurement results of laboratory size concrete specimens are presented in this paper. The purpose of this research work is to study various aspects of the radar method in an effort to develop an improved radar system for nondestructive testing of concrete structures. The radar system used for the study is an Inverse Synthetic Aperture Radar (ISAR), which is capable of transmitting microwaves at three different frequency ranges of 2-3.4, 3.4-5.8, and 8-12 GHz. Radar measurement setup is such that the radar is located 14.4 m away from a concrete target to satisfy a far-field criterion. The concrete target is rotated for 20 degrees during the measurements for the generation of two-dimensional (cross-range) imagery. Concrete targets used for the measurements have the dimensions of 305 mm (width) x 305 mm (height) x 92 mm (thickness) with different inside configurations. Comparisons are made for dry and wet specimens, specimens with and without inclusions. Each specimen is made to model various situations that a concrete structure can have in reality. Results show that center frequency, frequency bandwidth, and polarization of the incident wave have different effects on identifying the thickness or inclusions inside concrete specimens. Results also suggest that a certain combination of measurement parameters is suitable for a specific application area. Thus, measurement parameters can be optimized for a specific problem. The findings are presented and discussed in details in the paper. Signal processing schemes implemented for imaging of the specimens are also discussed.

Imaging of Concrete Specimens Using Ground Penetrating Radar

--- Hong C. Rhim, Nondestructive Evaluation and Structures Laboratory, Department of Architectural Engineering, Yonsei University, Seoul 120-749, Korea

---Ground Penetrating Radar (GPR) has been used to image inside concrete specimens embedded with steel bars and delamination. Three different antennas are used at 900 MHz, 1 GHz, and 1.5 GHz. An imaging algorithm has been developed to improve measurement output generated from a commercial radar system. Parameters for the measurements are antenna frequency, cover depth of inclusions, size of inclusions, and number of inclusions. For the experiments, laboratory size concrete specimens are made with the dimensions of 1,000 mm (W) x 1,000 mm (L) x 250 mm (D). The concrete was cast with water/cement/sand/coarse aggregate mix ratio of 1 : 2.22 : 5.65 : 7.12 by weight. The radar measurements are made under air-dry condition of the concrete specimens at the age of 4 weeks. Inclusions of steel bars and delamination are located at depths of 50, 100, 150, and 200 mm from the top surface of concrete. The size of the steel bars is varied from 10 mm to 20 mm. Both single bar and double bars are placed in the specimens. The thickness of air-filled delamination is varied from 10 mm to 20 mm. The inclusions have the same length as the specimens. An imaging scheme utilizes the database of electromagnetic properties of concrete and impedance mismatch between concrete and the steel bar. The results have shown improved output of the radar measurements compared to commercially available processing methods. As results, the developed results can be used for the detection of reinforcing steel bars and voids inside concrete, pavements, and underground.

Wednesday, August 1, 2001

SESSION 18
STRESS MEASUREMENTS
W. Veronesi and A. Lavrentyev, Co-Chairpersons
Sills 117

8:30 AM **Ultrasonic Evaluation of the Effects of Treatment and High Cycle Fatigue in Aircraft Engine Turbine Blades**
---D. E. Bray, Don E. Bray, Inc., P. O. Box 10315, College Station, TX 77842-0315; U. Suh, General Electric Aircraft Engines, Cincinnati, OH 45215; C. L. Hough, Engineering and Testing, College Station, TX 77841

8:50 AM **Nondestructive Inspection of Surface Layer of Residual Stress in Titanium Alloy**
---L. Koo, GE Aircraft Engines, QTC/Mail Drop Q8, Cincinnati, OH 45215; C.-S. Man, University of Kentucky, Department of Mathematics, Lexington, KY 40506-0027; M. J. Shepard, Air Force Research Laboratory, Materials and Mfg. Directorate, Wright-Patterson AFB, OH 45433-7817

9:10 AM **Characterization of Shot-Peened Surfaces with Rayleigh Waves**
---E. A. Lindgren and J. R. Mandeville, SAIC-Ultra Image International, New London, CT; J. C. Poret and L. P. Martin, Industrial Quality, Inc., Gaithersburg, MD; J. Kochnover, Johns Hopkins University, Department of Materials Science and Engineering, Baltimore, MD; I. M. Perez, Naval Air Warfare Center, Aircraft Division, Patuxent Naval Air Station, MD

9:30 AM **Ultrasonic Characterization of Near-Surface Material Properties in Shot-Peened Waspaloy**
---A. I. Lavrentyev and W. A. Veronesi, United Technologies Research Center, M/S 129-73, East Hartford, CT 06108

9:50 AM **Residual Stress Measurement Needs for Component Life Extension: An Air Force NDE Perspective**
---M. Blodgett, B. Sanbongi, R. John, and J. Larsen, Air Force Research Laboratory, Metals, Ceramics, and NDE Division, Wright-Patterson Air Force Base, Dayton, OH 45433

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

10:30 AM **Thermoelectric Nondestructive Evaluation of Residual Stress in Shot-Peened Metals**
---H. Carreon and P. B. Nagy, University of Cincinnati, Department of Aerospace Engineering, ML 0070, Cincinnati, OH 45221-0070; M. Blodgett, Air Force Research Laboratory, Metals, Ceramics, and NDE Division, Wright-Patterson Air Force Base, Dayton, OH 45433

10:50 AM **Electric Potential Noise – A New Way to Characterize Residual Stress**
---N. Meyendorf, Univ. of Dayton, Center for Materials Diagnostics, 300 College Park, Dayton, OH 45469-0121; H. Roesner and P. Banjan, Fraunhofer Institute for Nondestructive Testing, Saarbrucken, Germany

11:10 AM **Evaluation of Stresses in Components Using Ultrasonic and Electromagnetic Techniques**
---E. Schneider and W. A. Theiner, Fraunhofer Institut Zerstörungsfreie Prüfverfahren, Germany

11:30 AM **Measurement of Residual Stress in Bent Pipelines**
---G. A. Alers and J. D. McColskey, National Institute of Standards and Technology, 325 Broadway, Boulder, CO 80305-3337

11:50 AM **The Influence of Microstructure on the Acoustoelastic Measurement of Stress in Aluminum Alloys**
---S. Wormley and R. B. Thompson, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011; R. Alers, Sonic Sensors of EMAT Ultrasonics, Inc., San Luis Obispo, CA; G. Alers, National Institute of Standards and Technology, Boulder, CO; M. F. A. Warchol, Alcoa Mill Products, Bettendorf, IA 52722

12:10 PM ***Lunch***

Ultrasonic Evaluation of the Effects of Treatment and High Cycle Fatigue in Aircraft Engine Turbine Blades

---Don E. Bray, Don E. Bray, Inc., P. O. Box 10315, College Station, TX 77842-0315; Ui Suh, General Electric Aircraft Engines, Cincinnati, OH 45215; Clarence L. Hough, Engineering & Testing, College Station, TX 77841

---Experiments were conducted with the L_{CR} ultrasonic wave on two sets of titanium (Ti-64) turbine blades. The ultrasonic frequency was 20 MHz. Group 1 contained 7 blades subjected to various levels of treatment as well as high cycle fatigue (HCF), and notching to initiate cracks. For these data, the analysis of the results shows significant differences in the treated and untreated areas, the top and bottom of the blades, high cycle fatigue and cracked and uncracked conditions. While these associations are strong, it was not possible from these data to associate the ultrasonic travel-times with the individual factors. Group 2 contained four blades subjected only to various levels of treatment. These blades were sampled with the L_{CR} wave before and after treatment, and this test set showed a significant trend of travel-time change with treatment. The difference between untreated and treated travel-times at probes located at the blade leading edge increased with treatment, in an almost linear pattern. The untreated blade properties and experimental error also affected the conclusions, however. The variations in untreated travel-times for the blades may be an intrinsic property of the individual blade.

Nondestructive Inspection of Surface Layer of Residual Stress in Titanium Alloy

---Lat Koo, GE Aircraft Engines, QTC/Mail Drop Q8, Cincinnati, OH 45215; Chi-Sing Man, Department of Mathematics, University of Kentucky, Lexington, KY 40506-0027; Michael J. Shepard, Materials and Manufacturing Directorate, Air Force Research Laboratory, Wright-Patterson AFB, OH 45433-7817

---To help improve the high-cycle fatigue performance of engineering components, surface enhancement processes such as shot peening are customarily used to create a thin layer of compressive residual stress at the surface of metallic parts. At present, the depth profile of residual stress induced by such surface enhancement processes can be determined only by destructive (or at least semi-destructive) methods such as X-ray diffraction, incremental hole-drilling, etc. No nondestructive inspection technique is as yet available. The present paper is a preliminary report of our efforts to develop an ultrasonic technique for such nondestructive inspections on components manufactured from titanium alloys. To reduce complications arising from surface roughness and texturing induced by shot peening, we begin by restricting our experimental study to samples with their layer of residual stress resulted from laser shock peening or low plasticity burnishing. By the same token, we elect to work with Ti-6Al-4V samples which, in their virgin state, have relatively weak crystallographic texture.

Characterization of Shot-Peened Surfaces with Rayleigh Waves

---Eric A. Lindgren and John R. Mandeville, SAIC-Ultra Image International, New London, CT; Jay C. Poret and L. Peter Martin, Industrial Quality, Inc., Gaithersburg, MD; Justin Kochnover, Department of Materials Science and Engineering, Johns Hopkins University, Baltimore, MD; Ignacio M. Perez, Aircraft Division, Naval Air Warfare Center, Patuxent Naval Air Station, MD

---Ultrasonic Rayleigh are being investigated as a method to characterize residual stresses that are generated at or near the surface of metals, such as those generated by shot-peening. To verify the performance of this method, several aluminum alloy samples with well-defined shot-peening treatments were evaluated. The results of these measurements demonstrate that there is a velocity change for the samples that were surface treated. The magnitude of the velocity change is greater than the value measured during the application of bend and tensile tests up to the yield stress for the aluminum alloy. In addition, a significant portion of the observed velocity changes was present after the sample was annealed. Microstructural analysis determined that the there were no readily visible changes in the microstructure due to the surface treatment or the annealing process. Characterization of roll-burnished samples indicated that the velocity change is present for multiple types of surface conditions. The possible sources for the observed behavior of the Rayleigh wave velocity will be discussed in detail, including the potential effect of constrained surfaces on the propagation of the surface wave.
The authors acknowledge funding provided by the Navy through an SBIR Phase II contract.

Ultrasonic Characterization of Near-Surface Material Properties in Shot-Peened Waspaloy

---Anton I. Lavrentyev and William A. Veronesi, United Technologies Research Center, M/S 129-73, East Hartford, CT 06108

---When a stream of shot impinges a metal surface, a near-surface layer undergoes an intensive cold working resulting in material property changes. One of the effects induced by shot peening, a near-surface compressive stress, helps to slow down initiation and propagation of surface breaking cracks resulting in an extended fatigue life of a component. The capability to non-destructively evaluate near-surface residual stress would greatly aid the assurance of proper fatigue life in these components. This paper presents results from an ultrasonic characterization study of shot peened Waspaloy surfaces. Rayleigh wave velocity measurements by a V(z)-curve method were made on smooth and shot peened samples using line-focus ultrasonic transducers. Several factors are believed to influence measured surface wave velocity including surface roughness, near-surface grain reorientation (texture), and residual stress. In this study we estimate quantitatively the effect of these factors and discuss how these effects can be separated and accounted for in residual stress measurements.

Residual Stress Measurement Needs for Component Life Extension: An Air Force NDE Perspective

---Mark Blodgett, Bryan Sanbongi, Reji John, and James Larsen, Air Force Research Laboratory, Metals, Ceramics, and NDE Division, Wright-Patterson Air Force Base, Dayton, OH 45433

---Surface-conditioning imparted residual stress is a subject of major importance and concern to the US Air Force. One objective of the Engine Rotor Life Extension (ERLE) initiative, led by the Air Force Research Laboratory's Materials and Manufacturing Directorate, is to develop the capability to take credit for beneficial residual stress in component-lifing calculations. Accurate life prediction of components requires complete characterization of the retained residual stress profile during service. Development of nondestructive methods to make this type of measurement is critical. The challenge for the NDE community is to develop methods from which independent parameters may be derived to reliably and accurately predict (or infer) the stress profile. It is especially important to measure this stress after exposure to conditions representing the engine environment (e.g. cyclic thermal and mechanical loads), which may force stress relaxation to occur. The bulk of the stress relaxation effect is thought to be a loss phenomenon proportional to the original stress profile, and recent studies have shown that the effect occurs across the entire stress profile, i.e. across the entire depth, consisting of compressive and tensile regions. However, the near-surface relaxation is typically disproportionately strong, due to high degrees of cold working in that region. This relaxation complication makes stress profiling extremely challenging for NDE. The focus of the ERLE residual stress effort is on shot peened materials exhibiting such cold working, but laser shock peening and low plasticity burnishing are also being considered. This paper reviews the near- and far-term goals of the nondestructive residual stress effort underway at the Air Force Research Laboratory. Additionally, the role of surface roughness, resulting from shot peening, and its effect on performance is presented for ultrasonic surface-wave velocity, eddy current electrical conductivity, and X-ray diffraction methods. In-depth 3D surface roughness data are presented to describe the statistical variance of four different shot peening intensities (Almen 4A, 8A, 12A, and 16A) in Ti-6Al-4V, Waspaloy, and IN100. Precision velocity measurements from an ultrasonic laser receiver system and electrical conductivity data from a Nortec 19e-II eddy current instrument are presented to illustrate some of the difficulties associated with conventional approaches.

Thermoelectric Nondestructive Evaluation of Residual Stress in Shot-Peened Metals

---Hector Carreon and Peter B. Nagy, Department of Aerospace Engineering, University of Cincinnati, ML 0070, Cincinnati, OH 45221-0070; Mark Blodgett, Metals, Ceramics, and NDE Division, AFRL, Wright-Patterson AFB, Dayton, OH 45433-7817

---Nondestructive evaluation (NDE) of the existing residual stress in the shallow subsurface layer of shot-peened components could be very beneficial during manufacturing to monitor and minimize process variations. Even more importantly, NDE is absolutely necessary after extended service if residual stresses were to be taken credit for in fatigue life predictions of critical components because of the very significant and highly variable stress release that might occur at elevated operating temperatures. Thermoelectric techniques are very unique among all other NDE methods in that they are solely sensitive to intrinsic material variations regardless of the size, shape, and surface topography of the specimen to be tested. It is also well known that the thermoelectric power of most metals is fairly sensitive to elastic strains. We have initiated the development of a noncontacting thermoelectric method based on magnetic detection of local thermoelectric currents in the compressed near-surface layer of metals when a temperature gradient is established throughout the specimen. Beside the primary residual stress effect, the thermoelectric method is also sensitive to the secondary "material" effects of shot peening (local texture, increased dislocation density, hardening), but it is entirely insensitive to its "geometrical" by-product, i.e., the rough surface topography. Our preliminary experimental results in copper indicate that the proposed method is one order of magnitude more sensitive to residual stress effects than to the secondary material effects. This method measures only the weighted average of the near-surface residual stress, which is sufficient for quantitatively evaluating the degree of thermally-induced stress release, but, in its present form, it is not suitable for detailed mapping of the residual stress profile.

Electric Potential Noise – A New Way to Characterize Residual Stress

---Norbert Meyendorf, Center for Materials Diagnostics, University of Dayton, 300 College Park, Dayton, OH 45469-0121; Henrik Roesner and Pamela Banjan, Fraunhofer Institute for Nondestructive Testing IZFP, Saarbrucken, Germany

---Magnetic properties of magnetostrictive materials are sensitive to residual stresses. A widely used magnetic technique for stress characterization is magnetic Barkhausen noise. An oscillating magnetic field generates noise detected by an inductive coil. State of the art Barkhausen noise equipment generates the magnetic field between the poles of a U-shaped electromagnet. But also an electrical current through the test piece can be used for magnetization. This technique is especially efficient for rod-shaped objects and wires. Instead of detecting Barkhausen noise with an inductive coil, it is also possible to analyze the electric potential between two electrodes attached to the test object. By using electronic filters, a signal can be extracted that is similar to Barkhausen noise and has the same origin. This potential noise signal can also be detected anywhere in the electric circuit, so that it can be used to characterize materials and especially wires with no excess for electric magnets and inductive coils. The paper will discuss several experiments that compare the generated potential noise to conventional Barkhausen noise technique and will show potential applications for stress measurements.

Evaluation of Stresses in Components Using Ultrasonic and Electromagnetic Techniques

---E. Schneider and W. A. Theiner, Fraunhofer Institut Zerstörungsfreie Prüfverfahren, IZFP, Germany

---Complementary to the established techniques to evaluate stress states, electromagnetic and ultrasonic techniques permit the evaluation of stresses in surface layers and in the bulk of components, respectively. One advantage of these techniques is the possibility of a fast evaluation of stress states, enabling a continuous analysis along traces to get information about the stress distribution and the stress inhomogeneities. Both, the electromagnetic and the ultrasonic techniques have been developed for different cases of application on homogeneous components and set-ups for the automated evaluation of stress states are in industrial use. A disadvantage of both techniques is the influence of changes of microstructural states on the measuring quantities. In case of the electromagnetic techniques, calibrations have to be done, using representative samples in tensile test experiments. The quantitative evaluation of stress states using ultrasonic techniques preassumes the knowledge of the acousto-elastic constants. These constants describe the interdependency between the ultrasonic measuring quantities (sound velocity or time-of-flight) and the strain or stress states. The influence of the microstructural state on the electromagnetic and acousto-elastic quantities has been studied. Depending on e.g. the steel grade, the hardness, the welding parameters, the microstructural state as well as the texture differs. It is found that the texture and microstructural influence on the acousto-elastic constants is not as significant as it was expected. Applying multiparametric regression algorithms on the electromagnetic quantities, the microstructural states influence can be suppressed. Using the evaluated acousto-elastic constants the stress states of rolled plates, in and around welds, along the length of rolls and gear shafts were mapped. Comparisons with the results of an established technique show the reliable application of both techniques. The presentation describes the experimental results and discusses the applicability of the electromagnetic and ultrasonic technique and the benefits using both techniques combined.

Measurement of Residual Stress in Bent Pipelines

---G. A. Alers and J. D. McColskey, NIST, 325 Broadway, Boulder, CO 80305-3337

---Buried gas and oil pipelines can be subjected to unexpected bending loads caused by such earth movements as earthquakes, wash-outs, road building, mining subsidence, etc. as well as by denting from unintentional digging. In order to make a fitness-for-service assessment, it is necessary to measure any residual stresses that are left in the pipe wall as well as the degree of plastic flow within regions of severe damage. A portable instrument that uses EMATs to rapidly measure ultrasonic shear wave birefringence in the wall of a pipe has been developed and applied to a 15 foot long section of 22" diameter linepipe loaded in three point bending by a five million pound mechanical testing machine. The results showed: (1) a large correction for shear wave anisotropy caused by texture in the steel had to be introduced and (2) the degree of plastic flow could be deduced from changes in this texture contribution. An attempt to separate the stress and texture effects by using SH wave modes in the pipe wall proved unreliable because of magnetostrictive effects in the periodic permanent magnet EMATs used for these experiments.

The Influence of Microstructure on the Acoustoelastic Measurement of Stress in Aluminum Alloys

---Samuel J. Wormley and R. Bruce Thompson, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011-3042; Ron Alers, Sonic Sensors of EMAT Ultrasonics, Inc., San Luis Obispo, CA; George Alers, National Institute of Standards and Technology, Boulder, CO; Mark Warchol, Alcoa, Bettendorf, IA

---The ultrasonic measurement of stress depends on sensing shifts in the velocities of ultrasonic waves and interpreting the data in terms of the stress in the material. One of the major challenges in implementation is in differentiating stress-induced changes in velocity from velocity shifts associated with microstructural changes. Measurements of the acoustoelastic constants (the proportionality constant relating stress to velocity shift) of aluminum alloys will be reported, a study undertaken with the goal of providing fundamental information to guide the development of techniques for measuring stress in those alloys. Data is presented quantifying the effects of texture, alloy content and heat treatment. The implications of these shifts on the measurement of stress will be discussed.---Support for this work was provided by Alcoa.

Wednesday, Auust 1, 2001

SESSION 19
IMAGE ANALYSIS AND INVERSE METHODS
S. Krishnaswamy, Chairperson
Cleaveland 151 (Druckenmiller)

8:30 AM **Time-Frequency Analysis for Surface Roughness Characterization Using Backscatter Ultrasound Imaging**
---S. Dos Santos, P. Marechal, J.-M. Girault, and F. Vander-Meulen, Laboratoire UltraSons Signaux et Instrumentation (LUSSI), Ecole d'Ingénieurs du Val de Loire, Rue de la Chocolaterie, BP 3410, F-41034 Blois, Cedex, France

8:50 AM **C-Scan Enhancement Using Recursive Subspace Deconvolution**
---U. Qidwai and C.-H. Chen, University of Massachusetts-Dartmouth, 285 Old Westport Road, N. Dartmouth, MA 02747

9:10 AM **Class Contrast: A Robust Method for Classification of Heterogeneous Zones in Solids Applied to NDT Thermal Images**
---A. Braggiotti, National Research Council, LADSEB, Padova, Italy; S. Marinetti, National Research Council, ITEF, Padova, Italy

9:30 AM **An Efficient Hole-Filling Algorithm for C-Scan Enhancement**
---U. Qidwai and S. Gottlieb, University of Massachusetts, ECE Department, Mathematics Department, 285 Old Westport Road, Dartmouth, MA 02747-2300

9:50 AM **Dipole Formulation for Image Restoration of Flaws from Over Surface Magnetic Field Measurement**
---V. Vengrinovich and S. Emelyanenkov, Laboratory of Computer Diagnostics, Institute of Applied Physics of Belarus Academy of Sciences, Akademicheskaya str. 16, Minsk 220072, Belarus; G.-R. Tillack, Department VIII.3, Bundesanstalt für Materialforschung und Prüfung, Berlin, 12205, Germany

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

10:30 AM **Reconstruction of Semielliptical and Epicyclic Cracks by Eddy-Current Inversion**
---H. A. Sabbagh, E. H. Sabbagh, and R. K. Murphy, Victor Technologies, LLC, P. O. Box 7706, Bloomington, IN 47407-7706

10:50 AM **Assessing Thermal Barrier Coatings by Eddy-Current Inversion**
---H. A. Sabbagh, E. H. Sabbagh, and R. K. Murphy, Victor Technologies, LLC, P. O. Box 7706, Bloomington, IN 47407-7706; J. Nyenhuis, Purdue University, West Lafayette, IN 47907-1285

11:10 AM **Finite Element Neural Networks for Electromagnetic Inverse Problems**
---P. Ramuhalli, L. Udpa, and S. S. Udpa, Iowa State University, Materials Assessment Research Group, Department of Electrical and Computer Engineering, 305 Durham Center, Ames, IA 50011

11:30 AM **Inversion of Elastic Constants for Orthotropic Plate Using Wavelet Transform and Artificial Neural Network**
---J. Yang and J. Cheng, National Lab of Modern Acoustics, Nanjing University, Nanjing 210093, P. R. China

12:10 PM ***Lunch***

Time-Frequency Analysis for Surface Roughness Characterization Using Backscatterer Ultrasound Imaging

---S. Dos Santos, P. Marechal, J.-M. Girault, and F. Vander-Meulen, Laboratoire UltraSons Signaux et Instrumentation (LUSSI), Ecole d'Ingénieurs du Val de Loire, Rue de la Chocolaterie, BP 3410, F-41034 Blois Cedex, France

---Detection of the roughness of a surface in movement is of great interest for the automotive industry if it is performed without contact, at low cost and in the real time. The evaluation of a calibrated surface roughness (mean grain size about 250e-6 m) at v=15 m/s translation velocity has been investigated with an ultrasonic backscattered imaging technique based on the Doppler effect working both in pulsed (400 kHz) and continuous (40 kHz) mode. The difficulty of the classical Fourier analysis to detect with accuracy the instantaneous changes of roughness has led us to use a time-frequency analysis. The need to analyze both frequency and temporal nature of data is due to the non stationarity of measured signals. Some statistical descriptions exist (Rayleigh or K-distributions) but the use of more general time-frequency methods seems to be promising when the 2D-surface to be analyzed is in movement. After a theoretical study of ultrasonic backscattering by a surface, experimental set-up and image processing used for a rapid visualization of the difference of roughness will be presented Finally, experimental results obtained on several surfaces with different roughness and velocities will be shown and compared with theory.

C-Scan Enhancement Using Recursive Subspace Deconvolution

---Uvais Qidwai and Chi-Hau Chen, University of Massachusetts-Dartmouth, 285 Old Westport Road, N. Dartmouth, MA 02747

---C-scan images are formed by mapping the windowed A-scan energy levels into pixel values. This operation limits the resolution of the resulting image due to the blurring effect of squared summations and the mechanical positioning resolution. However, one feature that is found in all such images that they are usually scanned in a raster scanning fashion (say horizontally). This collects most of the information in the rows of the scan. This paper explores the possibilities of applying a decomposition of the image in the row subspace and to filter out the stochastic effects as well as approximate the image parameters within a mean squared error criterion (MSE). Image is modeled as auto regressive structure with emphasis on the row-wise decomposition and suitable subspace deconvolution is implemented for suitable orders. Utilizing an initial guess, system parameters are identified recursively. Each recursion would imply an increase in signal to noise ratio, as can be shown by the entropy values for the image, and hence a better identification as well. The results are presented with artificial defects.

Class Contrast: A Robust Method for Classification of Heterogeneous Zones in Solids Applied to NDT Thermal Images

---Alberto Braggiotti, National Research Council, LADSEB, Padova, Italy; Sergio Marinetti, National Research Council, ITEF, Padova, Italy

---Contrast methods are based on evaluation of the "distance" between the values of a representative parameter of the phenomenon affecting the zones to be classified. Contrast methods are powerful when SNR is high, that is when the reference signal represents with maximum probability the class it is supposed to belong to (usually the signal over a sound zone). In case of low SNR, the probability of the reference parameter to represent its class lowers, leading to a possible misclassification. Moreover the selection of a particular value of the reference by means of an operator is based on the fact that the operator has an a priori knowledge about the specimen. The Class Contrast method presented in this paper overcomes these limitations and works on the basis of 2 guidelines: 1) contrast methods are differential methods, therefore final result should not depend on the arbitrary selection of the reference points; 2) classes are represented by a certain number of points, all affected by the same noise, and all these points should contribute to increase the final SNR. Class Contrast has been successfully applied to thermal NDT on composites. Results are reported together with comparison with results from application of classical thermal contrast method.

An Efficient Hole-filling Algorithm for C-Scan Enhancement

---Uvais Qidwai and Sigal Gottlieb, ECE Department, Mathematics Department, 285 Old Westport Road, University of Massachusetts, Dartmouth, MA 02747-2300

---One of the challenging problems in enhancing C-scans is getting the smooth edges for various regions and artifacts in the image. Usually, some form of 2D enhancing filters would convolve with the image pixels and approximate the pixels with the effects of blur and noise suppressed. In doing so, however, many closed boundaries would be lost due to the structure of filter. The closed boundaries are important as per two accounts. Firstly, it represents the object in a better way, and secondly, the closed boundaries area needed for post processing or region of interest (ROI) calculations that are needed to do operations like background suppression and smoothing. In this paper, a simple interpolation technique is presented that can approximate the broken edges by polynominal approximation of the vicinities of the open ends. A preprocessing step of 'specifying' the abscissa for the binary image pixels. This corresponds to re re-arranging the co-existing pixels with a small and monic displacement. This key step would enable the interpolating algorithm to be free from the ambiguity of abscissa co-occurrence for different ordinate values. A polynomial approximation, as a next step, would not only result in smoothing of the points, but also of minor quantizational errors. This however, should not destroy the prominent edges. Hence, the selection of an appropriate order for the polynomial is important. The algorithmic results are verified by applications to real c-scans of various defect geometries.

Dipole Formulation for Image Restoration of Flaws from over Surface Magnetic Field Measurement

---Valeriy Vengrinovich and Sergei Emelyanenkov, Laboratory of Computer Diagnostics, Institute of Applied Physics of Belarus Academy of Sciences, Akademicheskaya str. 16, Minsk 220072, Belarus; Gerd-Ruediger Tillack, Department VIII.3, Bundesanstalt für Materialforschung und Prüfung, Berlin 12205, Germany

---The problem of image restoration of flaws from over surface magneto static field measurement numbers a variety of approaches, any of them yet being out of wide practical application. Basically they start from reducing the problem to the solution of non linear inverse problem emerged from the attempt to inverse non linear Maxwell equations. Thus, complexity in forward problem solution creates many difficulties for reasonable inversion. The idea of the present work is based upon the consideration of a flaw like a set of magnetic dipoles, each contributing independently into an over surface magnetic field. Then the forward solution becomes linear what makes the inverse problem solution easily attainable within Bayesian formulation with a priori knowledge consideration. The dipole moment is assumed to be dependent upon orientation of a dipole, magnetizing force of exciting magnetic field, flaw opening and material's magnetic properties. The prior knowledge favors the integrity of the flaw and integrates the flaw's boundary support concept developed in our previous works. The feasibility study have been provided and the method was validated by the flaws image reconstruction from simulated data. It is shown that computational burden is reduced in times given a reasonable reconstruction error.

Reconstruction of Semielliptical and Epicyclic Cracks by Eddy-Current Inversion

---Harold A. Sabbagh, Elias H. Sabbagh, and R. Kim Murphy, Victor Technologies, LLC, P. O. Box 7706, Bloomington, IN 47407-7706

---We describe the application of VIC-3D? , a proprietary volume-integral code, to the inversion of benchmark eddy-current data and the reconstruction of semielliptical and epicyclic cracks. These are modeled as relatively thin surface-breaking slots, whose depth into the workpiece is described by either a semiellipse, or a linear combination of semiellipses. The latter curves, called epicyclic, have a rather complex double-peaked, shaped, and are well suited to model a crack with multiple initiation sites. VIC-3D? is used to provide model data for the probe-flaw interaction, which are then fitted to the measured data. The process is quite efficient and provides accurate reconstructions.

Assessing Thermal Barrier Coatings by Eddy-Current Inversion

---Harold A. Sabbagh, Elias H. Sabbagh, and R. Kim Murphy, Victor Technologies, LLC, P. O. Box 7706, Bloomington, IN 47407-7706; John Nyenhuis, Purdue University, West Lafayette, IN 47907-1285

---The nondestructive evaluation (NDE) of high-temperature coatings is one of the important factors in achieving a high-level of structural integrity in advanced gas turbines. In this paper, we demonstrate that sophisticated eddy-current techniques can be utilized to measure the thickness and remaining life of high-temperature coatings. Some research has been conducted to apply such techniques to the pre-service case, for which the coating has one nicely defined layer, and nothing of consequence has diffused into the base metal that would create additional layers of anomalous material. We discuss the much more difficult in-service case, in which the time-temperature exposure of the combustion turbine blade has created a four-layered system, in addition to the base metal.

Finite Element Neural Networks for Electromagnetic Inverse Problems

---Pradeep Ramuhalli, Lalita Udpa, and Satish S. Udpa, Iowa State University, Materials Assessment Research Group, Department of Electrical and Computer Engineering, 305 Durham Center, Ames, IA 50011

---Inverse problems in nondestructive evaluation involve determining defect parameters, such as length, width, depth or the three-dimensional profile, from measurement signals. Phenomenological approaches to solving the inverse problem typically use the forward model in an iterative process. A cost function measuring the error between the measured signal and the signal predicted by the forward model is minimized using gradient-based methods or stochastic methods (such as simulated annealing), with respect to the defect profile. One of the drawbacks of these approaches is that the use of numerical models in iterative approaches is computationally expensive. Secondly, such models do not provide explicit functional relationships between the input and the output, making computation of gradients difficult. This paper proposes a finite element neural network (FEMNN) that combines the advantages of both neural networks and finite element models, enabling fast and accurate solution of the forward problem while embedding the physical process into the neural network. The FEMNN can then be used as the forward model in a phenomenological approach to solve the inverse problem. Gradient-based optimization methods are easily applied since the FEMNN provides an explicit functional mapping between the defect profile and the measured signal. Results of applying the FEMNN to several simple electromagnetic forward and inverse problems are presented. These results indicate that the FEMNN performance as a forward model is comparable to the finite element method. In addition, it is capable of accurately recovering the defect profile from the measured signal. The parallel nature of the FEMNN also makes it an attractive candidate for parallel implementation in hardware and software.

Inversion of Elastic Constants for Orthotropic Plate Using Wavelet Transform and Artificial Neural Network

---Jing Yang and Jianchun Cheng, National Lab of Modern Acoustics, Nanjing University, Nanjing 210093, P.R. China

---We present an inverse method of elastic constants for the orthotropic plate, by combination with the laser-generated Lame wave and the techniques of the wavelet transform (WT) and artificial neural network (ANN). The transient waveforms obtained by theoretical simulations under different elastic constants are taken as the input of ANN for training and learning ANN. The raw Lamb wave signal is first transited to a pre-processor. The pre-processing technique used involves the application of wavelet packet analysis for extracting the eigen-vectors from the signals. The pre-processor output is then input to a multi-layer feed-forward neural network with resilient back-propagation algorithm for training and learning in order to inverse the elastic constants of the materials. Inversion results show the effectiveness of the method.

SESSION 20
GUIDED WAVES
B. Drinkwater, Chairperson
Cleaveland 151 (Druckenmiller)

1:30 PM **Ultrasonic Guided Wave Propagation in Pipes with Viscoelastic Coatings**
---J. N. Barshinger, Krautkramer, 50 Industrial Park Road, Lewistown, PA 17044; J. L. Rose, The Pennsylvania State University, Engineering Science and Mechanics, University Park, PA 16802

1:50 PM **Measurement on the Dispersion Relation of Leaky Lamb Waves with a Laser-Generation/LFB Detection Hybrid Technique**
---C.-H. Yang and M. F. Huang, Chang Gung University, Department of Mechanical Engineering, 259 Wen-Hua 1st Road, Kwei-Shan, Taoyuan, Taiwan

2:10 PM **Frequency Domain Phase Tuning of Guided Waves**
---S.-C. Wooh and Y. Shi, Massachusetts Institute of Technology, Department of Civil and Environmental Engineering, 77 Massachusetts Avenue, Cambridge, MA 02139

2:30 PM **Monitoring of Fatigue Crack Growth at Fastener Holes Using Guided Lamb Waves**
---P. Fromme and M. B. Sayir, Institute of Mechanical Systems, ETH – Swiss Federal Institute of Technology, CLA G 35, Tannenstr. 3, CH – 8092 Zurich, Switzerland

2:50 PM **Ultrasonic Guided Waves for Aging Wire Insulation Assessment**
---R. F. Anastasi, U. S. Army Vehicle Technology Directorate, ARL, AMSRL-VT-S, Nondestructive Evaluation Sciences Branch, NASA Langley Research Center, Hampton, VA 23681; E. I. Madaras, Nondestructive Evaluation Sciences Branch, NASA Langley Research Center, Hampton, VA 23681

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

3:30 PM **The Mode Extraction from Multiple Modes of Lamb Wave**
---T. Hayashi and K. Kawashima, Nagoya Institute of Technology, Department of Mechanical Engineering, Nagoya, 466-8555, Japan

3:50 PM **Separation of Lamb Waves by Bayesian Parameter Estimation**
---S. W. Kercel, Oak Ridge National Laboratory, Instrumentation and Controls Division, P. O. Box 2008, MS 6011, Oak Ridge, TN 37831-6011

4:10 PM **Double-Blind Test of Lamb Wave Diffraction Tomography**
---M. K. Hinders and K. R. Leonard, College of William and Mary, Department of Applied Science, P. O. Box 8795, Williamsburg, VA 23187; E. V. Malyarenko, Nascent Technology Solutions, LLC, Hampton, VA

4:30 PM **Reflection and Scattering of the S_0 Lamb Mode for 3D Circular Defects in Plates**
---O. Diligent, M. J. S. Lowe, and P. Cawley, Imperial College, Department of Mechanical Engineering, Exhibition Road, London SW7 2BX, United Kingdom

4:50 PM **An Evaluation of Different Piezoelectric Materials for 'Smart' Structural Monitoring Applications: The Issue of Structural Integrity in the Host Structure and Mechanical Compatibility of Embedded Transducers**
---B. Hailu, G. Hayward, A. McNab, A. Gachagan, and R. Farlow, University of Strathclyde, Center for Ultrasonic Engineering, Glasgow, Scotland, United Kingdom

Ultrasonic Guided Wave Propagation in Pipes with Viscoelastic Coatings

---James N. Barshinger, Krautkramer, 50 Industrial Park Road, Lewistown, PA 17044; Joseph L. Rose, Engineering Science and Mechanics, The Pennsylvania State University, University Park, PA 16802

---The presence of viscoelastic coatings on pipes causes a practical difficulty for performing a guided wave inspection. This is due to the fact that the coating causes attenuation of the propagating guided wave modes and decreases the signal to noise ratio of the test, sometimes to a level where testing becomes impossible. However, due to the multi-mode character of guided waves, there may be situations where propagation parameters can be chosen to overcome this problem. To explore this possibility, a theoretical model is developed for the two layer elastic/viscoelastic cylinder model. Numerical results are obtained and exhibited as phase velocity, group velocity and attenuation dispersion curves. Experimental results are used to verify the behavior of the theoretical model. Data is presented using an array of low frequency, piezo-composite transducers positioned radially around the pipe. Finally, a discussion is presented on the implications of the theoretical and experimental work on guided wave pipe inspection.

Measurement on the Dispersion Relation of Leaky Lamb Waves with a Laser-Generation/LFB Detection Hybrid Technique

---C.-H. Yang and M. F. Huang, Department of Mechanical Engineering, Chang Gung University, 259 Wen-Hua 1st Road, Kwei-Shan, Taoyuan, Taiwan

---Line-Focused-Beam (LFB) transducer manufactured with a PVDF film operating at a central frequency of about 10 MHz has been proven to be successful in the area of material characterization. In the current research, a hybrid technique employing a laser generation/LFB detection technique is presented for the measurement on the dispersion relations of leaky Lamb waves (LLW). In this technique, an Nd-Yag pulse laser provides a point generation of LLW propagating along a flat plate immersed in a fluid. While the LLW propagates along the immersed plate, the leakage of the LLW into the surrounding fluid is detected with a LFB transducer. With this hybrid technique, measurement results on the LLW dispersion relations of several materials are presented. First of all, LLW propagating along immersed plates of isotropic materials, such as stainless steel and aluminum, are presented. More importantly, LLW propagating along immersed LiNbO3 piezoelectric plate are also measured. The measured dispersion curves agree well with the theoretical model for the prediction of dispersion relations of piezoelectric plate immersed in a fluid accounting both the mechanical and electrical loading.

Frequency Domain Phase Tuning of Guided Waves

---Shi-Chang Wooh and Yijun Shi, Department of Civil and Environmental Engineering, Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, MA 02139

---We revisit the method for generating and detecting multimode Lamb waves reported in the previous QNDE meeting, which utilizes a linear array whose elements are activated according to a prescribed time delay profile. Besides this phased array approach, it was shown that a desired guided wave mode can be tuned by synthetically constructing a virtual wave from individually acquired waveform data. In addition to the development of such a synthetic phase tuning (SPT) technique, a pseudo pulse-echo (PPE) operation scheme was also developed for nondestructive testing. The experimental results, compared with those obtained by more traditional techniques using variable angle wedges and array transducers, show that the new technique is convenient, robust and flexible in utilizing multi-mode guided waves for NDE. The same approach is processed in the frequency domain for better flexibility of operation and filtering.

Monitoring of Fatigue Crack Growth at Fastener Holes Using Guided Lamb Waves

---Paul Fromme and Mahir B. Sayir, Institute of Mechanical Systems, ETH- Swiss Federal Institute of Technology, CLA G 35, Tannenstr. 3, CH – 8092 Zurich, Switzerland

---Airplane fuselage often consists of aluminum face sheets, connected with fasteners or containing holes, which are sources of stress concentration and crack formation at their boundaries. We propose an experimental method for the monitoring of the growth of such cracks in test specimens, based on guided wave propagation. The first anti-symmetric mode A0 of Lamb waves is excited selectively by means of a piezoelectric transducer with a well-defined time signal. When the wave hits a discontinuity like a hole, a typical scattered displacement field is obtained, which can be analyzed accurately both in theory and in experiment. A crack at the hole changes the scattered field and can thus be detected and its growth monitored. In the experimental set-up, a heterodyne laser-interferometer is used to monitor the scattered field close to the hole during crack growth. The fatigue crack is initiated and propagated by cyclic tensile loading of the test specimen in a servo-hydraulic material testing machine. The minimum detectable crack length and the sensitivity of the method are discussed. Problems like crack closure and the possible use in a full scale aircraft fatigue test are addressed.

Ultrasonic Guided Waves for Aging Wire Insulation Assessment

---Robert F. Anastasi, U.S. Army Vehicle Technology Directorate, ARL, AMSRL-VT-S, Nondestructive Evaluation Sciences Branch, NASA Langley Research Center, Hampton, VA 23681; Eric I. Madaras, Nondestructive Evaluation Sciences Branch, NASA Langley Research Center, Hampton, VA 23681

---Aging wiring has become a critical issue to NASA, Navy, Air Force, Army, FAA, and industry. Environmentally aged wire insulation becomes brittle and cracks, thus exposing the underlying conductive wire to the potential for short circuits and fire. Development of methods to check and monitor aging wire systems is thus highly warranted. In the laboratory, we are examining a method that uses ultrasonic guided waves to infer insulation condition. We devised a simple model to see if guided waves would propagate in a thin plastic coated wire. The model consisted of a solid aluminum cylinder that represents a wire conductor and a polymer sheath of heat shrink tubing that represents the insulation. The aluminum cylinder diameter is 0.125" and the total model diameter is 0.175". We examined the behavior of several modes in the bare conductor and in the polymer-coated conductor. The phase velocity of the lowest order axisymmetric mode in the solid cylinder and then in the polymer-coated cylinder were 5175 m/s and 4597 m/s, respectively. We also examined some mil-spec wire with promising results. Our initial measurements indicate that ultrasonic wave velocity can be a means of monitoring insulation stiffness and thus its potential for cracking.

The Mode Extraction from Multiple Modes of Lamb Wave

---Takahiro Hayashi and Koichiro Kawashima, Department of Mechanical Engineering, Nagoya Institute of Technology, Nagoya, 466-8555, Japan

---Multiple reflections of Lamb waves scattered at delaminations and square notches in plates were found in the computer simulations. In this study, a single mode extraction technique was developed to confirm the multiple reflections experimentally. Lamb waves scattered at defects consist of many dispersive modes. Therefore it is difficult to identify a particular mode and characteristics of defects from such signals. The single mode extraction is base on two-dimensional FFT of received signals in time and space, filtering and 2D inverse FFT. Air-couple transducers were adopted for non-contact fast data acquisition. Using this technique, the A0 and S0 modes were clearly separated in preliminary tests of intact plates. Furthermore, multiple reflections of the A0 mode were experimentally confirmed in reflection tests of plates with a square notch. From the group velocity of A0 mode, the extracted two wave packets were estimated to be the reflected waves from the edges of the square notch. Its time of flight gave the widths of notches.

Separation of Lamb Waves by Bayesian Parameter Estimation

---Stephen W. Kercel, Instrumentation and Controls Division, Oak Ridge National Laboratory, P. O. Box 2008, MS 6011, Oak Ridge, TN 37831-6011

---The problem of disentangling overlapping modes has been a persistent stumbling block in the path of those who would use ultrasonic Lamb waves for NDE. In the time-domain, the ultrasonic signature of overlapping Lamb modes is an unintelligible mess. Because each Lamb mode is dispersive (not narrow-band), and because many modes overlap in the frequency-domain, Fourier analysis is of little practical help. A much more fruitful strategy is the use of Bayesian parameter estimation. The signature of any given Lamb mode is well modeled as a Gaussian-windowed linearly-chirped sinusoid. The chirp-rate, center-frequency, window-width, and time-of-window-peak characterize each mode. These parameters provide a four-dimensional feature space in which each Lamb mode is quite distinct and well separated from all the others. Using the maximum entropy method developed by Bretthorst, the parameters for each Lamb mode are easy to estimate. The author has used this technique to analyze the Lamb wave signatures generated by a laser ultrasonic sensor in Tailor-welded blanks. The mode structure for good and defective welds are quite distinct, and readily identifiable. The Bayesian approach has great potential for many NDE applications using ultrasonic Lamb waves.

Double-Blind Test of Lamb Wave Diffraction Tomography

---Mark K. Hinders and Kevin R. Leonard, Department of Applied Science, College of William and Mary, P. O. Box 8795, Williamsburg, VA 23187; Eugene V. Malyarenko, Nascent Technology Solutions, LLC, Hampton, VA

---Lamb waves are guided ultrasonic waves capable of propagating relatively long distances in plates and laminated structures, such as airframe skins, storage tanks and pressure vessels. Their propagation properties in these media depend on the vibrational frequency as well as on the thickness and material properties of the structure. Structural flaws such as disbands, corrosion and fatigue cracks represent changes in effective thickness and local material properties, and therefore measurement of variations in Lamb wave propagation can be employed to assess the integrity of these structures. Lamb wave measurements can be made for a number of relative transducer positions (projections) and an image of the flawed region can be reconstructed tomographically to give a quantitative map of a quantity of interest, e.g. thickness loss due to corrosion. As a test of the Lamb wave scanning apparatus and diffraction tomography reconstruction algorithms, we have undertaken an experiment which is double-blind in the medical sense. Since our motivation is identifying flaws in aging aircraft structures, we have purchased a number of identical aluminum plates, into which representative flaws have been introduced prior to scanning with our existing Lamb wave tomography system and verification with traditional ultrasonic C-scans in an immersion tank. All personnel “calling the flaws” from the reconstructions are blinded from both the Lamb wave and immersion scanning results, with scoring metrics determined before hand. These and other results will be presented in this talk.

Reflection and Scattering of the S_0 Lamb Mode for 3D Circular Defects in Plates

---O. Diligent, M. J. S. Lowe, and P. Cawley, Department of Mechanical Engineering, Imperial College, Exhibition Road, London SW7 2BX, United Kingdom

---The detection of corrosion in large plate-like structures such as oil tanks and pressure vessels using guided wave array transducers is being investigated at Imperial College. In order to make use of the results obtained from such an array, it is necessary to understand the interaction of a guided wave with a 3-dimensional defect. Initial results from a 2-dimensional Finite Element investigation have been presented at the QNDE 2000 meeting. The work presented then was the interaction between an input S_0 Lamb wave with a circular hole through the full thickness of the plate. It was shown that the scattered field contains the SH_0 mode as well as the S_0 mode, the proportion of each depending on the monitoring angle. In this paper the studies will be extended for partial-depth defects. Results will be shown for two different hole depths: 50% and 33% of the thickness. The diameter of the hole will vary between one and three wavelengths of the S_0 mode at 100kHz. The results obtained from such a model will be compared with those from the 2-dimensional problem as well as with results from the case of S_0 waves normally incident at an infinitely wide defect (notch), presented at the QNDE 2000 meeting.

An Evaluation of Different Piezoelectric Materials for 'Smart' Structural Monitoring Applications: the Issue of Structural Integrity in the Host Structure and Mechanical Compatibility of Embedded Transducers

---Bulti Hailu, Gordon Hayward, Alistair McNab, Anthony Gachagan, and Roger Farlow, Center for Ultrasonic Engineering, University of Strathclyde, Glasgow, Scotland, United Kingdom

---In the realization of active structures with embedded sensors and actuators, the structural integrity of the host structure itself and the reliability of the embedded device under operational mechanical load conditions are two major issues of great concern. A two-dimensional finite element model is developed for calculating the stress concentration in uni-directional carbon-fiber plates with embedded piezoelectric transducers. The inter-laminar stresses developed at the interfaces of adjacent piles of the uni-directional carbon-fiber plate and the stress concentrations around the embedded device under tensile and compressive loads were calculated as a function of the piezoelectric material type and dimension. It was shown that, different piezoelectric materials having the same dimension experience different stress levels when the host structure is subjected to an externally applied stress. For a pre-encapsulated piezoelectric transducer, the magnitudes of both the normal and shear stresses may be minimized by a suitable choice of the material type for the encapsulation. On the other hand, the inter-laminar stress magnitudes do not vary significantly for piezoelectric materials of the same dimensions, especially for those regions in the host plate far from the active device and its boundaries.

SESSION 21
NEW TECHNIQUES
B. Lepine, Chairperson
Druckenmiller 016

1:30 PM **Preliminary Experimental Results for a Non-Intrusive Scheme for the Detection of Flaws in Metal Pipelines**
---K. Aydin, S. Shinde, M. Suhail, A. Vyas, and K. W. Zieher, Texas Tech University, Department of Electrical and Computer Engineering, Lubbock, TX 79409-3102

1:50 PM **Detection and Characterization of Flaws in CFRP by SQUID Gradiometer Using Evolutionary Computation**
---F. Kojima and R. Kawai, Kobe University, Graduate School of Science and Technology, 1-1 Rokkodai, Nada-ku, Kobe 657-8501, Japan; N. Kasai, Electrotechnical Laboratory, 1-1-4 Umezono, Tsukuba, Ibaraki 305-8568, Japan; Y. Hatsukade, Waseda University, Graduate School of Science and Engineering, 3-4-1 Ohkubo, Shinjuku-ku, Tokyo 169-8555, Japan

2:10 PM **Damage Detection of Structural Members Based on Wavelet Transforms**
---H. Jeong, Wonkwang University, Division of Mechanical Engineering, Iksan, Chonbuk, South Korea

2:30 PM **Ultrasonic Techniques for Sealant Evaluation in Airframe Components**
---I. N. Komsky, Northwestern University, Center for Quality Engineering and Failure Prevention, 2137 N. Sheridan Road, Evanston, IL 60208

2:50 PM **Electrostatic Detection of Density Variations in Green-State Powder Metallurgy Compacts**
---G. Leuenberger, R. Ludwig, and D. Apelian[1], [1]Metal Processing Institute, Department of Mechanical Engineering, Electrical and Computer Engineering Department, Worcester Polytechnic Institute, Worcester, MA 01609-2280

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

3:30 PM **Modulated Eddy Current Drive and Phase-sensitive Detection for Advanced EC Data Acquisition**
---N. Nakagawa, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

3:50 PM **Capabilities and Limitations of Transient Eddy-Currents for NDE of Multi-Layer Airframe Structures**
---G. R. Hugo and R. A. Smith*, Defence Science and Technology Organization, Aeronautical and Maritime Research Laboratory, 506 Lorimer Street, Fishermans Bend, Victoria 3207, Australia; *Structural Materials Center, Defense Evaluation and Research Agency, Farnborough, Hants, GU14 0LX, United Kingdom

4:10 PM **Application Ultrasonic and Eddy Current Methods for Detection of Surface Fatigue Cracks**
---S. Mayevskyy, National Technical University of Ukraine, Prospect Peremogy 37, Kyiv 03056, Ukraine

4:30 PM **Noncontact Thermoelectric NDE**
---V. K. Kinra and K. Maslov, Texas A&M University, Center for Mechanics of Composites, Department of Aerospace Engineering, College Station, TX 77843-3141

4:50 PM **Acquisition of TOFD Data by Mobile Robots**
---S. Mondal, T. Sattar, and B. Bridge, Centre for Automated and Robotic NDT School of EEIE, 103 Borough Road, London SE1 0AA, United Kingdom

Preliminary Experimental Results for a Non-Intrusive Scheme for the Detection of Flaws in Metal Pipelines

---Kaan Aydin, Sachin Shinde, Mohammed Suhail, Aditya Vyas, and Klaus W. Zieher, Department of Electrical and Computer Engineering, Texas Tech University, Lubbock, TX 79409-3102

---A scheme for non-intrusive detection of flaws in metal pipelines has been investigated. In the laboratory a pressure pulse is generated in an empty pipeline section. The pulse propagates in the wall of the pipe. Flaws in the wall, like thin spots due to corrosion, will reflect the pulse, thus indicating the existence and, from the time delay, the location of the defect. The generation and detection of the pressure pulse is non-intrusive and can be performed without mechanical contact of the pipe. The pulse is generated by a pulsed magnetic field enclosing a short section of the pipe. The detection is by an electrostatic detector surrounding a short section of the pipe. Reflected pulses from thin areas, with a longitudinal extension of about 1/2 pipe diameter and a reduction of the wall thickness by 33%, can be detected clearly. Preliminary experimental results will be presented.---This work was supported by the Texas Advanced Research Program Grant No. 003644-0196-1999.

Detection and Characterization of Flaws in CFRP by SQUID Gradiometer Using Evolutionary Computation

---Fumio Kojima and Ryousuke Kawai, Graduate School of Science and Technology, Kobe University, 1-1 Rokkodai, Nada-ku, Kobe 657-8501, Japan; Naoko Kasai, Electrotechnical Laboratory, 1-1-4 Umezono, Tsukuba, Ibaraki 305-8568, Japan; Yoshimi Hatsukade, Graduate School of Science and Engineering, Waseda University, 3-4-1 Ohkubo, Shinjuku-ku, Tokyo 169-8555, Japan

---This paper is concerned with a quantitative nondestructive evaluation of a carbon fiberglass reinforced plastic (CFRP) using the low temperature superconductor (LTC) SQUID gradiometer. Recently, interest has grown for the structural integrity of CFRP which is widely used for aircraft and space structure. SQUIDs have the potential to detect material defects in conductors due to their extremely high magnetic flux sensitivity for magnetic fields. The SQUID based NDE system developed is composed of an LTC-SQUID gradiometer, a dewar, a scanning table, a lock-in amplifier and a computer to gather data and control the scanning table. The evaluation can be implemented by applying the alternative current injection to the CFRP with a defect. The gradiometer is a planer type one which pick-up coils are directly coupled to a SQUID arranged at the center of the pick-up coils. The use of the gradiometer has made it possible to inspect materials outside magnetic shield. A three dimensional finite element code is developed for analyzing the SQUID based nondestructive system. Using the evolutionary programming, an efficient inverse scheme is proposed for recovering flaws in CFRP. The proposed algorithm is tested for the detection and characterization of flaws in the CFRP samples.

Damage Detection of Structural Members Based on Wavelet Transforms

---Hyunjo Jeong, Division of Mechanical Engineering, Wonkwang University, Iksan, Chonbuk, South Korea

---A new damage detection method for structural members is proposed based on the vibration modes and their wavelet transforms. Changes in the physical properties of the structures such as reduction of stiffness or mass will cause detectable changes in the modal properties of the structure. Most vibration-based methods require knowledge of the undamaged state the structure that is sometimes unavailable. However, the present method directly works only with the fundamental modes of damaged beams or plates: no vibration mode shapes of undamaged members are necessary. Applying the concept of vanishing moments of wavelet functions, we show that wavelet transforms are effective damage detectors. A finite element method is used to generate the mode shapes of a beam and a plate with varying degree of damage. The simulation results show that the damage location is easily found on the scale- distance plane, while the magnitude of the wavelet coefficients at the damage location show a close correlation to the severity of damage.

Ultrasonic Techniques for Sealant Evaluation in Airframe Components

---Igor N. Komsky, Center for Quality Engineering and Failure Prevention, Northwestern University, 2137 N. Sheridan Road, Evanston, IL 60208

---Sealant layers between exterior skins and interior spars, straps, and doublers are utilized to prevent fuel leaks in the airframe structures. They also serve to protect internal components from moisture penetration. Therefore the sealant inspection is an imperative part of the airplane maintenance. The integrity of the sealant layers also plays an important role in the ultrasonic inspection procedures for crack detection in the internal structural layers from the airplane skin. Since most of the cracks are located underneath the sealant layers, it is necessary to verify the integrity of the sealant to make the decision on the inspectability of the internal structures. Several ultrasonic techniques have been developed for the sealant evaluation in the Fairchild226/227 and Cessna Citation 650 lower wing structures. Representative specimens were developed with the commercial PRC aircraft sealant to simulate adequate or inadequate sealant integrity. The sealant evaluation techniques have been integrated with the inspection procedures for crack detection and characterization. The techniques are being validated on the Fairchild and Cessna airplanes.---This material is based upon work supported by the Federal Aviation Administration under Contract # DTFA03-98-D-00008, Delivery Orders # 98-IA005 and #98-IA017 and performed at Northwestern University as part of the Center for Aviation Systems Reliability program through the Airworthiness Center of Excellence.

Electrostatic Detection of Density Variations in Green-State Powder Metallurgy Compacts

---Georg Leuenberger, Reinhold Ludwig, and Diran Apelian[1], [1]Metal Processing Institute, Department of Mechanical Engineering, Electrical and Computer Engineering Department, Worcester Polytechnic Institute, Worcester, MA 01609-2280

---Producing P/M compacts is generally a low-cost, high-volume manufacturing effort with very special quality assurance requirements. When considering the three basic P/M steps of mixing, compacting, and sintering, it is the compaction process producing the green-state parts that offers the highest pay-off for quality control through nondestructive evaluation (NDE) techniques. A detection of compacting-related problems in the green-state samples would permit early process intervention, and thus prevent the creation of potentially significant numbers of faulty parts. Work at WPI has recently resulted in the development of an electrostatic multi-pin instrument capable of testing green-state compacts directly following compaction. By monitoring an electric current flow through the sample (and recording the voltages over the surface) valuable information is gathered, leading to the prediction of surface-breaking and subsurface defects. While crack detection requires the determination of large differences in material properties over small flaw sizes, density prediction requires the detection of small changes in material properties over large regions. In this paper progress is reported to relate the density of green-state compacts (with and without lubricants) to electric conductivity, a relationship that is key to applying the electrostatic NDE methodology. It will be shown that density and material conductivity follow a complex behavior that is determined by the type and concentration of the lubricant. Specifically, the material conductivity increases as the sample density increases for densities of up to approximately 6.9 – 7.0 g/cm^3. Interestingly, any further density increase causes a decrease in conductivity. Theoretical and experimental data will be provided to explain this phenomenon.

Modulated Eddy Current Drive and Phase-sensitive Detection for Advanced EC Data Acquisition

---Norio Nakagawa, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---This paper presents a concept and a proof-of-principle demonstration of modulated eddy current drive/detection methodologies. The objective of the investigation is to enhance EC inspection data qualities, thereby advancing detection and defect characterization capabilities. Our modulated EC approach uses conventional EC probes driven at usual EC frequencies, except that the “carrier” signal is modulated by a lower-frequency time-harmonic. Either amplitude or phase (frequency) modulation may be used. It will be shown that the AM-EC measurements yield two independent Lisajou trajectories from a crack scan, the first being the usual EC output, while the second trajectory arises from the demodulation channel. The primary usage of the second Lisajou trajectory is to resolve potential signal degeneracy in the primary channel between different defect conditions. We will also present phase-modulated EC inspection data. The use of a phase-locked loop for PM detection and its potential for high-accuracy phase measurements will be explained. The presentation will conclude with the prospect of the modulated EC method toward resolution of outstanding inspection problems such as scratch-crack discrimination and crack sizing. Illustrations of laboratory instrumentations for both the AM and PM EC measurements will be included.---This work was supported by the NSF Industry/University Cooperative Research program.

Capabilities and Limitations of Transient Eddy-Currents for NDE of Multi-Layer Airframe Structures

---G. R. Hugo and R. A. Smith*, Defence Science and Technology Organization, Aeronautical and Maritime Research Laboratory, 506 Lorimer Street, Fishermans Bend, Victoria 3207, Australia; *Structural Materials Center, Defense Evaluation and Research Agency, Farnborough, Hants, GU14 0LX, United Kingdom

---Research by an number of groups working in Australia, Canada, UK and USA has shown that transient (or pulsed) eddy-current techniques have significant potential for nondestructive evaluation of hidden corrosion in multilayer airframe structures. Indeed, a recent round-robin evaluation[1] rated the transient/pulsed eddy-current technique to be the most effective of the techniques trialed for detection and quantification of second-layer corrosion in aircraft lap-joints. The authors are conducting a systematic assessment of the capabilities and limitations of transient eddy-current technology utilising Hall-effect magnetic field sensors. The detection limits for both hidden corrosion and subsurface cracks are being determined as a function of defect depth for multilayer Al-alloy structures up to 15 mm total thickness. The results of this work will be reported, including a review of the effectiveness of currently available analysis tools for liftoff compensation, quantification of metal loss and subtraction of edge effects. Results for a number of practical inspections will be presented, including a particularly difficult inspection in which mushroom-headed fasteners over a four-layer structure prevents adequate inspection for corrosion using other techniques. This has proven to be an ideal application for transient eddy-currents, despite the enforced liftoff and associated reduction in signal-to-noise ratio.

---Operating Assignment MAT-TP-5-O17 *Detection of Corrosion in Multi-layer Aluminium Structures* conducted under The Technical Cooperation Program between Australia, Canada, New Zealand, UK and USA.

Application Ultrasonic and Eddy Current Methods for Detection of Surface Fatigue Cracks

---S. Mayevskyy, National Technical University of Ukraine, Prospect Peremogy 37, Kyiv 03056, Ukraine

---The detection of fatigue cracks on surfaces of constructional elements is decided as rule by use highly sensitive eddy current flaw detectors with manual scanning. Such flaw detector is effective for detection of microcracks near to concentrators of mechanical stresses. The manual method of scanning of inspected item surface can overleap of defect and the detection of a separate microcrack does not guarantee thus. An apart from a possibility of the similar differential approach to a solution of a problem of detection of microcracks other integrated method of an evaluation of their availability is necessary also. This problem can be decided by using method what based on a measurement of a velocity propagation of surface waves in some to a beforehand selected zone of an inspected surface. The joint application of both methods brings good outcomes. The features developed by us Eddy Current flaw detector working on frequency of electromagnetic oscillations 6 MHz are circumscribed, and also the method, developed by us, of a precise measurement of a velocity propagation of surface ultrasonic waves is described too. The sharing of both methods accelerates the detection and evaluation of surface fatigue cracks of elements of constructions.

Noncontact Thermoelectric NDE

---Vikram K. Kinra and Konstantin Maslov, Center for Mechanics of Composites, Department of Aerospace Engineering, Texas A&M University, College Station, TX 77843-3141

---A new technique for the characterization of the microstructure of an alloy by remote measurement of its thermoelectric power has been developed. It is based on the measurement of the magnetic field which appears in an electrically-conducting alloys subjected to a temperature gradient. The magnetic field depends only on the spatial variations in the thermoelectric power. Since this method does not require contact measurements, it has the potential for in situ measurements. We will report some preliminary measurements demonstrating the variations in thermoelectric power caused by damage in an aluminum alloy structure.

Acquisition of TOFD Data by Mobile Robots

---Shyamal Mondal, Tariq Sattar, and Bryan Bridge, Centre for Automated and Robotic NDT School of EEIE, 103 Borough Road, London SE1 0AA, United Kingdom

---Results are described of TOFD data acquired by the scanning of 6 and 7 axis robot arms carried by mobile wall climbing and curved surface adapting vehicles which are particularly useful for remote data acquisition in hazardous environments. Data acquisition by three different robot vehicles dedicated to different tasks is described. The three vehicles and associated tasks are as follows: a vehicle that uses suction cups to travel on 860 mm diameter feeder pipes in the primary circuit of a nuclear power plant to inspect nozzle welds; a vehicle that uses suction cups to climb on the wall of oil storage tanks to detect corrosion thinning of the wall; a vehicle that uses magnetic adhesion to climb the hull of cargo container ships to inspect seam welds. The main advantage of TOFD data acquisition by robotic arms mounted on mobile vehicles, over manual deployment, is that the quality of data is much improved due to the ability of the robotic devices to maintain more constant probe contact forces and to obtain repeatable data unaffected by fatigue which manual operators find very difficult to match when operating in remote and hazardous locations.

Wednesday, August 1, 2001

SESSION 22

ELASTIC/ANELASTIC MATERIAL PROPERTIES

W. Winfree, Chairperson
Sills 117

1:30 PM **Visco-Elastic Tensor Recovery in the Absence of Known Material Symmetry**
---M. Sun and M. L. Peterson, University of Maine, Mechanical Eng., Orono, ME 04469-5711

1:50 PM **Temperature and Stress Dependence of Ultrasonic Velocity; Further Measurements**
---R. L. Weaver and O. I. Lobkis, University of Illinois, Department of Theoretical and Applied Mechanics, 104 S. Wright Street, Urbana, IL 61801

2:10 PM **Monitoring of Recrystallization in Aluminum Alloy by Resonance EMAT**
---C.-S. Man and X. Fan, University of Kentucky, Department of Mathematics, 715 Patterson Office Tower, Lexington, KY 40506-0027; J. G. Morris, University of Kentucky, Department of Chemical and Materials Engineering, Lexington, KY 40506; K. Kawashima, Tokyo University of Technology, School of Engineering, Hachioji, Tokyo 192, Japan

2:30 PM **Inversion of V(z) Responses for Determining c_{ij} Elastic Constants by Using an Optimization Method on the Singularities of the Reflection Coefficient**
---Y. Benmehrez and G. Bourse, Départment Mécanique et Comportement des Matériaux, Ecole des Mines de Douai, Douai, France; W.-J. Xu and M. Ourak, Université de Valenciennes, Inst. d'Elect. et de Microélect. du Nord, Dépt. d'-Opto-Acousto-Elect., Valenciennes, France

2:50 PM **A Theory for the Ultrasonic Attenuation and Backscattering in Duplex, Cubic, Alloy**
---P. D. Panetta and L. J. Bond, Engineering Physics, Pacific Northwest National Laboratory, P. O. Box 999, MSIN K5-26, Richland, WA 99352; R. B. Thompson, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011-3042

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

3:30 PM **Backscattering and Attenuation in Duplex Ti-6Al-4V: Experimental and Theoretical Comparisons**
---P. D. Panetta[1] and R. B. Thompson[2], [1]Pacific Northwest National Laboratory, 902 Battelle Boulevard, P. O. Box 999, MSIN K5-26, Richland, WA 99352; [2]Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

3:50 PM **Determination of Elastic Constants by Line-Focus Acoustic Microscopy: Effect of Initial c_{ij} Values on the Optimization Method Accuracy and Influence of Geometric Probe Parameters on the Determination of the SAW Velocity**
---M. Lematre, Y. Benmehrez, and G. Bourse, Département Mécanique et Comportement des Matériaux, Ecole des Mines de Douai, Douai, France; W.-J. Xu and M. Ourak, Institut d'Electronique et de Microélectronique du Nord, Département d'Opto-Acousto-Electronique, Université de Valenciennes, Valenciennes, France

4:10 PM **Focused Acoustic Beam Applied to Elastic Property Determination in Plates**
---D. Fei and D. E. Chimenti, Iowa State University, Center for NDE and Department of Aerospace Engineering and Engineering Mechanics, Ames, IA 50011

4:30 PM **Determination of Anisotropic Elastic Properties of Zr-2.5 Nb Pressure Tube Using Resonant Ultrasonic Spectroscopy**
---Y.-M. Cheong, S.-S. Kim, and Y.-S. Kim, Korea Atomic Energy Research Institute, Yusong P. O. Box 105, Taejon, Korea 305-600

4:50 PM **Laser Ultrasonic Determination of the Elastic Constants of Damaged Propellant**
---C. Bescond, A. Moreau, and D. Lévesque, Industrial Materials Institute, National Research Council of Canada, Boucherville, Québec, J4B 6Y4, Canada; F. Wong, Defense Research Establishment Valcartier, Val Belair, Québec, G3J 1X5, Canada; L. Bertrand, École Polytechnique de Montréal, Départment de Génie Physique, Montréal, Québec, H3C 3A7, Canada

Visco-Elastic Tensor Recovery in the Absence of Known Material Symmetry

---Miao Sun and M. L. Peterson, Mechanical Engineering, University of Maine, Orono, ME 04469-5711

---In many critical design applications that employ anisotropic materials, full knowledge of the material properties is required. The modulus, damping and the strength may be required to determine the deformation for particular loading case and to predict failure modes. While elastic properties are reasonably well defined, the damping anisotropy and the strength are less well understood. However, even in the case of the elastic properties, this knowledge is compromised if the material axes are found to be misoriented relative to the geometric axes of the part. For natural as well as man-made materials, lower than nominal materials symmetry may exist. The recovery of the full visco-elastic tensor for several practical materials is considered. Natural variability of wood is contrasted with processing variation in composites manufacturing. Materials produced in diffusion-controlled processes such as chemical vapor infiltration or which grow like wood in annual rings are of particular interest. For these materials, the full symmetry exists only in the curvilinear coordinates. This situation effectively reduces the symmetry of the material for tests on specimens cut on Cartesian axes. Experimental results are shown for several applications and the effect of the symmetry error on the response of the material is considered.

Temperature and Stress Dependence of Ultrasonic Velocity; Further Measurements

---Richard L. Weaver and Oleg I. Lobkis, Department of Theoretical and Applied Mechanics, University of Illinois, 104 S. Wright Street, Urbana, IL 61801

---It has been reported that the temperature dependence of ultrasonic velocity varies with stress. Highly variable values for the parameter d ln [dV / dT] / d Stress have been reported, including (our own) values indistinguishable from zero. Naive theoretical estimates for the parameter suggest that it should be of the order of an inverse Young's modulus. Some groups have reported values as much as 100 times greater, as high as an inverse Yield modulus. This suggests that an explanation for the anomalously high and variable coefficient is that it depends on plastic history. In an effort to resolve the discrepancies we revisit the measurements, but now on specimens with different plastic histories. The times-of-flight of multiply reflected 10 MHz ultrasound pulses in aluminum bars were resolved to within 1 nanosecond. Natural wavespeeds were measured to within a part in 100,000. Compressive elastic loads were applied on an axis perpendicular to the direction of the longitudinal acoustic wave. Loads were controlled, and held fixed, as the specimens cooled from 50 degrees C to 20. The specimens with large (10%) plastic pre-strain were found to show a 5% change in d ln V/ dT when applied elastic strain was 0.1% This is 50 times greater than the naive theory would have predicted. Consistent with our previous reports, specimens with no significant plastic history showed no discernable coefficient.

Monitoring of Recrystallization in Aluminum Alloy by Resonance EMAT

---Chi-Sing Man and Xingyan Fan, Department of Mathematics, University of Kentucky, 715 Patterson Office Tower, Lexington, KY 40506-0027; James G. Morris, Department of Chemical & Materials Engineering, University of Kentucky, Lexington, KY 40506; Katsuhiro Kawashima, School of Engineering, Tokyo University of Technology, Hachioji, Tokyo 192, Japan

---Suitable annealing, which induces recrystallization of deformed grains (primary recrystallization), improves the formability of aluminum sheets. Annealing at excessively high temperatures, however, promotes exaggerated grain growth (secondary recrystallization), which degrades formability and is undesirable. In this paper we show that (i) the texture coefficient W400 serves as a good indicator of the degree of primary and secondary recrystallization during annealing of a strip-cast 5xxx aluminum alloy; (ii) for sheets of this alloy the value of W400 can be determined at processing temperatures by measurement with resonance EMAT, so long as the temperature of the sample is determined by another means. We present examples where the progression of primary recrystallization in AA5xxx samples at different temperatures was monitored in real time with repeated resonance EMAT measurements in short time intervals.

Inversion of V(z) Responses for Determining c_{ij} Elastic Constants by Using an Optimization Method on the Singularities of the Reflection Coefficient

---Y. Benmehrez and G. Bourse, Département Mécanique et Comportement des Matériaux, Ecole des Mines de Douai, Douai, France; W. -J. Xu and M. Ourak, Institut d'Electronique et de Microélectronique du Nord, Département d'Opto-Acousto-Electronique, Université de Valenciennes, Valenciennes, France

---The material signature (V(z) curve) obtained by using line-focus acoustic microscopy has been used to determine c_{ij} elastic constants. The method, we propose in this paper is based on the comparison of measured and calculated R reflection coefficient. Experimentally we record V(z) curve on the specimen, and then we extract the measured R by inversion of the V(z) curve. The c_{ij} elastic constants have influence on the shape of the reflection coefficient on selected angular ranges in terms of phase and modulus. The determination of the c_{ij} elastic constants is obtained by using an optimization method, also called simplex method which minimizes the square difference summation $(Rm-Rc)^2$ between the measured and calculated reflection coefficient (phase and modulus) on the limited angular ranges. This method also enables the determination of surface acoustical waves velocities. This paper deals with the case of isotropic and anisotropic cubic substrates (silicon and MgO).

A Theory for the Ultrasonic Attenuation and Backscattering in Duplex, Cubic, Alloys

---Paul D. Panetta and Leonard J. Bond, Engineering Physics, Pacific Northwest National Laboratory, P. O. Box 999, MSIN K5-26, Richland, WA 99352; R. Bruce Thompson, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011-3042

---It is well known that the microstructure can affect a propagating ultrasonic beam. For example, the sound velocity can provide information about crystallographic texture. In addition, the microstructure backscatters energy, creating noise, which masks signals from small flaws. Furthermore, a flaw signal can be attenuated by absorption and scattering of energy. These effects can have deleterious effects on flaw detection and characterization. However, due to the link between backscattered grain noise, attenuation and the microstructure, measurement of these ultrasonic quantities can be used as accurate materials characterization tools if appropriate models exist. Theoretical predictions of attenuation have been made successfully in the past in materials consisting of texture free, equiaxed grains. However, there is a lack of adequate models describing the attenuation in duplex alloys with a preferred texture such as commonly used steel and titanium alloys. The multiple forward scattering, which controls the attenuation, is of particular interest. In this paper, we will present theoretical predictions of attenuation and backscattering in duplex, cubic, polycrystalline materials consisting of elongated grains.

Backscattering and Attenuation in Duplex Ti-6Al-4V: Experimental and Theoretical Comparisons

---P. D. Panetta[1] and R. Bruce Thompson[2], [1]Pacific Northwest National Laboratory, 902 Battelle Boulevard, P. O. Box 999, MSIN K5-26, Richland, WA 99352; [2]Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---Developing a quantitative understanding of ultrasonic wave propagation in engineering alloys is important because flaw signals can be altered greatly by the microstructure that the ultrasound propagates through between the transducer and the flaw. Two consequences of the microstructure are particularly important: backscattering which competes with flaw signals and forward scattering which controls the attenuation and can modulate the strength of flaw signals by causing phase aberrations in the ultrasonic field. Each of these effects is controlled by the inherently complex microstructure which develops during routine processing. A detailed understanding of the effects of the microstructure on the ultrasonic wave propagation can also serve as the basis for a method to characterize the material. This paper presents an experimental test of the theories for backscattering and attenuation in duplex titanium alloys. Current theories for backscattering and attenuation suggest that the most important physical feature which controls scattering is the two-point correlation of elastic constant perturbations, which is in turn controlled by local variations in crystallographic orientation. The local orientations were mapped utilizing Orientation Imaging Microscopy (OIM) performed in a scanning electron microscope (SEM) and were used to determine the two-point correlation of elastic constant perturbations, as input to theories of backscattering and attenuation. Agreement between the experimental measurements and theoretical predictions were very good for backscattering and reasonable for attenuation. Physical interpretation of these levels of agreement will be discussed as well as future directions for theoretical development.---Pacific Northwest National Laboratory is operated for the U.S. Department of Energy by Battelle under Contract DE-AC06-76RLO18310.

Determination of Elastic Constants by Line-Focus Acoustic Microscopy: Effect of Initial c_{ij} Values on the Optimization Method Accuracy and Influence of Geometric Probe Parameters on the Determination of the SAW Velocity

---M. Lematre, Y. Benmehrez, and G. Bourse, Département Mécanique et Comportement des Matériaux, Ecole des Mines de Douai, Douai, France; W. -J. Xu and M. Ourak, Institut d'Electronique et de Microélectronique du Nord, Département d'Opto-Acousto-Electronique, Université de Valenciennes, Valenciennes, France

---The determination of elastic constants in anisotropic solids by line-focus acoustic microscopy is discussed. The velocity of leaky surface acoustic waves (SAWs) has been obtained for different directions of propagation. The experimentally measured SAW velocities are compared to calculated velocities, which are obtained from a simulation model of V(z) curves. The same procedure based on the Kushibiki method is used to determine experimental and calculated velocities. The search of elastic constants was made by the use of the optimization algorithm based on the simplex method. This processing consists in minimizing the square difference summation $(Vm-Vc)^2$ between the measured and calculated velocities determined from the V(z,phi) curves. This paper deals with the case of cubic crystallite solids, which have three independent elastic constants (c11, c12, and c44). The influence of the starting values of cij on the final result is discussed in the case of MgO substrate and TiN deposited on MgO substrate. The experimentally SAW velocity profile is measured on (100) silicon substrate as function of the direction of propagation. The influence of the acoustic probe parameters (aperture, curvature, and frequency) and the effect of the defocusing distance in the material are also discussed.

Focused Acoustic Beam Applied to Elastic Property Determination in Plates

---Dong Fei and Dale E. Chimenti, Iowa State University, Center for NDE and Department of Aerospace Engineering and Engineering Mechanics, Ames, IA 50011

---The output voltage of the receiving transducer in a fluid- or air-coupled leaky Lamb wave experiment contains the contribution from both intrinsic material properties and extrinsic experimental parameters including geometry and transducer beam characteristics. In this work we have developed a complex transducer point model to include all those factors to permit the prediction of the k-f (wave number-frequency) domain result obtained from a synthetic aperture scan of either planar or focused transducers in a pitch-catch reflection arrangement. Extensive experiments are performed to test the model and demonstrate the transducer beam effects on the k-f domain result, which leads to a very efficient method for mapping major portions of the guided wave dispersion spectrum in planar media. By taking advantage of the large angular beam spread of a pair of highly focused transducers, almost the entire angular range accessible by phase-matched water coupling can be measured with the transmitting and receiving transducers at a single orientation angle. We have then developed a novel stepwise, targeted procedure to allow a rapid estimate of material elastic properties with only a minimal use of the mapped, highly redundant dispersion data. Experiments on both isotropic and anisotropic plates show a measurement error of about 5% from contact acoustic estimates for most of the elastic constants.---This work was supported in part by the Institute for Physical Research and Technology at Iowa State University.

Determination of Anisotropic Elastic Properties of Zr-2.5 Nb Pressure Tube Using Resonant Ultrasonic Spectroscopy

---Yong-Moo Cheong, Sung-Soo Kim, and Young-Suk Kim, Korea Atomic Energy Research Institute, Yusong P. O. Box 105, Taejon, Korea 305-600

---Anisotropic elastic constants of Zr-2.5 Nb pressure tube materials were determined by a high temperature resonant ultrasound spectroscopy(RUS). The resonance frequencies were measured using a couple of Alumina wave guides and wide-band ultrasonic transducers into a small furnace. The rectangular parallelepiped specimens were fabricated along with the axial, radial, and transverse direction of the pressure tube. The estimated elastic stiffness was determined using its orientation distribution function by x-ray diffraction and the reported elastic stiffness of a zirconium single crystal. A nine elastic stiffness tensor for the orthorhombic symmetry was determined in the range of room temperature~400?C. As the temperature increases, the elastic constant tensor, c_{ij} gradually decreases. Higher elastic constants along the transverse direction compared to those along the axial or radial direction are similar to the case of Young's modulus or shear modulus. A crossing of elastic constants along axial direction and radial direction was observed near 120?C. This fact is well agreed to the results of yield strength from mechanical testing.

Laser Ultrasonic Determination of the Elastic Constants of Damaged Propellant

---C. Bescond, A. Moreau, and D. Lévesque, Industrial Materials Institute, National Research Council of Canada, Boucherville, Québec, J4B 6Y4, Canada; F. Wong, Defense Research Establishment Valcartier, Val Belair, Québec, G3J 1X5, Canada; L. Bertrand, École Polytechnique de Montréal, Département de Génie Physique, Montréal, Québec, H3C 3A7, Canada

---The mechanical properties of solid rocket propellants can change during storage because temperature variations can weaken the bond between the oxidizer particles and the elastomeric matrix. The internal damage can be evaluated by measuring the stiffness changes that occur in the material. In order to simulate the mechanical properties of damaged solid propellants, a hydroxyl-terminated polybutadiene (HTPB) elastomeric matrix with glass or KCl particles is studied under uni-axial deformations. A laser ultrasonic system is coupled to a tensile testing machine to measure the elastic constant variations as a function of deformation. During loading, the partial debonding between the particles and the matrix produces an anisotropy in the material. Elastic constants are calculated from group velocities measurements in non principal directions. The calculation is based on a minimization of a system of two functions that relates the group velocity to the elastic constants. Finally, the stiffness variations are compared with predictions of a micro-mechanical model for the damage of such materials.

Wednesday, August 1, 2001

SESSION 23
BENCHMARK PROBLEMS

This session is organized by members of the World Federation of NDE Centers to compare results on a standard set of magnetic flux leakage, eddy current, and ultrasonic problems. It will convene in three separate subsessions (starting at 1:30 PM-3:10 PM) as listed. Subsessions will join for the second half (3:30 PM-5:30 PM).

1:30 PM ***Magnetic Flux Leakage – A. Pignotti, Chairperson (Smith Auditorium, Sills)***

Numerical Simulation Results for the Magnetic Flux Leakage Benchmark Problem
---Y. Li, Z. Zhang, Y. Sun. L. Udpa, and S. S. Udpa, ISU, Dept. of EE/Comp. Eng., Ames, IA 50011

3D Model Calculation of MFL Benchmark Problem
---A. Pignotti and G. Sánchez, Centro de Investigación Ind. FUDETEC, Campana, Buenos Aires, Argentina

Forward Numerical Solutions to Some MFL and Eddy Current Testing Problems
---V. Lunin and D. Podobedov, Moscow Power Engineering Institute (TU), Electrical Engineering & Introscopy Department, Krasnokazarmennaja 14, Moscow, 111250, Russia

Magnetic Flux Leakage Benchmark Problem
---R. Schifini and A. C. Bruno, Pontificia Universidade Catolica, Departamento de Fisica, Rua Marquês de São Vicente 225, Rio de Janeiro, RJ 22453-900, Brazil

Prediction of the Radial, Axial and Circumferential Components of the Magnetic Flux Leakage Signal Around Defects Machined on a Steel Pipe
---J. Philip, P. Kalyanasundaram, and B. Raj, Indira Gandhi Centre for Atomic Res., Kalpakkam, 603 102, India

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

1:30 PM ***Eddy Currents – R. Sikora, Chairperson (107 Sills)***

Field Computation in Inconel 600 Tube with Defect
---G. H. Shirkoohi, South Bank University, School of Engineering, 103 Borough Road, London SE1 0AA, United Kingdom

Numerical Simulation Results for the Eddy Current Benchmark Problem
---Z. Zhang, Y. Li, Y. Sun, L. Udpa, and S. S. Udpa, ISU, Dept. of EE/Comp. Eng., Ames, IA 50011

Comparison of Different Measurement Configurations for Non-destructive Testing of Well-conducting Materials
---R. Sikora, Technical University of Szczecin, A. Piasow 19, 70-310 Szczecin, Poland; R. Palka, Institut f. elektr. Maschinen, Hans-Sommer-Str. 66, 38106 Braunschweig, Germany

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

1:30 PM ***Ultrasonics – R. B. Thompson, Chairperson (207 Sills)***

Simulation of Ultrasonic Signals from Spherical and Planar Reflectors
---S. K. Dewangan, P. Kalyanasundaram, and B. Raj, Indira Gandhi Centre for Atomic Research, Kalpakkam (Tamil Nadu) 603 102, India

Ultrasonic Modeling of Benchmark Problems
---L. W. Schmerr, Jr., ISU, Center for NDE and Department of Aerospace Engineering and Engineering Mechanics, Ames, IA 50011; A. Sedov, Lakehead University, Department of Mechanical Engineering, Thunder Bay, Ontario, Canada P7B 5E1

Predication of Flaw Signals of the Ultrasonic Round Robin Problems by Sungkyunkwan University
---S.-J. Song, H.-J. Kim, and C.-H. Kim, Sungkyunkwan University, School of Mechanical Engineering, 300 Chunchun-dong, Jangan-ku, Suwon, Kyungggi-do, 440-746, Korea

Simulating a Standard Type Problem of Ultrasonic Testing – A Contribution to the Comparison of Ultrasonic Models
---M. Spies, W. Müller, and W. Arnold, University of Saarland, Fraunhofer-Institute for Nondestructive Testing (IZFP), Building 37, 66123 Saarbrüken, Germany

Solution of an Ultrasonic Benchmark Problem within the Paraxial Approximation
---T. Gray and R. B. Thompson, ISU, Center for NDE, 1915 Scholl Road, Ames, IA 50011

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

Summaries of Benchmark Comparisons and Discussion – S. Udpa (Smith Auditorium, Sills)

3:30 PM **Summaries of Benchmark Comparisons**
A. Pignotti, Magnetic Flux Leakage
R. Sikora, Eddy Currents
R. B. Thompson, Ultrasonics

4:30 PM **Discussion**

Numerical Simulation Results for the Magnetic Flux Leakage Benchmark Problem

---Y. Li, Z. Zhang, Y. Sun, L. Udpa, and S. Udpa, Iowa State University, Department of Electrical and Computer Engineering, Ames, IA 50011

---This paper presents numerical results predicted by a finite element model for the magnetostatic benchmark problem proposed by the World Federation of Nondestructive Evaluation Centers. The benchmark problem involves the prediction of the radial, circumferential, and axial components of the MFL signal around defects machined on a steel pipe whose nonlinear magnetization characteristics are specified. The excitation is provided by passing 500 Ampere D.C. current through a copper rod that runs the entire length of the pipe and is concentrically located along the pipe's axis. Four defects are machined on the outer surface of the pipe. The first defect is an axisymmetric slot. The second, third and fourth are rectangular defects oriented longitudinally along the axis of the pipe, with different widths and depths. A numerical model implemented with edge-based finite elements is used to predict the MFL signal around the defects. The finite element model is based on a magnetic vector potential formulation. The gauge condition on the magnetic vector potential is imposed with the help of three and co-tree separation using graph theory. The nonlinearity issue handled using an interative scheme. Results obtained using the numerical model will be presented.

3D Model Calculation of MFL Benchmark Problem

---Alberto Pignotti and G. Sánchez, Centro de Investigación Industrial, FUDETEC, Campana, Buenos Aires, Argentina

---A three-dimensional finite-element code developed at our Center for Industrial Research is used to solve a MFL benchmark problem proposed by the World Federation of Nondestructive Evaluation Centers. The problem involves prediction of the radial, axial and circumferential components of the leaked magnetic field around defects machined on a steel pipe. The excitation field is provided by a 500 Amp DC current through a copper rod that runs the entire length of the pipe and is concentrically located along the pipe's axis. The nonlinear relation between the magnetic flux density and the magnetic field, provided as part of the problem definition, is implemented by iteration. The results will be presented at a special session on benchmark problems and compared with calculations carried out by other participating centers and measurements performed at ISU.

Forward Numerical Solutions to Some MFL and Eddy Current Testing Problems

---V. Lunin and D. Podobedov, Moscow Power Engineering Institute (TU), Electrical Engineering & Introscopy Department, Krasnokazarmennaja 14, Moscow, 111250, Russia

---Recent developments of measurement instruments have shown that testing by means of magnetic flux leakage (MFL) and eddy current (EC) techniques can be successfully used to detect many kinds of flaws in highly stressed tubes in industry. Additionally, reliable methods must be developed to identify and locate these flaws. Some advanced estimation algorithms, which take into account the nonlinearity of this inverse problem, have appeared in the literature. A first step of such algorithms is to generate a signal data set that can be used in training an appropriate estimator to recognize flaw parameters. Therefore, an accurate and fast three-dimensional field computation is required which is able to resolve the very small field perturbations generated by a flaw. The objectives of this study are to implement the simulation of the model of some flaws in ferromagnetic and nonmagnetic tubes, to quantify the characteristics of signals due to this flaws, and to compare predicted signals with experimental data. In order to predict the signal, a nodal three-dimensional finite element (3D-FEM) package MagNum3D is used as a numerical analysis tool. In MFL problem, we investigate the relation between slots with different depths and widths (by fixed length) and detecting signals. The slots exist on the outer surface of ferromagnetic (with known nonlinear characteristic) tube and orients longitudinally along the axis. Excitation field is provided by passing steady direct current through a copper rod located concentrically inside the tube. Each detecting signal is radial, axial and circumferential components of magnetic flux density near the slots area. In case of EC testing problem, two identical coils connected differentially move along the axis inside of nonferromagnetic tube passed through supporting plate made of ferromagnetic steel with linear characteristic. The coils are excited by alternative current of different test frequencies. The flaw of sectorial form is located on outer surface of the tube just under the support plate. Output signal of the detecting coils means impedance change when the coils are moved along flawed area.

Magnetic Flux Leakage Benchmark Problem

---Ricardo Schifini and Antonio C. Bruno, Departamento de Fisica, PUC-Rio, Pontificia Universidade Catolica, Rua Marquês de São Vicente 225, Rio de Janeiro, RJ 22453-900, Brazil

---As a member of the World Federation of Nondestructive Evaluation Centers we present our results for the proposed magnetic flux leakage benchmark problem. This benchmark problem consists of simulating a magnetostatic problem for four surface defects on a steel pipe. To solve this, we have taken a finite element approach. A finite element mesh was created for each defect and solved using Vector Field's Opera3D software. We show the radial and circumferential components of the MFL signal for every defect.

Prediction of the Radial, Axial and Circumferential Components of the Magnetic Flux Leakage Signal Around Defects Machined on a Steel Pipe

---John Philip, P. Kalyanasundaram, and Baldev Raj, Indira Gandhi Centre for Atomic Research, Kalpakkam (Tamil Nadu) 603 102, India

---MFL (Magnetic flux leakage technique) is one of the popular non-destructive testing (NDT) techniques used for sizing surface and subsurface flaws in magnetic specimens. Here, the magnetic flux lines are bent around the defect, which leads to leakage of magnetic flux out of the sample. This technique has been used to locate and assess discontinuities in ferromagnetic materials during per-service and in- service inspections. We are working on theoretical modeling to predict the flux leakage profiles given in the bench mark problem. During the meeting, we would present the predicted results of the radial, axial and circumferential components of the leakage magnetic field strength around defects machined on a steel pipe. We have used an extended dipole model of Zatsepin and Shcherbinin, where the leakage magnetic fields of a crack have been modeled by infinitely long strip dipoles, for predicting the normal and tangential components of leakage magnetic flux from rectangular slots of different dimensions. In the above approach, it is assumed that the surface magnetic charge density on the faces of the slot is constant, the experimental results from a new optical probe show good agreement with this model calculations. Therefore, we use this treatment for the evaluation of the components (axial and radial components) of leaked magnetic flux from the rectangular slots. We would also evaluate the components of magnetic flux leakage (axial, radial and circumferential), using the analytical approach of Edward and Palmer, from the defects of different sizes and permeability, where the surface polarity on a slot is determined from a solution of Laplace's equation and the leakage field is evaluated by integrating over the slot surface. Using the above approach, we calculate the MFL at the epicenter of the defects for the entire magnetizing fields given in the problem. However, by considering the lengthy computation time, we calculate the variation of these leakage fields for one particular magnetizing field. Regarding the experimental part, we attempt to measure the leakage flux values using a hall probe to compare the predicted results.

Field Computation in Inconel 600 Tube with Defect

---G. H. Shirkoohi, Magnetics Laboratory, School of Engineering, South Bank University, 103 Borough Road, London SE1 0AA, United Kingdom

---Field computation for several conditions for the benchmark problems was carried out. In this problem, two identical coils, each coil has1000 turns of copper wire of diameter 0.1mm are considered. The coils are connected differentially, with various separations, and move along the infinitely long tube, with and without a supporting ferromagnetic plate. An impressed AC current energises coils. Frequency of the impressed current f = 1, 10, 100 and 200 kHz. Flux distributions in the models are presented. The results show that the flux distribution is affected by the presence of the crack, as expected. The respective positions of the probe are discussed.

Numerical Simulation Results for the Eddy Current Benchmark Problem

---Z. Zhang, Y. Li, Y. Sun, L. Udpa and S. S. Udpa, Iowa State University, Department of Electrical and Computer Engineering, Ames, IA 50011

---This paper presents results obtained by simulating the eddy current benchmark problem proposed by the World Federation of Nondestructive Evaluation Centers. The geometry consists of two identical coils connected in a differential mode, which moves along an infinitely long tube anchored by a carbon steel support plate. A defect is located in the tube wall in the middle of the support plate region. Coils are energized with an AC source at four different frequencies. An edge-based finite element forward model is employed to simulate the eddy current phenomenon and predict the eddy current probe response. The eddy current problem formulation is based on the vector magnetic potential $\underline{A}$. A gauge condition based on tree and co-tree separation is introduced to fix the arbitrariness associated with $\underline{A}$. The complex impedance $?Z$ is calculated after the vector magnetic potential is determined along each edge. Results obtained using the simulation model will be presented.

Comparison of Different Measurement Configurations for Non-destructive Testing of Well-conducting Materials

---Ryszard Sikora, Technical University of Szczecin, Al. Piasow 19, 70-310 Szczecin, Poland; Ryszard Palka, Institut f. elektr. Maschinen, Hans-Sommer-Str. 66, 38106 Braunschweig, Germany

---One of the most important properties of each measurement configuration for non-destructive testing is it's sensitivity. This paper proposes a fundamental configuration for finding cracks in well-conducting materials consisting of two identical coils connected differentially which move along the infinitely long tube. The coils are energized by an impressed high frequency AC current. The changes of the impedance of these coils depend on the position of the cracks in the tube. Optimization of all properties of this system (dimensions of the coils and their relative positions) in order to increase its sensitivity has been done by numerical calculations using finite element method. The application of this method requires a very fine finite (tuned) element grid, because of extremely small skin depth of electromagnetic field at high frequencies for well-conducting regions. Additionally some boundary transitions for electromagnetic field have to be defined. Numerical calculations have been done for four modifications of the main system by defining different properties of surrounding areas. Based on these results some requests are formulated for the developer of NDT-sensors.

Simulation of Ultrasonic Signals from Spherical and Planar Reflectors

---Sandeep K. Dewangan, P. Kalyanasundaram, and Baldev Raj, Indira Gandhi Centre for Atomic Research, Kalpakkam (Tamil Nadu) 603 102, India

---This paper describes the ultrasonic model based approach currently being developed at the author's laboratory, for simulation of the A- scan signals from flaws of various geometry in immersion ultrasonic mode of testing. In this study, preliminary approximation of ultrasound generation, propagation and interaction with flaws in the medium will be done by using ray-tracing model assuming the simulated waveform as given in the benchmark problem and detailed study will be carried out with beam model. In the ray-tracing model, the sound pressure is expressed as the density of the ray elements, and the reflection from defect surface is drawn by Snell's law. The beam model will be used for simulating the ultrasound fields from focused or unfocussed transducers through interfaces and different media in three-dimensions. The beam model will incorporate the effects of various phenomena such as transmission/ reflection and mode conversion at the interfaces, attenuation during propagation, transducer characteristics, geometry of the specimen and the embedded flaw. The analysis is three-dimensional and the model will be used for (i) predicting ultrasound propagation in the given specimen for a flaw geometry by ray tracing approach and (ii) prediction of the ultrasonic A- scan signal from the above flaw. Simulation program using these modeling approaches is being written in Visual Basic. This will be an interactive Windows based package with facilities for simulation of ultrasonic A- scans for a given set of material (acoustic properties) and geometric conditions (dimensions of the specimen, dimensions and orientation of the defect) and transducer characteristics (i.e. transducer dimensions, frequency bandwidth etc.). This model will be applied for the benchmark problem and the predicted A-scan signals for all cases would be described in the paper.

Ultrasonic Modeling of Benchmark Problems

---Lester W. Schmerr, Jr., Center for NDE and Department of Aerospace Engineering and Engineering Mechanics, Iowa State University, Ames, IA 50011; Alexander Sedov, Department of Mechanical Engineering, Lakehead University, Thunder Bay, Ontario, Canada P7B 5E1

---This work is part of an effort to compare the ultrasonic models used in various organizations around the world on a simple set of benchmark problems that can demonstrate the consistency (or lack thereof) in current modeling approaches and to test a variety of modeling approximations. Our part in this effort will center around the assumption that the scattering amplitude of a small flaw can be considered to be "slowly varying" about a particular scattering direction , an assumption used in many of the modeling efforts that have been described to date in the literature. We will model a number of the benchmark problems using both a standard paraxial modeling approach and a more general "near-field" model as described in Chapter 13 of *Fundamentals of Ultrasonic Nondestructive Evaluation* by L.W. Schmerr Jr., Plenum Press, 1998.---This work was supported by the NSF Industry/University Cooperative Research program.

Prediction of Flaw Signals of the Ultrasonic Round Robin Problems by Sungkyunkwan University

---Sung-Jin Song, Hak-Joon Kim, and Chang-Hwan Kim, School of Mechanical Engineering, Sungkyunkwan University, 300 Chunchun-dong, Jangan-ku, Suwon, Kyungggi-do, 440-746, Korea

---This paper will describe the approaches and the results of Sungkyunkwan University (SKKU) to solve the ultrasonic round robin problems proposed by World Federation of NDE Centers (WFNDEC). The approaches of SKKU involve four steps including 1) modeling of the front surface response, 2) calculation of the system efficiency factors using the front surface response models, 3) modeling of the flaw responses in the frequency domain, and 4) prediction of the time-domain flaw signals by the Fourier synthesis. The models for the prediction of flaw responses are currently under investigation are based on the multi-Gaussian model and Rayleigh-Sommerfeld integral with high frequency approximation. The results to be presented are the time-domain flaw signals predicted by the models.

Simulating a Standard Type Problem of Ultrasonic Testing – A Contribution to the Comparison of Ultrasonic Models

---M. Spies, W. Müller, and W. Arnold, Fraunhofer-Institute for Nondestructive Testing (IZFP), University of Saarland, Bldg. 37, 66123 Saarbrüken, Germany

---Models play a key role in all engineering disciplines by allowing simulation of experimental results without time and cost of constructing specimens and performing measurements. However, before such models can be used with confidence, it is necessary that they be validated. Ultimately, this must be done by comparison of model-based simulations to benchmark experiments. As a first step within this process, a simple problem is addressed that will allow a preliminary comparison of the various models available. Using a point source superposition method, the signal from spherical and crack-like reflectors observed in a pulse-echo measurement are predicted. Normally incident longitudinal waves, generated by circular focused and unfocused transducers, respectively, of 5 MHz center frequency are assumed in an immersion geometry. Two sets of scattering objects are considered: spherical pores of diameters ranging from 0.125 mm to 4 mm centered at a distance of 25.4 mm into an aluminum block, and circular cracks of the same diameters and depth. As a reference waveform for the incident signal a raised-cosine time function is considered. 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. Reference measurements performed at a similar configuration will be also presented.

Solution of an Ultrasonic Benchmark Problem within the Paraxial Approximation

---T. A. Gray and R. Bruce Thompson, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---The current form of a measurement model developed at the Center for NDE over a number of years will be described, followed by the presentation of numerical predictions for two benchmark problems. The modular form of the model will first be reviewed. Included will be algorithms that treat the radiation from the transducer into water, the modification of that radiation pattern by passage through a liquid-solid interface, the scattering from a flaw, and the prediction of ultrasonic signal strengths that would be observed in the laboratory in terms of the outputs of these modules. The role of the paraxial approximation in increasing speed of these computations under appropriate conditions will then be discussed. Finally, numerical results will be presented, in a form suitable for comparison with predictions of other theories, for a benchmark problem involving the scattering from spherical and crack-like reflectors in a solid medium. Both planar and focused probe illumination will be considered.

Wednesday, August 1, 2001

SPECIAL EVENING SESSION

Smith Auditorium (Sills)

8:00 PM **Visions of Future Directions of NDE Research**

---A special discussion session will be held to anticipate the NDE needs of the coming decades. The strategy will be for a few, thought-provoking visions of the future to be presented by representatives of industry and government, followed by a general audience discussion. Speakers will make 10 to 15 minutes presentations addressing their visions of future technical directions of their organizations and the implications of those directions in terms of the needs for nondestructive measurement tools. Issues such as the quantities that need to be measured, the time in the life cycle at which sensing needs to occur, how the information obtained should be processed, and the work force training that is needed to support these solutions are examples of topics that might be addressed. Needs that require revolutionary as well as evolutionary advances will be considered. The talk will be followed by a general audience discussion, with the speakers serving as a panel.

It is hoped that this session will provide an excellent opportunity to inform the NDE technical community of the next generation of challenges and start the thought processes that will lead to the ultimate solutions.

SESSION 24
COMPOSITES NDE
M. Hinders, Chairperson
Druckenmiller 016

8:30 AM **The Reassigned Short Time Fourier Transform (STFT) for Damage Detection in Composites**
---S. I. de Smirnoff and C. Valle, University of Maine, Department of Mechanical Engineering, Orono, ME 04469-5711

8:50 AM **Evaluation of Dynamic Properties of Composites in an Oxidizing Environment**
---M. L. Peterson, University of Maine, Mechanical Engineering, 5711 Boardman Hall, Orono, ME 04469-5711

9:10 AM **Fiber Orientation Study Using Ultrasonic C-Scan of Ply Interfaces**
---D. Fei, Z. Liu, and D. K. Hsu, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

9:30 AM **Propagation of Lamb Waves in Anisotropic and Absorbing Plates: Theoretical Derivation and Experiments**
---G. Neau[1,2], M. Deschamps[1], and M. J. S. Lowe[2], [1]Laboratoire de Mécanique Physique, Université Bordeaux 1, UMR CNRS 5469, 351, Cours de la Libération, 33405 Talence Cedex, France, [2]Department of Mechanical Engineering, Imperial College of Science, Technology and Medicine, Exhibition Road, London SW7 2BX, United Kingdom

9:50 AM **Ultrasonic Resonance Spectroscopy of Composite Rims for Flywheel Rotors**
---L. M. Harmon, Cleveland State University, Civil Engineering, Cleveland, OH 44135; G. Y. Baaklini, Nondestructive Evaluation Group, NASA Glenn Research Center, Cleveland, OH 44135

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

10:30 AM **Dry Electrochemical Impedance Spectroscopy for NDE of Bonded Composites**
---M. J. Roberts, Nondestructive Evaluation Sciences Laboratory, Mail Stop 231, NASA Langley Research Center, 3 East Taylor Road, Hampton, VA 23681-0001

10:50 AM **Time Resolved Infrared Radiometry for the Inspection of Composite Retrofits**
---V. K. Kinra and K. Maslov, Texas A&M University, Department of Aerospace Engineering, College Station, TX 77843-3141

11:10 AM **AC and DC Conductivity Based Microstructural Characterization of Composites (Ceramics)**
---D. S. McLachlan, K. Cai, and G. Sauti, University of Witwatersrand, Physics Department, PO Wits 2050, Johannesburg, South Africa

11:30 AM **Microscopic Thermal Characterization of C/C and C/C-SiC Composites by Photoreflectance Microscopy**
---J. Jumel, F. Lepoutre, and J.-C. Krapez, DMSE/MEC, ONERA, Chatillon, 29 avenue de la division leclerc, BP 72, 92322 Chatillon Cedex, France; F. Enguehard, CEA, Monts, France; J.-P. Roger, UPRA0005, CNRS, Paris, France; M. Cataldi, SEP, SNECMA, Saint Medard en Jalles, France; G. Neuer, IKE, Stuttgard, Germany

11:50 AM **Line Focus Acoustic Microscopy of Multilayered Anisotropic Crystalline Structure Inclined to Sample Structure: Determination of Elastic Constants of Ti-6242 ? /? -Single Colony**
---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

12:10 PM ***Lunch***

The Reassigned Short Time Fourier Transform (STFT) for Damage Detection in Composites

---Severine Imbert de Smirnoff and Christine Valle, Department of Mechanical Engineering, University of Maine, Orono, ME 04469-5711

---Lightweight, high temperature composite materials have the potential to provide significant economic and performance benefits to aerospace structures. However, one problem inherent in using composites within complex structures in harsh environments is the variety of damage mechanisms experienced by the composite itself. Therefore, conventional NDE techniques that are sensitive to only one kind of damage, can give an overly optimistic assessment of the health of the composite. A global measure that takes into consideration all of the different damage mechanisms better addresses the nondestructive evaluation needs of composites used in critical applications. This study investigates the relationship between the composite's dispersion relationships, obtained 1) analytically by the classic partial wave technique, and 2) numerically with the reassigned STFT representation of transient ultrasonic signals, for various types of composite damage (delaminations and notches). The reassigned STFT was recently proven to be capable of localizing flaws in metals. Therefore, the present study is a logical extension of the technique to transversely isotropic composites.

Evaluation of Dynamic Properties of Composites in an Oxidizing Environment

---M. L. Peterson, University of Maine, Mechanical Engineering, 5711 Boardman Hall, Orono, ME 04469-5711

---A key element to exploiting the performance advantages of advanced composites is the use of design strategies that fully utilize the material anisotropy. This type of optimal design is particularly challenging when the material properties change significantly with time. The elastic properties and the strength change during environmental degradation have been considered by a number of investigators. In addition, material damping changes have been used to indicate changes in the matrix properties. For some applications, changes in the damping can also directly affect the performance of the materials. The current work extends previous work with elastomeric and thick composites to commercially produced carbon-carbon composites. Methods to evaluate the in-situ performance of these materials in an oxidizing environment are considered as well as the effects of oxidation on the matrix and overall properties. Degradation of the matrix is shown to impact the dynamic performance of the materials as well as alter the mechanisms of failure. The use of ultrasonic testing in high temperature and hostile environments is demonstrated with an emphasis on comparison to more standard materials characterization methods.

Fiber Orientation Study Using Ultrasonic C-Scan of Ply Interfaces

---Dong Fei, Zhanjie Liu, and David K. Hsu, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---When longitudinal ultrasonic waves impinge on a composite laminate at normal incidence, the reflected signals are not expected to be sensitive to the fiber directions in the laminate. However, it was discovered recently that, due to the inhomogeneities always present in composites, ultrasonic C-scan images actually contain considerable information about the fiber orientation of the plies. In this work we report two significant findings: (1) C-scans of the ply interfaces in carbon epoxy laminates can reveal fiber directions even at frequencies where no periodic interfacial echoes are discernable, and (2) Two-dimensional spatial Fourier transform of ultrasonic C-scan images can determine the fiber directions with much greater precision than directly from the images. These techniques were used for checking the fiber directions in an unknown layup and for detecting mis-oriented plies in a laminate. The sensitivity of this method was quite good: a single 90-degree ply in a 25-ply composite laminate was detected. The approach is also applicable in both prepreg tape-based composites and fiber placement tow-based composites. The simplicity of the method lends it the potential for being a useful technique in the NDE of composite laminates.---This work was supported by the NSF Industry/University Cooperative Research Center for NDE at Iowa State University.

Propagation of Lamb Waves in Anisotropic and Absorbing Plates: Theoretical Derivation and Experiments

---G. Neau[1,2], M. Deschamps[1], and M. J. S. Lowe[2], [1]Laboratoire de Mécanique Physique, Université Bordeaux 1, UMR CNRS 5469, 351, Cours de la Libération, 33405 Talence Cedex, France, [2]Department of Mechanical Engineering, Imperial College of Science, Technology and Medicine, Exhibition Road, London SW7 2BX, United Kingdom

---The aim of this work is to gain a better understanding of propagation of Lamb waves in anisotropic and absorbing plates. A study of energy-related velocities and attenuation of Lamb waves in such media is presented here. In the first part, propagation in non-principal directions has been studied for the non-absorbing case, taking into account the spatial dispersion (variation of the velocity with the direction of propagation) as well as the frequency dispersion. Results of the predictions and of experiments on a unidirectional Glass Epoxy plate show that these two types of dispersion affect both the speed and the direction of the Lamb modes. In the second part of this work, the absorbing case is studied. Solutions of the Lamb system are now expressed in complex slowness, where the real part stands for the propagation term and the imaginary part for the attenuation divided by the pulsation. In order to measure attenuation of guided modes, an experimental set-up has been developed using a laser sensor. Modeling and experimental results are presented for a [0/90] cross-ply Carbon Epoxy plate.

Ultrasonic Resonance Spectroscopy of Composite Rims for Flywheel Rotors

---Laura M. Harmon, Civil Engineering, Cleveland State University, Cleveland, OH 44135; George Y. Baaklini, Nondestructive Evaluation Group, NASA Glenn Research Center, Cleveland, OH 44135

---Flywheel energy storage devices comprising multilayered composite rotor systems are being studied extensively for utilization in the International Space Station (ISS). These composite material systems were investigated with a recently developed ultrasonic resonance spectroscopy (URS) technique. The ultrasonic system employs a continuous swept sine waveform and performs a fast Fourier transform (FFT) on the frequency response spectrum. In addition, the system is capable of equalizing the amount of energy at each frequency. Equalization of the frequency spectrum, along with interpretation of the second FFT ensures evaluation of the fundamental frequency. The frequency responses from multilayered material samples, with and without known defects, were analyzed to assess the capabilities and limitations of this nondestructive evaluation (NDE) technique for material characterization and defect detection. Amplitude and frequency changes were studied from ultrasonic responses of thick composite rings and a multi-ring composite rim. A composite ring varying in thickness was evaluated to investigate the full thickness resonance. Ultrasonic responses, from regions with and without machined voids in a composite ring, were compared. Then, the frequency response characteristics from naturally occurring voids in a composite ring were investigated. Finally, ultrasonic responses from the multi-ring composite rim were compared before and after proof spin testing to 63,000 rpm.

Dry Electrochemical Impedance Spectroscopy for NDE of Bonded Composites

---Mark J. Roberts, Nondestructive Evaluation Sciences Laboratory, Mail Stop 231, NASA Langley Research Center, 3 East Taylor Road, Hampton, VA 23681-0001

---Aircraft and ground vehicle structures used by NASA and the U.S. Army utilize composite materials containing adhesive joints. This paper discusses electrochemical impedance spectroscopy as an alternative NDE approach to analyze bonds in joined composites for moisture contamination and corrosion levels by measuring small signal ac electrical impedance. A brief literature review, which relates electrical circuit equivalent models to the various stages of corrosion progression, is given. Electrical circuit models representing simply bonded metals, graphite epoxy and honeycomb composites are investigated. Complex impedance of circuit models obtained as a function of frequency can correlate how different layers of a bonded structure contribute to impedance as moisture and corrosion occur. Simulations are shown for metals, graphite epoxy and honeycomb composites as electrical circuit parameters change as a function of bond moisture content and corrosion state. Traditionally, electrical impedance spectroscopy approaches require submerging the test material in an electrolytic solution. Dry measurements are required to test composite samples since they cannot be placed in an electrolytic solution. A possible electrical impedance instrumentation set up is proposed which may address this problem.

Time Resolved Infrared Radiometry for the Inspection of Composite Retrofits

---Vikram K. Kinra and Konstantin Maslov, Department of Aerospace Engineering, Texas A&M University, College Station, TX 77843-3141

---Composite materials are used to protect concrete from adverse environment, to rehabilitate older concrete structures and for seismic retrofits. They are applied to concrete in field conditions hence subjected to debonds at the composite-concrete interface. A scanning infrared camera which measures temperature change at the outer surface, in conjunction with radiation heaters, was used to image delaminations at the composite/concrete interface. An elementary theoretical model that accounts for the radiation absorption as well as convection air cooling at the surface was constructed. The temperature-time response was used to correct the image for surface emissivity and heater intensity variations. Transient analysis of surface temperature response to heating and cooling allows one to differentiate between delaminations and variations in composite thickness and thermal conductivity. Data obtained from thermographic tests on a variety of adhesively-bonded fiberglass/resin retrofit systems applied to steel-reinforced concrete columns were compared with the results of (destructive) inspection after the composite had been removed from the concrete. We will demonstrate that the thermographic method can successfully detect delaminations in most of the retrofit systems tested, with the exception of a few cases where the composite was extremely inhomogeneous and porous.

AC and DC Conductivity Based Microstructural Characterization of Composites (Ceramics)

---David S. McLachlan, Kefeng Cai, and G. Sauti, Physics Department, University of Witwatersrand, PO Wits 2050, Johannesburg, South Africa

---The microstructures, upon which the widely used Maxwell Wagner and the Bruggeman Symmetric and Anti-symmetric Effective Media theories apply are based, are presented and the limitations of these methods discussed. The results of AC conductivity experiments, or Impedance Spectroscopy, at temperatures between 150 and 4000C, on 8% Yttrium Stabilized Zirconium (YSZ) discs, with different grain sizes and deliberately introduced impurities are analyzed using the Maxwell Wagner theory. Known values for the dielectric constant and conductivities of the crystalline phase and realistic values for the volume fraction of the grain boundaries, are used as starting or fixed parameters. The microstructures characterizing percolation systems are then discussed and a new two exponent phenomenological model for continuum binary composites, which uses percolation concepts and parameters, is introduced. The results for YSZ and the DC and AC conductivity results for a series of TiC – Al2O3 percolation composites are analyzed using this phenomenological equation.

Microscopic Thermal Characterization of C/C and C/C-SiC Composites by Photoreflectance Microscopy

---J. Jumel, F. Lepoutre, and J.-C. Krapez, DMSE/MEC, ONERA, Chatillon, 29 avenue de la division leclerc, BP 72, 92322 Chatillon Cedex, France; F. Enguehard, CEA, Monts, France; J.-P. Roger, UPRA0005, CNRS, Paris, France; M. Cataldi, SEP, SNECMA, Saint Medard en Jalles, France; G. Neuer, IKE, Stuttgard, Germany

---C/C and C/C-SiC composites have a complex microstructure at a very local scale. The microscopic thermo-elastic properties of their components (matrix and fibres) are often not well known because classical characterization methods are unusable at this scale. To use a multi-scale approach it is essential to determine precisely these microscopic physical properties in order to supply the code with realistic material parameters. Since several years, multi-scale characterization methods are developing rapidly. Among them the modulated photothermal methods have demonstrated their ability to measure the thermal properties of complex materials at scales ranging from micrometers to millimetres. The photoreflectance microscopy, for instance, has a spatial resolution large enough to characterize a 8 micrometers carbon fibre. After a presentation of the principle of photoreflectance microscopy, we detail the various thermal parameters extraction scheme used to interpret the phothermal measurement perform, either on the different phases of the matrix of a C/C-SiC composite, on different kinds of carbon fibres, on different varieties of pyrocarbon matrix. The results are correlated to the morphology of the material and enable to quantify the effect of the process parameters on the microscopic thermal properties. This study demonstrates that photoreflectance microscopy is a powerfull tool to measure quantitatively the microscopic thermal properties of complex materials such as C/C and C/C-SiC composites constituents.

Line Focus Acoustic Microscopy of Multilayered Anisotropic Crystalline Structure Inclined to Sample Structure: Determination of Elastic Constants of Ti-6242 ?/? -Single Colony

---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

---Propagation of surface acoustic waves on a semispace formed by arbitrary anisotropic layers inclined to the surface is studied. Effective elastic constants of the multilayered structure are derived, based on which the surface wave velocity in non-principal planes is calculated. The model is applied to determination of elastic constants of Ti-6242 ?/?-single colony having a quasi-random lamellar microstructure. The colony is formed by 10 ?m thick cubic ? phase layers oriented in an off-symmetry direction in a hexagonal ?-crystal matrix. The colony is approximated as a layered quasi-periodic anisotropic structure with both ?- and ?-crystal layers oriented arbitrary and inclined to the sample surface. Time-resolved line-focus acoustic microscopy with 50 MHz ultrasonic transducer is performed for the Ti-6242 ?/?-single colony and ?-single crystal samples. Surface wave velocities are obtained as a function of a propagation angle using leaky surface wave time-delay measurements. Effective and constituent elastic constants of the ?/?-single colony and the ?-single crystal are inversely determined from the measured and calculated overall surface wave velocities. Determined ?-elastic constants from the ?/?-single colony are compared with those of the ?-single crystal. Possible effect of residual stresses on the surface wave velocity is discussed.---Authors acknowledge Prof. M. Mills and J. Williams for interaction and providing Ti-6242 ?/?-single colony sample. This work was sponsored by the Federal Aviation Administration (FAA) under Contract #97-C-001 as a part of the project “Evaluation and Microstructure-Based Modeling of Cold Dwell Fatigue in Ti-6242” through the Airworthiness Assurance Center of Excellence.

Thursday, August 2, 2001

SESSION 25
NDE FOR CORROSION
T. Moran, Chairperson
Cleaveland 151 (Druckenmiller)

8:30 AM **Setting NDI Requirements for Comprehensive Damage Management**
---D. Peeler, AFRL/ML, 2179 12th Street, Room 122, WPAFB, OH 45433-7718

9:10 AM **Evaluation of Hidden Corrosion Detection Technologies**
---W. C. Hoppe, J. L. Pierce, and N. D. Schehl, University of Dayton Research Institute, Structural Integrity Division, 300 College Park Avenue, Dayton, OH 45469-0120

9:30 AM **Simulation of Eddy Current Interaction with Hidden Corrosion**
---J. R. Bowler, N. Nakagawa, C.-P. Chiou, and V. Katyal, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

9:50 AM **Scanning with Magnetoresistive Sensors for Subsurface Corrosion**
---R. D. Rempt, Boeing Phantom Work, Mechanical Physics, Mail Code 8H-05, P. O. Box 3999, Seattle, WA 98124-2499

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

10:30 AM **Corrosion Structured Experiment**
---M. Ashbaugh and M. Bode, Airworthiness Assurance Department, Sandia National Laboratories, 3260 University Boulevard, SE, Albuquerque, NM 87106

10:50 AM **Development and Verification of NDI for Corrosion Detection and Quantification in Airframe Structures**
---D. S. Forsyth and B. A. Lepine, Institute for Aerospace Research, Building M14, 1200 Montreal Road, Ottawa, Ontario, Canada K1A 0R6

11:10 AM **Field Application of Corrosion Detection Using Automated Ultrasonic and Eddy Current Methods**
---M. J. Concordia[1], M. Scaturo[2], and M. Golis[3], [1]SAIC – Ultra Image International, 2 Shaw's Cove, Suite 101, New London, CT 06320; [2]MRC Associates, 31 Alviso Drive, Camarillo, CA 93010; [3]Advanced Quality Concepts, P. O. Box 141388, Columbus, OH 43214

11:30 AM **Early Detection of Corrosion at Aircraft Structures**
---N. Meyendorf, R. G. Buchheit[1], J. P. Hoffmann, M. Khobaib, S. Sathish, and E. B. Shell, University of Dayton, Center for Materials Diagnostics, 300 College Park, Dayton, OH 45469-0121; [1]The Ohio State University, Department of Materials Science & Engineering, Columbus, OH 43210

11:50 AM **Eddy-Current Response Due to Small-Area Corrosion: A Comparison of Measurements with Theoretical Predictions**
---J. R. Bowler and M. J. Johnson, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

12:10 PM ***Lunch***

Setting NDI Requirements for Comprehensive Damage Management

---Deborah Peeler, AFRL/ML, 2179 12th Street, Room 122, WPAFB, OH 45433-7718

---For over 30 years the USAF has successfully managed the structural integrity of its aircraft using fracture mechanics techniques. With the end of the Cold War, the realities of the operational environment began to shift. Aircraft flying hours/year decreased significantly, and modernization/replacement budgets were reduced right along with them. As a result of no replacement, the calendar life of the aircraft was greatly extended, because it has not yet approached its fatigue life limit. Thus, while designed and managed to a cyclic life limit, current operational reality for USAF aircraft now invites the accrual of corrosion damage in amounts of structural significance due to exposure to the environment. Damage initiated as intergranular corrosion, progressing under cyclic load, resulted in a fatigue life reduction of a C-5 aircraft primary structure of more than an order of magnitude, while Stress Corrosion Cracking (SCC) has resulted in the unplanned change out of major components on entire fleets. These instances, and others, have forced the USAF to review both the status of its fleet and the comprehensiveness of its damage management philosophy. Critical to the strategy for managing the fleet is the ability to assess its damage state; both as a point in time health assessment and as a basis for predicting future damage accrual in the operational environment. The USAF has begun a process that will, by structural component, define the critical damage flaw that will need to be identified by NDI in order to effect comprehensive damage management in these aging systems. This paper will review the critical role that focused NDI development will play in AF Damage Management as clear NDI requirements are established for structural component inspection. Emerging requirements will be briefed.

Evaluation of Hidden Corrosion Detection Technologies

---Wayy C. Hoppe, Jennifer L. Pierce, and Norman D. Schehl, Structural Integrity Division, University of Dayton Research Institute, 300 College Park Avenue, Dayton, OH 45469-0120

---An evaluation method has been developed to assess the detection capability of hidden corrosion inspection systems in terms of probability of detection (POD) and other performance characteristics. Extrapolating from crack detection methodologies, the corrosion detection assessment approach makes use of the spatial resolution of each inspection system to define non-overlapping inspection cells that represent independent inspection opportunities. Inspection results are compared to actual corrosion levels as measured by thickness loss, the chosen metric, within each cell to enable POD analysis methods established in the past for crack detection capability assessment. Ten inspection systems were assessed according to this approach in a comprehensive evaluation as part of the Automated Corrosion Detection Program. The evaluation method will be reviewed including the techniques employed to perform specimen characterization and data analysis. Results of the evaluation will be discussed and summarized. Lessons learned concerning the evaluation method employed will also be shared.---This program was performed under the Automated Corrosion Detection Program, a Warner Robins Design Engineering Program (USAF Contract F009603-95-D-0175). Technical Program management provided by the Nondestructive Evaluation Branch of the Air Force Research Laboratory (AFRL/MLLP).

Simulation of Eddy Current Interaction with Hidden Corrosion

---J. R. Bowler, N. Nakagawa, C.-P. Chiou, and Vipul Katyal, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---A computer simulation has been developed for evaluating the effects of hidden corrosion on eddy currents. Of special interest is the sensitivity of semiconductor array probes to roughness on the faying surface. The theoretical and computational model has been developed based on a volume integral formulation whose discrete numerical approximation is a matrix equation for the electric field in the flaw. In earlier studies with this type of model, computed predictions of probe impedance were shown to agree with experiment to an accuracy of within a few percent. Here semiconductor sensors signals due to corrosion are computed and the new results validated by comparison with experimental measurements on artificial flaws. We report on the validation of the calculations and assess the sensitivity of semiconductor array probes to roughness on hidden surfaces.
---This work was supported by a subcontract with Universal Technology Corporation under Prime Agreement F33615-97-D-5271 from the Air Force Research Laboratory.

Scanning with Magnetoresistive Sensors for Subsurface Corrosion

---Raymond D. Rempt, Boeing Phantom Work, Mechanical Physics, Mail Code 8H-05, P. O. Box 3999, Seattle, WA 98124-2499

---The new high performance magnetoresistive (MR) sensors constitute a useful and valuable means of performing eddy current NDI of aircraft structure. They are more sensitive than coil configurations for an equivalent amount of excitation current at the surface of the sample. They are also less severely dependent on low frequency, permitting penetration to greater depths. During recent years Boeing has have developed scanning techniques using these sensors to image the subsurface condition of metallic aircraft structure. More recently, the Air Force Research Labs have partnered with Boeing in furthering this work. I present a number of scans from eddy current inspections using the MR sensors. Some of the scans presented are taken with a single sensor, while others with an array of the sensors. I present and discuss scans of corrosion standards used to calibrate sensors used in the field as well as samples excised from airplanes. I also present some discussion of which applications lend themselves best for the exploitation of the considerable sensitivity available in detection schemes employing these devices.

Corrosion Structured Experiment

---Mike Ashbaugh and Mike Bode, Airworthiness Assurance Department, Sandia National Laboratories, 3260 University Blvd., SE, Albuquerque, NM 87106

---The FAA and the aviation industry recognize that the National Aging Aircraft Research Program (NAARP) has produced a number of potentially beneficial NDI techniques. These new techniques require evaluation and quantitative comparison to expedite their integration into aircraft inspection programs. Following the detection of corrosion on aircraft skins, NDT is often employed to characterize skin material thickness. In this mode, NDT is used to determine if a condition exists which requires repair actions. The focus of this experiment is restricted to lap splice inspection for corrosion of transport category aircraft during heavy maintenance checks. Ten percent material loss is a common large transport aircraft industry level that makes a structural repair or replacement necessary. For this reason a fundamental question of any NDT technique to be applied for the detection of faying surface corrosion is whether it is capable of reliably detecting corrosion that results in 10 percent parent material loss. The structured experiment approach discussed in this presentation is designed not only to answer the question concerning the reliability of detecting faying surface corrosion in lap splice structures, but also to provide quantification of the material loss that can reliably be achieved including levels of less than 10%.

Development and Verification of NDI for Corrosion Detection and Quantification in Airframe Structures

---David S. Forsyth and Brian A. Lepine, Institute for Aerospace Research, Building M14, 1200 Montreal Road, Ottawa, Ontario, Canada K1A 0R6

---The development of nondestructive inspection (NDI) for the quantification of corrosion damage in airframes has in general been aimed at measuring “thickness loss”. This metric is necessary but not sufficient for complete structural integrity assessments of the lap splice joint, a common element in the construction of transport aircraft. Current programs sponsored by the United States Air Force and others are developing a damage tolerance framework which includes the effects of corrosion damage. Models being developed for these programs are generating additional requirements for NDI, and more clearly defining metrics beyond general thickness loss. In this paper, we describe metrics required for structural integrity assessments of lap joints, and how NDI can be developed and verified in terms of these metrics. Special attention is paid to practical issues of inspection; such as paint condition, protruding fasteners, pillowing deformation, and interlayer gap. If these issues are not considered at the appropriate time in the development of new NDI technology, they may invalidate the results of expensive development programs.

Field Application of Corrosion Detection Using Automated Ultrasonic and Eddy Current Methods

---M. J. Concordia[1], M. Scaturo[2], and M. Golis[3], [1]SAIC – Ultra Image International, 2 Shaw's Cove, Suite 101, New London, CT 06320; [2]MRC Associates, 31 Alviso Drive, Camarillo, CA 93010; [3]Advanced Quality Concepts, P. O. Box 141388, Columbus, OH 43214

---In the wake of the Aloha Airlines Boeing 737 incident of 1988 and the ever-increasing average age of the Airforce and Navy aircraft fleets (some over 40 years), much time and effort has been focused on the challenges to maintain and service aging aircraft. The paramount concerns of safety and effective fleet management demand the ability to locate, quantify and repair hidden corrosion and fatigue in a timely manner. Doing so with a high degree of confidence is critical. Automated inspection techniques that are combined with carefully planned Probability of Detection (POD) studies represent the optimal approach to achieve this goal for most aircraft inspections. The NDI techniques employed need not be revolutionary, however, the field application of them must be leading edge: basic ultrasonic and eddy current techniques have been automated and employed to measure general thinning, exfoliation and pitting corrosion in aluminum structures and joints located on aircraft in 'real world' settings. Examples of such applications and the equipment enabling the successful execution of the inspection will be discussed along with validation processes and the POD philosophy. The authors acknowledge funding provided by the Airforce, Navy and Lockheed Martin through the Corrosion Fatigue Structural Demonstration (CSFD) program.

Early Detection of Corrosion at Aircraft Structures

---Norbert Meyendorf, Rudolph G. Buchheit[1], Jochen P. Hoffmann, Mohammad Khobaib, S. Sathish, and Eric B. Shell, Center for Materials Diagnostics, University of Dayton, 300 College Park, Dayton, OH 45469-0121; [1]Department of Materials Science & Engineering, The Ohio State University, Columbus, OH

---Corrosion is one of the limiting factors for extended use of aircraft. Early detection of corrosion using nondestructive techniques is an important task for progress in understanding corrosion process, as well as maintenance of aircraft. The paper summarizes newer results on nondestructive characterization of corrosion using ultrasonic and thermal techniques and presents concept for prediction of remaining lifetime of corroded parts. Studying aluminum airframe structures under corrosion protective coatings, we employed Scanning Acoustic Microscopy (SAM) and Fan Thermography. SAM revealed potential to determine the curing quality of the coatings. It was also possible to detect small corrosion pits under delaminated areas. Fan Thermography (hot air heating) made it possible, to observe sites of poor adhesion. For quantification of corrosion defects, such as corrosion pits or cracks and for detecting of corrosion activities benchmark techniques like white light interferometry and scanning vibrating electrode technique are used. Correlation of ultrasonic and profilometric data with residual fatigue life will be performed using neural network analysis.

Eddy-Current Response Due to Small-Area Corrosion: A Comparison of Measurements with Theoretical Predictions

---J. R. Bowler and M. J. Johnson, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---A pulsed eddy-current system has recently been developed for the detection of cracks and corrosion in aircraft. The system features a current-driven probe that excites transient eddy currents in the workpiece. Flaws are detected by measuring the magnetic field between the coil and the surface of the metal sample using a Hall sensor. Transient field measurements using a Hall device have been made to determine the pulse signals due to simulated hidden corrosion in aluminum plates. These measurements have been compared with the predictions of a new theoretical and computation model based on a time domain volume integral formulation. The model describes the electromagnetic field migration starting at the surface of the metal at the time when a pulse excitation of the coil is initiated. The interaction of the field with a subsurface region of corrosion is represented by a time varying polarization of the flaw region. The evolution of the flaw polarization determines the flaw signal at the Hall sensor. Evaluation of this signal allows comparisons of model predictions and observations. Agreement between theory and experiment ensures that the measuring system is behaving as planned and that the model yields valid results.---This material is based upon work supported by the Federal Aviation Administration under Contract #DTFA03-98-D-00008, Delivery Order #IA026 and performed at Iowa State University's Center for NDE as part of the Center for Aviation Systems Reliability program.

Thursday, August 2, 2001

SESSION 26

LASER ULTRASONICS

H. Ringermacher, Chairperson
Smith Auditorium (Sills)

8:30 AM **Laser Generated Rayleigh and Lamb Waves**
---C. Edwards, T. Stratoudaki, S. Dixon, and S. B. Palmer, University of Warwick, Department of Physics, Gibbet Hill Road, Coventry, CV4 7AL, United Kingdom

8:50 AM **An Algorithm for the Determination of Coating Properties from Laser Generated and Detected Rayleigh Waves Using Wavelet Analysis. Application to Sputtered Tantalum**
---M. Doxbeck, M. A. Hussain, J. Rama, and J. Frankel, U. S. Army Armament, Munitions and Chemical Command, Army Research Development and Engineering Center, Benét Laboratories, Watervliet, NY 12189-4050; A. Abbate, Panametrics Inc., 221 Crescent St., Waltham, MA 02154

9:10 AM **Progress on the Development of an Advanced Laser Ultrasound Generation Source for Inspecting Polymer-Marix Composites**
---M. Dubois, P. W. Lorraine, and R. J. Filkins, GE Corporate Research and Development Center, P. O. Box 8, Schenectady, NY 12301; T. E. Drake, K. R. Yawn, and S.-Y. Chuang, Lockheed Martin Aeronautics Company, Ft. Worth, TX 76108

9:30 AM **Laser-Generated Ultrasonic Signals in Layered Anisotropic Plates: Simulation and Measurement**
---A. P. Cheng, T. W. Murray, A. Cheng, and J. D. Achenbach, Center for Quality Engineering and Failure Prevention, 2137 N. Sheridan Road, Evanston, IL 60208-3020

9:50 AM **Laser Based Ultrasound Using Different Wavelengths for the Inspection of Composite Materials**
---T. Stratoudaki, C. Edwards, S. Dixon, and S. B. Palmer, University of Warwick, Department of Physics, Coventry, United Kingdom

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

10:30 AM **Laser Generation of Lamb Waves**
---S.-C. Wooh, Y. Shi, and M. E. Orwat, Department of Civil and Environmental Engineering, Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, MA 02139

10:50 AM **Near Field Analysis of Laser-Generated Ultrasonic: The Effects of Thermal Diffusion and Optical Penetration**
---I. Arias, T. W. Murray, and J. D. Achenbach, Northwestern University, Center for Quality Engineering and Failure Prevention, 2137 Sheridan Road, Evanston, IL 60208-3020

11:10 AM **An Optoacoustic Transfer Function for Laser-Ultrasonics: Definition and Its Characterization for Various Lasers in the Ablation Regime**
---A. Moreau and M. Lord, Industrial Materials Institute, National Research Council of Canada, Boucherville, QC, Canada; J.-C. Kieffer and B. La Fontaine, Institut National de la Recherche Scientifique (INRS)-Énergie et Matériaux, Varenne, QC, Canada

11:30 AM **Performance Comparison of Adaptive Laser Ultrasonic Receivers Based on Polarization Self-Modulation and Two-Wave Mixing**
---M. Klein, B. Pouet, K. Peithmann, and S. Breugnot, Lasson Tech. Inc., Culver City, CA 90230; A. Kamshilin and V. Prokofiev, Univ. of Joensuu, Dept. Physics, Joensuu FIN-80101, Finland

11:50 AM **Influence of Wet Surface Condition on the Propagation Behavior of Laser-Generated Ultrasound**
---S.-C. Wooh, Q. Zhou, and J. Wang, Department of Civil and Environmental Engineering, Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, MA 02139

12:10 PM ***Lunch***

Laser Generated Rayleigh and Lamb Waves

---C. Edwards, T. Stratoudaki, S. Dixon, and S. B. Palmer, Department of Physics, University of Warwick, Gibbet Hill Road, Coventry, CV4 7AL, United Kingdom

---Laser generated Rayleigh and Lambwaves are studied in Aluminum samples. Broadband Rayleigh waves are generated using a TEMoo mode Nd:YAG laser. In the thermoelastic regime the Rayleigh wave impulse response from a laser line source is a negative going (inward displacement) delta function. It shows how aperturing the laser beam produces high thermal gradients resulting in large amplitude broadband Rayleigh waves. The symmetric and antisymmetric Lambwave modes in thin aluminium plates are also studies, and a simple model showing that there is a 50:50% energy split between these two modes is developed.

An Algorithm for the Determination of Coating Properties from Laser Generated and Detected Rayleigh Waves Using Wavelet Analysis. Application to Sputtered Tantalum

---Mark Doxbeck, M. A. Hussain, Jason Rama, and Julius Frankel, U. S. Army Armament, Munitions and Chemical Command, Army Research, Development and Engineering Center, Benét Laboratories, Watervliet, NY 12189-4050; Agostino Abbate, Panametrics Inc., 221 Crescent St., Waltham, MA 02154

---Previously we studied the quality of coatings via laser ultrasonics. As a continuation we now use the dispersion curves to determine the elastic properties and thickness of the coating, after we decide on the quality of the coating and the relative “acoustic hardness”. The effect of the coating thickness, and the elastic properties of the coating and substrate on the dispersion is well defined by theoretical models. We use the simplex method in an algorithm to obtain the elastic properties (Poisson ratio, density, and Rayleigh velocity) of the coating and substrate together with the coating thickness in the theoretical model to fit the dispersion curves calculated from the data. An automated Labview system which incorporates a Matlab program was developed in which the Rayleigh signal obtained by averaging data for a number of pulses, automatically undergoes signal processing via wavelet analysis and produces a dispersion curve. The dispersion curve is obtained by using a ridge-peak-following routine for the wavelet transforms in the frequency-time domain.

Progress on the Development of an Advanced Laser Ultrasound Generation Source for Inspecting Polymer-Matrix Composites

---Marc Dubois, Peter W. Lorraine, and Robert J. Filkins, GE Corporate Research and Development Center, P. O. Box 8, Schenectady, NY 12301; Tommy E. Drake, Kenneth R. Yawn, and Shu-Yuan Chuang, Lockheed Martin Aeronautics Company, Ft. Worth, TX 76108

---Laser ultrasound is proving to be a cost effective means for inspecting composite components. In this paper, we report the progress made towards the development of a new source for the laser-ultrasound inspection of composite parts. Previously, it was experimentally demonstrated that an optical parametric oscillator (OPO) having an output between 3 and 5 μm is significantly more efficient per energy unit to generate ultrasonic waves than a CO_2 laser. Two factors explain the better performances of the OPO: its short pulse duration and its operating wavelength range that corresponds to larger optical penetration depths than the one corresponding to the CO_2 laser wavelength. In this paper, these two factors are analyzed separately and their individual contributions to improvement in generation efficiency over the CO_2 laser are quantitatively estimated.

Laser-Generated Ultrasonic Signals in Layered Anisotropic Plates: Simulation and Measurement

---A. P. Cheng, T. W. Murray, A. Cheng, and J. D. Achenbach, Center for Quality Engineering and Failure Prevention, 2137 N. Sheridan Road, Evanston, IL 60208-3020

---The transient response of an anisotropic layered plate under pulsed laser illumination is formulated by using Fourier and Laplace integral transform techniques and the Thompson transfer matrix method. Several numerical results are presented showing the normal surface displacements for the following configurations: a Silicon half-space, a homogeneous Silicon plate, TiN coating layer on a Silicon plate, and a three layered plate of Silicon/TiN/Silicon. The characteristics of the laser-generated transient signals and their dispersion phenomena are studied. The numerical inversion procedures that transfer the displacements from the Fourier and Laplace transform domains to the time-domain are demonstrated in some detail. Numerical results have been verified experimentally for a number of cases. The preliminary results show good agreement between simulations and measurements.

Laser Based Ultrasound Using Different Wavelengths for the Inspection of Composite Materials

---Theodosia Stratoudaki, Chris Edwards, Steve Dixon, and Stuart B. Palmer, Department of Physics, University of Warwick, Coventry, United Kingdom

---Laser based ultrasound (LBU) by means of pulsed laser irradiation was used on carbon fiber reinforced composites. The ultrasound was detected with a stabilized Michelson interferometer, which measures the absolute displacement. This paper investigates damage free ultrasound generation using a range of different lasers: TEA CO2, Nd:YAG (emitting at the fundamental wavelength) and a XeCl excimer laser. The later two laser wavelengths can be fiber coupled. Nd:YAG lasers in particular are now very compact and can operate at high repetition rates. Special care was given to the beam quality of the Nd:YAG laser (TEM00). The objective of the research is to identify the most efficient lasers to use on composite materials. The laser damage thresholds of the samples are presented and compared. It is essential that no damage is caused to the components and this restricts the generation to the thermoelastic regime, where ultrasonic generation is due to rapid thermal expansion.

Laser Generation of Lamb Waves

---Shi-Chang Wooh, Yijun Shi, and Mark E. Orwat, Department of Civil and Environmental Engineering, Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, MA 02139

---The generation and propagation of Lamb wave in an elastic plate loaded by a laser excitation is studied. An analytical solution is derived using a two-dimensional Fourier analysis for an arbitrary transient traction. The theoretical dispersion curves and excitation efficiency functions are derived and compared with the dispersion curves obtained from the simple Rayleigh-Lamb frequency equations for various loading conditions. The study is extended to derive the displacement fields and the modal excitation efficiencies are computed. The results are compared with those obtained by the normal mode expansion method. Various condition parameters, including the illumination area, signal bandwidth, and distribution of loads, are studied to demonstrate the possibility of selecting the desired wave modes.

Near Field Analysis of Laser-Generated Ultrasonic: The Effects of Thermal Diffusion and Optical Penetration

---Irene Arias, Todd W. Murray, and Jan D. Achenbach, Northwestern University, Center for Quality Engineering and Failure Prevention, 2137 Sheridan Road, Catalysis Building, Room 331, Evanston, IL 60208-3020

---An analytical formulation has been derived for the transient response of an isotropic half-space submitted to a pulsed laser line-source operating in the thermoelastic regime of laser-pulse energy density. The formulation takes into account optical penetration into the material and thermal diffusion from the source, and is therefore a suitable representation for the field near the source, where these effects become significant. Fourier and Laplace integral transform techniques have been used to obtain analytical solutions in the domain of transformed variables. At each point of the half-space, the time domain signal has been obtained numerically. The field near the source has been studied in detail. Several numerical results showing the normal surface displacement are presented and compared to the ones given in previous works where the effects of thermal diffusion and optical penetration were neglected.

An Optoacoustic Transfer Function for Laser-Ultrasonics: Definition and Its Characterization for Various Lasers in the Ablation Regime

---André Moreau and Martin Lord, Industrial Materials Institute, National Research Council of Canada, Boucherville, QC, Canada; Jean-Claude Kieffer and Bruno La Fontaine, Institut National de la Recherche Scientifique (INRS)-Énergie et Matériaux, Varenne, QC, Canada

---To maximize the signal-to-noise ratio of a laser-ultrasound system, one may choose to reduce the noise by using a better interferometer (and associated laser, optics, etc.), or to increase the signal by selecting a better generation laser. Given that interferometers have reached the detection limit of photon statistics, we focus our attention on ultrasound generation. To do so, we define an optoacoustic transfer function that describes the ultrasound generation efficiency of a pulsed laser on a specific material in a predetermined frequency bandwidth. On this basis, we compare the generation efficiency of various lasers on metals in the ablation regime. It is found that, at constant fluence, shorter pulses (ps) and shorter radiation wavelengths (UV) generate ultrasound more efficiently than longer pulses (ns) and longer radiation wavelengths (IR). It is also found that the generation efficiency is inversely proportional to frequency, as it should be if the generated ultrasonic pulse is a step function.

Performance Comparison of Adaptive Laser Ultrasonic Receivers Based on Polarization Self-Modulation and Two-Wave Mixing

---Marvin Klein, Bruno Pouet, Konrad Peithmann, and Sebastien Breugnot, Lasson Technologies, Inc., Culver City, CA 90230; Alexei Kamshilin and Victor Prokofiev, Department of Physics, University of Joensuu, Joensuu FIN-80101, Finland

---Adaptive receivers for laser ultrasonics have received considerable attention in recent years because of their high bandwidth, their ability to process speckled beams from rough surfaces while rejecting low frequency noise and their simple, rugged design. At the current time, three separate approaches are being developed, each using a photorefractive crystal as the critical compensating element. These approaches are (1) photo-emf detection, in which the crystal is used as an adaptive photodetector, (2) two-wave mixing (TWM), in which the crystal is used as an adaptive beam combiner and (3) polarization self-modulation (PSM), in which the crystal is used as a spatial polarization modulator. The latter two approaches bear some similarity to each other, with closely related crystal requirements. In this work we will report the results of experiments intended to compare the experimental performance of TWM and PSM, using the same photorefractive material in each case. The measured performance will be compared with models that predict this performance. The advantages of each approach will be discussed.

Influence of Wet Surface Condition on the Propagation Behavior of Laser-Generated Ultrasound

---Shi-Chang Wooh, Quanlin Zhou, and Jiyong Wang, Department of Civil and Environmental Engineering, Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, MA 02139

---It is known that the efficiency of generating laser ultrasound is greatly enhanced by moisturizing the surface with water or oil. Although this is a common technique used in practice, the physical behavior under such condition is not well understood. This paper deals with a theoretical model to study the influence of the wet surface condition on the behavior of wave propagation. The solutions for both longitudinal and shear waves are obtained using the Fourier analysis and evaluating the transform integral asymptotically. This model, developed by assuming an elliptical distribution of normal surface tractions over the illuminated source area, can predict the directivity patterns. Both circular and line focused source beams are considered. The theory was evidenced by the experimental study, in which the effects of the most influential parameters such as beam diameter and frequency of the propagating wave are investigated. The experimental results are in excellent agreement with the theoretical predictions. It is concluded that the elliptical loading model works very well for the analysis of laser-generated ultrasound.

SESSION 27
NDE RELIABILITY, VALIDATION, AND EVALUATION
I. Perez, Chairperson
Sills 117

8:30 AM **Fuselage Disbond Inspection Procedure Using Pulsed Thermography**
---M. Ashbaugh, Airworthiness Assurance Department, Sandia National Laboratories, 3260 University Boulevard S.E., Albuquerque, NM 87106; J. G. Thompson, Boeing Service Engineering, Everett, WA 98195

8:50 AM **Meshless Element-Free Galerkin Method in NDT Applications**
---L. Xuan, Z. Zeng, B. Shanker, and L. Udpa, Iowa State University, Department of Electrical and Computer Engineering, Ames, IA 50011

9:10 AM **Detection of Cracks Beneath Rivet Heads via Pulsed Eddy Current Technique**
---J. S. R. Giguere[1], B. A. Lepine[2], and J. M. S. Dubois[3], [1]Air Vehicle Research Section, National Defense Headquarters, Ottawa, Ontario; [2]Institute of Aerospace Research, National Research Council, Ottawa, Ontario; [3]Royal Military College of Canada, Kingston, Ontario

9:30 AM **Defect Characterization in Multi-layered Conductive Components with Pulsed Eddy Current**
---Y. A. Plotnikov, S. C. Nath, and C. W. Rose, General Electric Corporate Research and Development, 1 Research Circle, KW-D254, Nishkayuna, NY 12309-1135

9:50 AM **Modeling of Current Excitation Waveforms for Magnetic Particle Inspection**
---Z. Zeng, L. Xuan, L. Udpa, and S. S. Udpa, Iowa State University, Material Assessment Research Group, Department of Electrical and Computer Engineering, Ames, IA 50011

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

10:30 AM **On the Reliability of Quantitative Evaluation of Penetrant Systems Quality**
---N. P. Migoun, P. P. Prokhorenko, and A. B. Gnusin, Institute of Applied Physics, National Academy of Sciences, Minsk, Belarus; M. Stadthaus and H.-M. Thomas, Federal Institute for Materials Research and Testing, Berlin, Germany

10:50 AM **Evaluation of Fluorescent Penetrant Inspection Practices**
---B. Larson and R. Lopez, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

11:10 AM **Errors in the Measurement of Ultrasonic Absorption for Materials Evaluation**
---R. E. Challis and A. Kalashnikov, University of Nottingham, School of Electrical and Electronic Engineering, University Park, Nottingham NG7 2RD, United Kingdom

11:30 AM **The Use of a Square Wave Pulser in Ultrasonic Crack Detection and Sizing Techniques**
---H. Thompson, Panametrics, Inc., 221 Crescent Street, Waltham, MA 02453

11:50 AM **The Role of Automated NDE Relative to Support the Aging Aircraft**
---D. D. Palmer, Jr. and N. L. Wood, The Boeing Company, P. O. Box 516, St. Louis, MO 63166; D. S. Wilcon, The Boeing Company, 2401 E. Wardlow Road, Long Beach, CA 90807-5309

12:10 PM ***Lunch***

Fuselage Disbond Inspection Procedure Using Pulsed Thermography

---Mike Ashbaugh, Airworthiness Assurance Department, Sandia National Laboratories, 3260 University Boulevard S.E., Albuquerque, NM 87106; Jeffrey G. Thompson, Boeing Service Engineering, Everett, WA 98195

---One use of pulsed thermography that has shown promise in aircraft inspection for some time is an inspection for disbonds in metallic or composite structures. The FAA has funded research at Wayne State University in this area and Boeing identified a specific inspection requirement for disbonds on Boeing 747 aircraft. Laboratory and subsequent field testing monitored by the AANC has demonstrated the reliability of this type of inspection. As a result Boeing expects to approve a general fuselage disbond inspection procedure using pulsed thermography in the 2nd Quarter of 2001. This presentation will show results of some of the validation testing and briefly discuss the Boeing inspection procedure.

Meshless Element-Free Galerkin Method in NDT Applications

---L. Xuan, Z. Zeng, B. Shanker, and L. Udpa, Department of Electrical and Computer Engineering, Iowa State University, Ames, IA 50011

---Finite element methods (FEM) are widely used for modeling a variety of problems in Nondestructive Evaluation (NDE). For example, in the modeling of multiplayer aircraft geometry with third layer cracks under fasteners, the reliance of FEM on a mesh leads to several problems, particularly when tight cracks have to be introduced into the sample. Furthermore re-meshing is often required for handling large geometrical discontinuities and probe motion, which is time consuming. Recently a new class of methods called meshless methods has been developed, where the approximation is entirely constructed in terms of a set of nodes. This paper presents a meshless Element-Free Galerkin method (EFG), which is applied to two dimensional magneto-static and eddy current NDT problems. The mathematical principles underlying moving least square approximation (MLSA) technique will be included for a two dimensional EFG model. The EFG method based on $A ? V$ formulation for eddy current problem will be validated and compared with results obtained using conventional FEM. The particular advantage of these methods for modeling tight cracks will be highlighted.

Detection of Cracks Beneath Rivet Heads via Pulsed Eddy Current Technique

---J. S. R. Giguè[1], B. A. Lepine[2], and J. M. S. Dubois[3], [1]Air Vehicle Research Section, National Defense Headquarters, Ottawa, Ontario; [2]Institute of Aerospace Research, National Research Council, Ottawa, Ontario; [3]Royal Military College of Canada, Kingston, Ontario

---All aircraft with aluminum fuselage skins will eventually reach an age where fatigue cracking can be expected to increase. Although the detection of fatigue cracks is prevalent in current inspection programs, continued airworthiness is dependent on the implementation of effective nondestructive evaluation methods to detect these cracks at an early stage. As a result, improving the detectability of fatigue cracks under installed fasteners is one of the many goals of the aging aircraft nondestructive evaluation community. The pulsed eddy current technique offers new capabilities to address this requirement. The aim of this paper is to evaluate the potential of this technique for detecting and quantifying notches under installed fasteners. Specifically, this paper compares the ability to three different types of probes to detect and quantify these defects and addresses limitations and potential improvements.

Defect Characterization in Multi-layered Conductive Components with Pulsed Eddy Current

---Yuri A. Plotnikov, Shridhar C. Nath, and Curtis W. Rose, General Electric Corporate Research and Development, 1 Research Circle, KW-D254, Nishkayuna, NY 12309-1135

---Capabilities of the Pulsed Eddy Current (PEC) method to perform in-depth scanning have been successfully demonstrated for hidden corrosion detection. In the present work, a drive pulse and the response is analyzed in terms of Fourier Transform to understand the scope of material penetration with PEC. Variations of the drive pulse shape can be an effective technique to control the depth of penetration of conductive materials. An observation time interval and a sampling rate are the components that can be used for “in-depth slicing” of conductive media. Two-dimensional scanning of multi-layered structures such as aircraft skin structures with a PEC probe provides detection of subsurface defects. Experiments have been performed on aluminum panels with flat bottom holes. An image processing routine is applied to reconstruct geometry of the component from a series of eddy current images obtained with a two-dimensional scanner. A problem of accurate reconstruction of the internal geometry of the component under test is considered. The advantages and limitations of the technique are discussed.

Modeling of Current Excitation Waveforms for Magnetic Particle Inspection

---Zhiwei Zeng, Liang Xuan, Lalita Udpa, and Satish Udpa, Material Assessment Research Group, Department of Electrical and Computer Engineering, Iowa State University, Ames, IA 50011

---In magnetic particle inspection, the sample is magnetized using current flow (coils) or flux flow (yoke). In both cases the excitation current may be alternating, full wave rectified, half wave rectified or pulsed. Further, these current waveforms vary significantly with current settings and time with no correlation between peak height and root mean square (rms) value. The choice of inappropriate electrical current waveform may result in missing some significant defects. This paper presents a finite element modeling study of the magnetization of a test sample due to different current wave forms. The model using time samples of the waveform will generate magnetic flux leakage variations at a defect due to different excitation currents and peak values. The results will be analyzed and discussed with respect to calibration of MPI systems.

On the Reliability of Quantitative Evaluation of Penetrant Systems Quality

---N. P. Migoun, P. P. Prokhorenko, and A. B. Gnusin, Institute of Applied Physics, National Academy of Sciences, Minsk, Belarus; M. Stadthaus and H.-M. Thomas, Federal Institute for Materials Research and Testing, Berlin, Germany

---The market of the penetrant systems is increasing every year. A sensitivity of the penetrant systems is one of the main criteria for a customer. Therefore the importance of reliable result of the determination of penetrant systems sensitivity is increasing as well. It was established in our experiments that repeating the procedure of type testing in accordance with ISO EN 3452-2, in many cases one can obtain rather variable results for the sensitivity level. The goal of our investigations was to establish the principal factors, influencing upon the result of penetrant system type testing. Our results show that the values of the duration of such penetrant inspection technological stages as penetrant and developer applications may be considerably lower than the values recommended by ISO EN 3452-2 for the type testing. At the same time the character of the procedure's realisation of excess penetrant removal and developer application strongly influences upon the type testing results. Some recommendations for obtaining more reliable results of the determination of penetrant system sensitivity are worked out and proposed.

Evaluation of Fluorescent Penetrant Inspection Practices

---Brian Larson and Rick Lopez, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---Fluorescent penetrant inspection (FPI) has been used since the 1960's to detect fatigue cracks in components during aircraft engine overhaul. While current FPI practices detect the vast majority of the defects, several relatively recent aircraft incidents have been attributed to disk failures that resulted due to cracks missed by the FPI process. In 1996, US Federal Aviation Administration conducted a technical review of a number of facilities that perform FPI of high-energy rotating engine components. The finding of this review caused some level of concern about the precleaning processes, the FPI process and the degree to which these processes were being followed. This prompted the initiation of an Engine Titanium Consortium project to evaluate current FPI practices, develop improvements where needed and assist in implementation of a best practices document. Current efforts are focused on an engineering study to evaluate pre-cleaning, etching and drying practices. The impact that current practices have on the brightness and size of FPI indications is being evaluated using a spectrophotometer and image analysis software. The measurements are being made on small low cycle fatigue cracks, which have been introduced into a set of Inconel and titanium specimens. This paper will present an overview of the project and the results of recent efforts.---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 Center for Aviation Systems Reliability program.

Errors in the Measurement of Ultrasonic Absorption for Materials Evaluation

---Richard E. Challis and Alexander Kalashnikov, School of Electrical and Electronic Engineering, University of Nottingham, University Park, Nottingham NG7 2RD, United Kingdom

---The ultrasonic absorption coefficient as a function of frequency is a useful variable in the non-invasive monitoring of the formation of many important materials such as thermoset resins used as adhesives or structural composites and of many liquid colloidal suspensions and emulsions. Its use is largely confined to laboratory studies at present but applications to manufacturing processes are expected to evolve rapidly. Measurements of absorption on nominally identical materials are known to vary considerably between laboratories and this implies that care is required in the design of industrial scale measuring systems. This paper considers how errors in the absorption coefficient develop from bias and variance errors in the raw ultrasonic data from which it is calculated. A statistical approach is adopted in which the coefficient is expressed as a Taylor expansion about the mean values of the constituent measurement variables. It relates the bias and variance in the coefficient to those errors in the constituent variables. It is shown that errors are functions of the total attenuation being measured, and, not surprisingly, the electronic system noise-to-signal ratio. The sources and influence of electronic noise are assessed for a typical system and the operating condition under which their effects are minimized is shown to be when the total attenuation being measured is around one Neper.

The Use of a Square Wave Pulser in Ultrasonic Crack Detection and Sizing Techniques

---Heather Thompson, Panametrics, Inc., 221 Crescent Street, Waltham, MA 02453

---Austenitic materials are widely used for piping and pressure vessel components in nuclear power and petro-chemical plants. In these materials, intergranular stress corrosion cracking (IGSCC) occurs as a consequence of many environmental factors. Ultrasonic techniques have been successfully employed to detect and size these cracks. The latest ultrasonic crack detection and sizing techniques are highly based on signal recognition and characterization; therefore, an ASNT Level III certified inspector is needed to interpret the results. Since the inspection and signal interpretation of these cracks can be very difficult and time consuming, there is a need for improvements in the ultrasonic equipment to produce faster and more accurate results. This paper will describe current ultrasonic crack detection and sizing techniques, as well as advances in electronics and signal processing to improve reliability. A particular emphasis will be placed on the comparison of square wave pulsing and conventional negative spike pulsing results in these crack detection and sizing techniques.

The Role of Automated NDE Relative to Support of Aging Aircraft

---Donald D. Palmer, Jr. and Nancy L. Wood, The Boeing Company, P. O. Box 516, St. Louis, MO 63166, Dwight S. Wilcon, The Boeing Company, 2401 E. Wardlow Road, Long Beach, CA

---As an aircraft ages, flaw conditions such as corrosion and fatigue damage become prevalent. Along with this increase in time dependent failure mechanisms come associated, but dramatically increasing, costs associated with maintaining older airplanes. Since nondestructive evaluation (NDE) forms an integral part of the aircraft maintenance process, the ability to introduce methods that both increase repetitive inspection cycles and reduce related labor hours are desirable. Through automation of NDE processes, cycle times attributed to labor-intensive manual inspections have been drastically reduced. In some cases, automation of conventional NDE processes has helped to eliminate visual inspections that require disassembly. In addition, automation has enabled the use of less invasive inspection approaches to address difficult inspections--thus allowing for a dramatic reduction in the labor and teardown required to perform the task. Most of the recent successes have centered on implementation of large area ultrasonic and eddy current scanning approaches for corrosion and crack detection. However, merging robotics with digital technology has also helped to reduce costs associated with radiographic inspection. These successes have resulted in millions of dollars saved relative to both military and commercial aircraft maintenance operations. Some of the specific automated NDE approaches, their successful applications, and their impact relative to the aircraft maintenance environment, will be discussed.

Thursday, August 2, 2001

SESSION 28 - POSTERS
SIGNAL PROCESSING, IMAGING, NDE SYSTEM QUALIFICATION, MAGNETIC MEASURES, MATERIALS, AND EDUCATION
Smith Union: Morrell and Lamarche Lounges

1:30 PM

Signal Processing

On-line Data Fusion of Pulse-Echo Ultrasound for Testing Composite Materials
---V. M. Noriega, Jr., R. A. Osegueda, and J. H. Pierluissi, University of Texas at El Paso, Fast Center for Structural Integrity of Aerospace System, El Paso, TX 79968

Ultrasonic Flaw Classification: Features and the Use of Modeling
---J. Xin[1], and L. W. Schmerr, Jr.[2], Iowa State University, [1]Department of Electrical and Computer Engineering; [2]Department of Aerospace Engineering and Engineering Mechanics, Ames, IA 50011

Identification of Flaw Signals in the Angle Beam Ultrasonic Testing of Welded Joints with Geometric Reflectors
---S.-J. Song, J. Y. Kim, and Y. H. Kim, Sungkyunkwan University, School of Mechanical Engineering, 300 Chunchun-dong, Jangan-ku, Suwon, Kyungggi-do, 440-746, Korea

Wavelet Transform of Signal for Enhancement of SNR in Wire Rope Inspection
---V. Lunin and V. Barat, Moscow Power Engineering Institute (TU), Electrical Engineering & Introscopy Department, Krasnokazarmennaja 14, Moscow, 111250, Russia

Restoring Separate Discontinuities from Ultrasonic Data
---S. Gautier, EDF/DRD, department SDM, 6, quai Watier, F-17401 Chatou, France

Imaging

Wet Paint Thickness Study with Thermal Wave Imaging
---G. Sun, GS Scientific Research, 117 Shaniko Cmn, Fremont, CA 94539; T. Wang and G. Gao, Materials Science Department, Ford Research Laboratory, P. O. Box 2053, MD3182-SRL, Dearborn, MI 48121-2053

On the Lateral Resolution of Eddy Current Imaging
---W. T. Hassan and M. Blodgett, Metals, Ceramics, and NDE Division, Air Force Research Laboratory (AFRL/MLLP), Wright-Patterson Air Force Base, Dayton, OH 45433; P. B. Nagy, University of Cincinnati, Department of Aerospace Engineering and Engineering Mechanics, Cincinnati, OH 45221

Statistical Characterization of Complex Object Structure by Dynamic Tomography
---G.-R. Tillack, J. Goebbels, and B. Illerhaus, Federal Institute for Materials Research and Testing (BAM), Division VIII.3, Unter den Eichen 87, 12205 Berlin, Germany; V. Artemiev and A. Naumov, Institute of Applied Physics, Akademicheskaya str. 16, 220072 Minsk, Belarus

A Non-Rotating X-Ray 3-D Imaging System
---E. M. A. Hussein, University of New Brunswick, Department of Mechanical Engineering, Fredericton, N.B. E3B 5A3, Canada; W. H. Makky, Aviation Security R&D, Federal Aviation Administration, FAA Technical Center, Atlantic City, NJ 08405

A New Photothermal Microscope for Microscopic Thermo Elastic Characterization
---J. Jumel, F. Lepoutre, and F. Taillade, DMSE/MECS, Onera Centre de Chattillon, 29 avenue de la division Leclerc, BP72, Chatillon Cedex, France

NDE System Qualification

An Approach to Determine NDI Intervals of Nuclear Power Plant Piping Systems Under Vibration Fatigue
---H. Jeong, Wonkwang University, Division of Mechanical Engineering, 344-2 Shinyong-dong, Iksan City, Chonbuk, 570-749, Korea

Computer Aided Inspection Qualification
---D. M. McNab, A. McNab, and A. Potts, University of Strathclyde, Center for Ultrasonic Engineering, Glasgow, G1 1XW, United Kingdom; M. W. Toft, Berkley Technology Center, BNFL Magnox Generation, Berkley, Gloucestershire, GL 13 9PB, United Kingdom; J. McDonald, University of Strathclyde, Center for Electrical Power Engineering, Glasgow, G1 1XW, United Kingdom

Enhancing Accuracy of Data Acquired by a Laser Vibrometer in a Field Setting
---E. S. Sazonov and P. Klinkhachorn, West Virginia University, Department of Computer Science and Electrical Engineering, P. O. Box 6109, Morgantown, WV 26506-6109; H. V. S. GangaRao and U. B. Halabe, West Virginia University, Constructed Facilities Center, Morgantown, WV 26506

An SNR Based Method for Estimating Ultrasonic POD
---R. S. Gilmore, General Electric Research and Development Center, P. O. Box 8, Schenectady, NY 12301

Magnetic Measures

Experimental and Modeling Studies of Barkhausen Effect in Steels and Nickel
---C. C. H. Lo, B. Zhu, L. C. Kerdus, and D. C. Jiles, Iowa State University, Center for NDE, Ames, IA 50011

Fatigue Evaluation of Magnetic Materials by Barkhausen Noise Under Rotational Magnetic Field
---Y. Tsuchida, T. Ando, and M. Enokizono, Oita University, Department of Electrical and Electronic Engineering, 700 Dannoharu, Oita, 870-1192, Japan

Barkhausen Noise Analysis for Stress Field Evaluation on Bearing Raceway Used in Aeronautic Engine
---S. Desvaux[1], J. Gualandri[2], M. Duquennoy[1], and M. Ourak[1], [1]Université de Valenciennes, Institut d'Electronique et de Microélectronique du Nord (UMR CNRS 8520), Département O.A.E., BP 311, 59313 Valenciennes Cedex 9, France; [2]SNFA, Department Material et Advanced Technics, Zl N?2 Batterie 900 Rouvignies, 59309 Valenciennes Cedex, France

A Comparison of Theory and Experiment for the Effects of Stress on Magnetic Hysteresis and Barkhausen Activity in Stainless Steel
---M. J. Johnson, C. C. H. Lo, B. Zhu, and D. C. Jiles, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50010; P. Zombo, Siemens-Westinghouse Power Corporation, Quadrangle Building, 4400 Alafaya Trail, Orlando, FL 32812

Neutron Fluence Effects on the Magnetic Parameter Changes in Linde 80 High Copper Weld
---B. Kim, S. Chi, and S. Lee, Nuclear Material Technology Developments, Korea Atomic Energy Research Institute, P. O. Box 105, Yusung, Taejon 305-600, Korea

A Magnetic Method in the Testing of Ferromagnetic Materials
---R. Sikora, M. Komorowski, S. Gratkowski, and J. Pacuk, Technical University of Szczecin, Faculty of Electrical Engineering, ul. Sikorskiego 37, 70-313 Szczecin, Poland

Thursday, August 2, 2001

Materials

Characterization of Complex Parameters for a Piezoelectric Thin Film Deposited on a Substrate
---Q. B. Zhou and S. Y. Zhang, Nanjing University, Lab of Modern Acoustics, Institute of Acoustics, Nanjing 210093, P. R. China

Evaluation of Residual Stress Distribution Using SAW
---S. D. Kwon, Andong National University, Department of Physics, Andong P. O. Box 203, Andong, Kyungsangpook-do 760749; S. J. Song and Y. Z. Lee, Sungkyunkwan University, School of Mechanical Engineering, Suwon, Kyunggi-do, Korea

Theoretical and Experimental Determination of the Natural and Initial Acoustoelastic Coefficients
---M. M. Duquennoy, M. M. Ouaftouh, M. M. Ourak, M. F. Jenot, M. W. Xu, Université de Valenciennes, Institut d'Electronique et de Microélectronique du Nord (UMR CNRS 8520), Département O.A.E., BP 311, 59313 Valenciennes Cedex 9, France

Rapid Transmission Coefficient Reconstruction and Material Property Estimation in Plates
---D. Fei, D. E. Chimenti, and S. Teles, Iowa State University, Center for NDE and Department of Aerospace Engineering & Engineering Mechanics, Ames, IA 50011

Non-Contact System to Measure the Material Properties of a Layered Viscoelastic Medium
---J. C. Stolzenburg and L. J. Jacobs, Civil and Environmental Engineering, Georgia Institute of Technology, Atlanta, GA 30332-0355; J. Jarzynski, GWW School of Mechanical Engineering, Georgia Institute of Technology, Atlanta, GA 30332-0355

Material Characterization Using Nonlinear Wave Propagation
---M. Maess, L. J. Jacobs, Civil and Environmental Engineering, Georgia Institute of Technology, Atlanta, GA 30332-0355; J. Qu, GWW School of Mechanical Engineering, Georgia Institute of Technology, Atlanta, GA 30332

A Two-Dimensional Reconstruction Theory of Thermal Conductivity Profiles Based on Thermal Wave Technique
---Q. B. Zhou[1], Y. K. Lu[1,2], S. Y. Zhang[1], and J. C. Cheng[1], [1]Nanjing University, Lab of Modern Acoustics, Institute of Acoustics, Nanjing 210093, P. R. China, [2]Ningxia University, Department of Physics, Yinchuan 750021, P. R. China

Anisotropic Effects in Noncontacting Thermoelectric Materials Characterization
---H. Carreon, A. H. Nayfeh, and P. B. Nagy, University of Cincinnati, Department of Aerospace Engineering, Cincinnati, OH 45221-0070

A Study on the Splitting of the Valence Band for a AgInS2/GaAs Epilayer Using Photocurrent Measurement
---K. J. Hong, J. W. Jeong, and H. W. Baek, Chosun University, Department of Physics, 375, Sosok-dong, Dong-gu, Kwangju 501-759, Korea; K. H. Im, Woosuk University, Department of Automotive Engineering, 490 Hujung-ri, Samrae-up, Wanju-kun, Chonbuk 565-701, Korea

Ultrasonic NDE and Mechanical Testing of Fiber Placement Composites
---Z. Liu, D. Fei, V. Dayal, and D. K. Hsu, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011; R. D. Hale, University of Kansas, Department of Aerospace Engineering, Lawrence, KS

Characteristic Evaluation of CFRP Composites Under Falling Weight Impact Loading
---K. H. Im[1], N. S. Park[2], D. K. Hsu[3], S. K. Kim[4], J. W. Park[5], and I. Y. Yang[5], [1]Woosuk University, Department of Automotive Engineering, Wanju-gun, Chonbuk, 565-701, Korea; [2]Chosun University, Department of Mechanical Design Engineering, 375 Seosuk-dong, Dong-gu, Kwangju, 501-759, Korea; [3]Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011; [4]Iksan National College, Department of Automobile Engineering, 194-5 Ma-dong, Iksan, Chonbuk, 570-752, Korea; [5]Chosun University, Factory Automation Research Center for Parts of Vehicles, 375 Seosuk-dong, Dong-gu, Kwangju, 501-759, Korea

Investigation of the Influence of Fraction of SiC Particles on the Elastic Model of SiC_p/Aluminum by Laser Ultrasonic Method
---J. He, X. R. Zhang, and S. Zhonghua, Nanjing University, Laboratory of Modern Acoustics and Institute of Acoustics, Nanjing 210093, China; F. Z. Hang and G. D. Zhang, Shanghai Jiaotong University, State Key Laboratory of Metal-Matrix Composite Materials, Shanghai 200030, China

Influence of Fraction of SiC Particles on the Thermal Diffusivity of Composite SiC_1/Aluminum by Mirage Effect
---X. R. Zhang, S. Lin, and J. He, Nanjing University, Laboratory of Modern Acoustics and Institute of Acoustics, Nanjing 210093, China; Z. Fan and Z. Guoding, Shanghai Jiaotong University, State Key Laboratory of Metal-Matrix Composite Materials, Shanghai 200030, China

Thermal Wave Determination of the Thermal Diffusivity of Composite ZrO_2/Aluminum
---S. Lin[1], X. R. Zhang[1], M. Zhou[2], and J. He[1], [1]Nanjing University, Laboratory of Modern Acoustics and Institute of Acoustics, Nanjing 210093, China; [2]Jiangsu University, College of Mechanical Engineering, Zhenjiang 212003, China

Acoustic Emission Characteristics on Microscopic Damage Behavior of Carbon Fiber Sheet Reinforced Concrete
---J.-K. Lee, Dong-Eui University, Department of Mechanical Engineering, Pusan 614-010, Korea; J.-H. Lee, Pusan National University, School of Mechanical Engineering, Pusan 609-735, Korea

Velocity Measurement on an Asphalt and Nondestructive Inspection of Pipe Under the Asphalt
---O. Kobori, Osaka Sangyo University, 3-1-1, Nakagaito, Daito City, Osaka Prefecture 574, Japan; Y. Udagawa, Imaging Supersonic Laboratories Co., Ltd. 12-7, Tezukayama-Nakamati, Nara City, Nara Prefecture 631, Japan

A Study on Annealing Effects of AgInS2/GaAs Epilayer Obtained from Photoluninescence Measurement
---K. J. Hong, J. W. Jeong, and H. W. Baek, Chosun University, Department of Physics, 375, Sosok-dong, Kwangju 501-759, Korea; K. H. Im, Woosuk University, Department of Automotive Engineering, 490 Hujung-ri, Samrae-up, Wanju-kun, Chonbuk 565-701, Korea

Education

Collaboration for Education in Nondestructive Testing – Extending the Reach
---B. Larson, S. Wormley, and L. W. Schmerr, Jr., Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011; B. Crouse, Cowley County Community College, Arkansas City, KS 67005; R. Walbridge and B. Wiley, Southeast Community College, Milford, NE 68405

Vertically Integrated Engineering Design for Combined Research and Curriculum Development in Materials Engineering and Nondestructive Evaluation
---D. C. Jiles[1,2,6], M. Akinc[2,6], S. B. Biner[2,6], K. Constant[2], J. N. Gray[3], M. Huba[4], S. W. Martin[2], L. W. Schmerr, Jr.[5], and R. B. Thompson[1,2,5], [1]Center for NDE, [2]Department of Educational Leadership and Policy Studies, [5]Department of Aerospace Engineering and Engineering Mechanics, [6]Ames Laboratory, US DOE, Iowa State University, Ames, IA 50011

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

On-line Data Fusion of Pulse-Echo Ultrasound for Testing Composite Materials

---Victor M. Noriega Jr., Roberto A. Osegueda, and Joseph H. Pierluissi, Fast Center for Structural Integrity of Aerospace System, University of Texas at El Paso, El Paso, TX 79968

---An on-line fusion system for testing composites using ultrasound has been developed. A composite plate with known defect location is used to test the system. The system avoids the problem of obtaining false defects caused by uneven surfaces of composite materials. The A-scan signal is treated as an amplitude modulated signal. Demodulating the signal helps track the thickness of the composite material as the transducer moves over it. Real-time digital signal processing is used to create a C-scan image using the information of the demodulated A-scan signal. Real-time digital signal processing allows the C-scan image to be displayed as the system scans the composite plate. Four different fusion methods are used to create the C-scan image. The four methods include average, maximum, front-back ratio, and Dempster-Shafer evidential reasoning method. All four methods detect the defects. It was found from the four methods used for generating a C-scan image that the Dempster-Shafer evidential reasoning method identified the defects more clearly than the other three methods.

Ultrasonic Flaw Classification: Features and the Use of Modeling

---Jianqiang Xin[1] and Lester W. Schmerr, Jr.[2], [1]Department of Electrical and Computer Engineering; [2]Department of Aerospace Engineering and Engineering Mechanics, Iowa State University, Ames, IA 50011

---Determining the type of flaw that produced a particular measured NDE response is a difficult NDE flaw classification problem and one that is ideally suited to the application of modern techniques such as neural networks. However, all neural network flaw classifiers, regardless of their type, require as inputs quantities (features) that are closely related to the type of flaw present in order to reach high performance levels. Unfortunately, in many previous cases, the choice of features in a particular domain has been done in a heuristic or purely statistical manner that results in less than optimal performance and poor generalization properties of the classifier being employed. In order to find features closely related to the physics of the inspection process, we are building a weld flaw inspection simulator in MATLAB for the examination of features in various domains. The types of flaws we are modeling include porosity, inclusions and cracks. The feature domains we are studying include the time domain, frequency domain, time-frequency domain and spatial domain. Here, we will describe our simulator and some simulation results. Some features we have investigated are also included. From a large set of possible features, it is desirable to reduce the dimension of features in preprocessing so that computation time is saved and better performance is achieved. Generalizing traditional Principal Component Analysis, some nonlinear dimension reduction methods such as auto-associative networks, and local PCA have been developed for dimension reduction purposes. We will also describe these new non-linear methods and their applications.---This work was supported by the NSF Industry/University Cooperative Research program.

Identification of Flaw Signals in the Angle Beam Ultrasonic Testing of Welded Joints with Geometric Reflectors

---Sung-Jin Song, Joon Young Kim, and Young Hwan Kim, School of Mechanical Engineering, Sungkyunkwan University, 300 Chunchun-dong, Jangan-ku, Suwon, Kyungggi-do, 440-746, Korea

---Interpretation of ultrasonic testing signals for the quantitative flaw characterization usually involves three steps including identification, classification and sizing. The identification of flaw signals is performed to select the portion of signals related to the flaws prior to the classification and sizing. However, it is quite often very difficult in the angle beam testing of welded joints due to the presence of geometric reflectors (such as weld roots and counter bores) generating non-relevant signals. This paper will describe a new approach to perform the flaw identification in such a problematic situation. This approach involves four steps: 1) acquisition of reference signals for both flaws and geometric reflectors, 2) correlation of angle beam testing signals with reference signals for the enhancement of signal source location, 3) construction of a source map with changing the interrogating positions, and 4) application of pattern recognition analysis to gated signals for the discrimination of flaw signals from geometric reflections. This paper will also present the performance of this approach with initial experiments.

Wavelet Transform of Signal for Enhancement of SNR in Wire Rope Inspection

---V. Lunin and V. Barat, Moscow Power Engineering Institute (TU), Electrical Engineering & Introscopy Department, Krasnokazarmennaja 14, Moscow, 111250, Russia

---The testing of steel wire ropes is based on the measurement of the magnetic flux leakage field (MFL) around the rope. The inspection tool is fitted with a circumferential array of magnetic heads with Hall sensors, which respond to defects in the wire rope. Almost any anomaly in the rope will produce magnetic disturbances under appropriate conditions, so signal processing is important. The long-term goal is to identify and measure the severity of all defects by correlating the responses from particular type of magnetic head. There are many difficulties, including the vast amount of material to be inspected, as well as noise and vibration. In the present paper we addresses the problem of utilizing the wavelet transform (WT) methodology for reducing the noise which corrupts a MFL signal containing fast (impulse in form) transients caused by defect. The identification of the coefficients originated by the signal has been performed by considering WT with different scale factors. It was shown how the wavelet coefficients can be processed to reconstruct a cleaner representation of the original data which enhances the signal-to-noise ratio. In particular it is also shown that the zoom feature of the method is suitable for detecting short duration high frequency transients in signals, which would be lost by a classic spectral analysis. This method has been successfully applied to experimental non-stationary signals.

Restoring Separate Discontinuities from Ultrasonic Data

---Steven Gautier, EDF/DRD, Département SDM, 6, quai Watier, F-17401 Chatou, France

---Ultrasonic non destructive testing data contains information about breaks in the inspected medium. Discontinuities due to a defect can be identified through the interpretation of those data. Still, the interesting information about the discontinuities does not always appear directly in the ultrasonic data. We have proposed a signal processing based on deconvolution, so as to estimate the discontinuities from the data. Still, the deconvolution results were corrupted with double spikes in the restored reflectors. We now show: a) double spikes can be avoided by improving the deconvolution process, b) this processing can be applied when several discontinuities are hidden in the same echo in the data (in that case, the processing is now able to restore separate reflectivities which are very close from each other). Processing results are given for the inspection of a mock-up with planar defects.

Wet Paint Thickness Study with Thermal Wave Imaging

---Gang Sun, GS Scientific Research, 117 Shaniko Cmn, Fremont, CA 94539; Tie Wang and Guilian Gao, Materials Science Department, Ford Research Laboratory, P. O. Box 2053, MD3182-SRL, Dearborn, MI 48121-2053

---Automotive painting process control is a key factor in meeting environmental regulation, customer satisfaction and corrosion protection requirements. Close-loop control strategies have been developed to improve paint transfer efficiency and first run capability. A critical element of the control strategies is the measurement of paint thickness and uniformity. At present the measurement is conducted after the paint is cured when a probe could make direct contact with the painted surface. This is not the most efficient method of process control since several dozen vehicles will be produced prior to the feed back on paint thickness and uniformity is obtained. A measurement prior to paint curing process, when the paint is wet, is desirable because it will substantially shorten the feed back loop. However, traditional probes that measure the thickness through direct contact with the painted surface cannot be used to conduct such measurements. A non-contact detection method is needed. This paper presents preliminary results of a non-contact, thermal wave imaging study on thickness and uniformity of a wet automotive paint on a metal sample. In the experiment an infrared camera captured the surface temperature of the sample as a function of time, while the sample was heated by an external illumination source with a designed temporal pattern. The captured thermal images showed distinguishable characteristics among various parts of the sample with different wet coating thickness. The results can be qualitatively analyzed by the difference of the thickness and thermal properties of the paint. The experiment demonstrated the possibility of thermal wave imaging as a wet paint thickness-monitoring tool, which can simultaneously monitor an area of 256x256 pixels instead of a single point.

On the Lateral Resolution of Eddy Current Imaging

---Waled T. Hassan and Mark Blodgett, Metals, Ceramics, and NDE Division, Air Force Research Laboratory (AFRL/MLLP), Wright-Patterson Air Force Base, Dayton, OH 45433; Peter B. Nagy, Department of Aerospace Engineering and Engineering Mechanics, University of Cincinnati, Cincinnati, OH 45221

---Analytical, finite element simulation, and experimental methods were used to investigate the lateral resolution of eddy current microscopy. It was found that the lateral resolution of eddy current imaging is ultimately limited by the probe-coil geometry and dimensions, but both the inspection frequency and the phase angle can be used to optimize the resolution, to some degree, at the expense of sensitivity. Although eddy current imaging is still in its infancy, a direct comparison of 5-MHz eddy current and 40-MHz acoustic microscopic images of the same coarse-grained Ti-6Al-4V sample indicated that the same features can be observed by both methods at approximately the same resolution level. Electric anisotropy exhibited by noncubic crystallographic classes of materials such as titanium alloys can play a very similar role in electromagnetic materials characterization of polycrystalline metals to that of elastic anisotropy in ultrasonic materials characterization. Our results demonstrate that eddy current microscopy can be enhanced via a high-resolution, small diameter probe-coil which delivers a unique materials characterization tool well suited for the evaluation of Ti alloys.

Statistical Characterization of Complex Object Structure by Dynamic Tomography

---Gerd-Ruediger Tillack, Jürgen Goebbels, and Bernhard Illerhaus, Federal Institute for Materials Research and Testing (BAM), Division VIII.3, Unter den Eichen 87, 12205 Berlin, Germany;Valentin Artemiev and Alexander Naumov, Institute of Applied Physics, Akademicheskaya str. 16, 220072 Minsk, Belarus

---Common tomographic techniques assign a measure of material properties to a discrete element in the object space in order to characterize a component. The discretization, i.e. the volume or size of a single element in the object space, is limited mainly by the physical mechanisms and the equipment used for the data acquisition. In any case the result of reconstruction yields a statistical average within the considered element in the object space. To evaluate the integrity of the component the determined measures have to be correlated with the mechanical properties of the component. Considering modern materials like reinforced plastics or metal foams the mechanical properties of the component are not determined by every single structural element like a single fiber in a composite. Moreover the ensemble mean and correlation properties of all structural elements form the mechanical properties of the component. Accordingly a statistical description of material properties on a macroscopic scale allow to characterize its mechanical behavior or aging. Special reconstruction algorithms are investigated that allow the statistical description of complex object structures including its dynamics. The algorithm is based on the Kalman filter using statistical prior. The prior includes knowledge about the covariance matrix as well as a prior assumption about the probability density distribution function. The resulting algorithm is recursive yielding the optimal or quasi-optimal solution at every reconstruction step. The applicability of the developed algorithm is discussed for the investigation of a specimen made from aluminum foam and compared to standard 3D CT.

A Non-Rotating X-Ray 3-D Imaging System

---Esam M. A. Hussein, Department of Mechanical Engineering, University of New Brunswick, Fredericton, N.B. E3B 5A3, Canada; Wagih H. Makky, Aviation Security R&D, Federal Aviation Administration, FAA Technical Center, Atlantic City, NJ 08405

---In conventional x-ray tomography, each section of the object needs to be subjected to a large number of intersecting radiation exposures, necessitating the rotation of the source or the interrogated object itself. This rotation mechanism, and the associated detection systems are responsible for the usually high cost of such systems. Moreover, the reconstructed image provides attenuation-coefficient information, which is not directly related to the material density due the photoelectric effect, present for most materials at the photon energy typically used in commercial x-ray. Also, the image reconstruction process is quite sophisticated as it in essence unscrambles information integrated over many pixels, along the path of the incident radiation, into pixel-by-pixel images. In addition, three-dimensional images can be only composed by acquiring multiple adjacent section-by-section images. This paper will present a non-rotating imaging system that provides directly three-dimensional images of, not only the attenuation coefficient of the material, but of its electron-density. The concept relies on measuring the radiation scattered and transmitted off a fixed beam of x-rays using fixed line-arrays of detectors. By a rectilinear motion of the object, each voxel in the object is subjected to the radiation beam once. By utilizing an x-ray machine in the 300 to 400 kV (peak), the probability of Compton scattering, and hence the strength of the scattering signal, is increased. With a simple voxel-by-voxel image reconstruction algorithm, multiple images of the same object are simultaneously obtained. These include images of the total attenuation coefficient at both the incident and scattering (effective) energies, and an image of the electron density. From the latter image, the Compton scattering attenuation coefficient can be calculated, enabling in turn an estimation of the photoelectric coefficient. Combination of these data can provide atomic-number information, which can be used to detect explosive materials.

A New Photothermal Microscope for Microscopic Thermo Elastic Characterization

---J. Jumel, F. Lepoutre, and F. Taillade, DMSE/MECS, Onera Centre de Chattillon, 29 avenue de la division Leclerc, BP72, Chatillon Cedex, France

---This paper presents a new photothermal microscope devoted to the measurement of the thermo-elastic properties with a spatial resolution of a few micrometers. This instrument, is based on both photoreflectance and interferometric microscopy. It enables to measure on the same field the periodic temperature increase and the periodic displacement fields at the surface of a sample heated by a focused intensity modulated laser beam. The dimensions of the scanned field ranged from few micrometers to few hundred micrometers depending on the chosen objective. The microscope operates in two different modes: imaging which provides 2D thermal or mechanical qualitative maps or characterizations which provides local quantitative measurements. The best resolution of this purely optical method is about one micrometer. The sensitivity of this microscope in the temperature variation measurement configuration is about 10-3 K, in the interferometric configuration it is few picometers. Precise interpretation of the measured signals shall be presented taking into account photoreflectance and photodeflexion phenomenons. Typical experimental results obtained on either simple isotropic homogeneous materials, composite materials, or functionally graded materials will demonstrate the large possibilities offered by this instrument either in imaging or characterization modes.

An Approach to Determine NDI Intervals of Nuclear Power Plant Piping Systems Under Vibration Fatigue

---Hyunjo Jeong, Division of Mechanical Engineering, Wonkwang University, 344-2 Shinyong-dong, Iksan City, Chonbuk, 570-749, Korea

---It is reported that approximately 80% of the fatigue failures in nuclear plants are due to vibration of socket welds and that such failures have a significant cost impact on the industry. The common practices are to nondestructively inspect them during the in-service inspection period on a random basis. Thus, it is necessary to develop a methodology to effectively inspect the small bore piping systems according to their susceptibility of fatigue damage. This paper describes a three-phase approach consisting of vibration measurement and stress analysis of various socket weld configurations, determination of cumulative damage based on the bending fatigue tests, and classification and grouping of hundreds of socket-welded pipes for the assignment of nondestructive inspection interval.

Computer Aided Inspection Qualification

---Douglas M. McNab, Alistair McNab, and Andrew Potts, Center for Ultrasonic Engineering, University of Strathclyde, Glasgow, G1 1XW, United Kingdom; Michael W. Toft, Berkley Technology Center, BNFL Magnox Generation, Berkley, Gloucestershire, GL 13 9PB, United Kingdom; James McDonald, Center for Electrical Power Engineering, University of Strathclyde, Glasgow, G1 1XW, United Kingdom

---An ultrasonic inspection is designed using the relevant standards and codes, but this does not guarantee that it is fit for its intended purpose. Inspection Qualification under the ENIQ methodology uses a Technical Justification as a key element in assuring the performance of the inspection. It combines a mixture of physical reasoning and modelling linked to limited experimental trial data from identified worst case defects, but the qualification process is costly and time-consuming. This paper describes an investigation into providing an integrated set of intelligent software tools to aid the process of inspection qualification. The main components of the system include a test simulator which takes a hierarchical approach with at the top-level geometrical ray-tracing using the ACIS 3D geometric modeller to model the component, and the probe beam interactions. This is linked to the second level where validated Kirchoff and GTD flaw response models are used to predict expected defect responses. The intelligent system components which incorporate rule and model based reasoning, interact with the simulator to automatically configure and run the flaw response models, assess beam coverage within the component and implement a search for the worst case defect position and orientations. Case based reasoning is also used to access a data base of experimental test results to identify cases where defect/ultrasonic beam interactions are similar to the one being considered.

Enhancing Accuracy of Data Acquired by a Laser Vibrometer in a Field Setting

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---The Laser Doppler Vibrometers (LDVs) have gained increased popularity among researchers and practitioners due to the great advantages over conventional methods: non-intrusiveness, ability for remote sensing on working machinery or hard-to-reach spots, and potentially, a very high spatial density of acquired data. At the same time, LDVs suffer from their dependency on the optical properties of the surface and sensitivity to external interference. Applying an LDV to large structures in a field setting, where traditional methods of controlling optical properties of the surface may not be applicable, poses new challenges. This paper considers the problems that were encountered during the design of an automated damage detection system for the Armored Vehicle Launched Bridge and solutions that were applied to enhance the accuracy of the acquired data.
The damage detection system employs an Ometron VS-100 laser vibrometer as its measurement device. Varying properties of the bridge surface, significant variability of the bridge profile, and the fact that the system is installed in a large industrial laboratory render control over the optical properties of the surface somewhat ineffective. Frequent occurrence of the signal "drop-outs" from the vibrometer caused substantial degradation in the quality of the acquired data. To correct the problem, special signal processing solutions were designed to analyze the acquired data in an attempt to recognize a signal drop-out. Involved signal processing algorithms take into account the properties of excitation applied to the structure and expected structural response. Unrealistic structural response is a good indicator of a drop-out. In case a drop-out is detected by the system, the corrective algorithm repositions the laser vibrometer within close vicinity from the original position until a reliable measurement spot is found. The applied solutions yielded a noticeable increase in the accuracy of the data acquired by LDV.

An SNR Based Method for Estimating Ultrasonic POD

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---As with most NDE sensor technologies, ultrasonic flaw detection relies on the flaw signals exceeding any electronic and/or material noise, which in combination may obscure them. For reliable detection, where flaw signals are clearly discriminated from noise, the signal to noise ratios (SNRs) are often specified to be at least 2.5 to 3.0 depending on the inspection procedure, the uniformity of the noise, and the method used to calculate the SNR. Almost all probability of detection (POD) discussions begin with schematic plots of the probability density functions for flaw signals and noise signals. Such schematics include thresholds, located between the two distributions, establishing the POD for the flaw signals falling above threshold, and also a Probability of False Alarm (PFA), where noise signals also above threshold could be confused for flaws. Despite this typical introduction, SNR based methods are seldom used for NDE. This discussion utilizes three signal distributions, all estimated from C-scan data to develop an SNR based estimation for ultrasonic POD and PFA. The first distribution is estimated from calibration target data. These data are acquired from blocks that include flat bottom holes and a "back-wall" at each calibration depth. These calibration signal distributions represent reflectors with a range in cross sectional area, but all have equivalent reflectivities of 1.0. The second is an estimated signal distribution for naturally occurring flaws. This distribution is constructed by combining the calibration information with a reflectivity distribution developed from natural flaw data. A noise signal distribution, estimated from flaw-free C-scan data completes the information required to construct receiver-operator characteristic curves (ROC Curves) linking SNR to POD and PFA depending on the operator selection of the detection threshold. In developing the ROC curves, a POD consistent definition for SNR will be presented.

Experimental and Modeling Studies of Barkhausen Effect in Steels and Nickel

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---Systematic measurements and simulations have been made to study the Barkhausen effect (BE) in steels and nickel subjected to different applied stresses and magnetizing field amplitudes, in order to validate the recently extended BE model for use in interpretation of measurement data for NDE purposes. The model incorporates the non-linear model of magnetic hysteresis into an existing stochastic process model of domain wall dynamics, thus allowing BE signal to be calculated over the hysteresis cycle with applied field changing with time at a variable rate. The simulated BE signals for nickel and a series of plain carbon steel samples with different carbon contents were found to closely resemble the measured results. The root-mean-square value and pulse height distribution of the experimental and modeled BE signals were found to be in good agreement. For the carbon steel samples a relationship between the BE model parameters and the carbon content was identified. The root-mean-square values of both the experimental and modeled BE signals exhibit the same dependence on the applied stress and magnetizing field amplitude. The present results suggest that the extended model is capable of simulating BE signals in different types of materials under various mechanical conditions.
---This work was supported by the NSF Industry/University Cooperative Research Program at the CNDE.

Fatigue Evaluation of Magnetic Materials by Barkhausen Noise Under Rotational Magnetic Field

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---In recent years, non-destructive testing has been playing an important role for safety and maintenance of structures. We have been doing the research on the fatigue evaluation of magnetic materials by Barkhausen noises. The Barkhausen noise is the signal generated by the movement of the 180-degree magnetic domain inside the magnetic materials. Though the Barkhausen noise of the magnetic materials is usually measured by the magnetic sensor under the alternative magnetic field, we revealed that the Barkhausen noises under the rotational magnetic field were different from the ones under the alternative magnetic field and named them as "Rotational Barkhausen noise". We also made clear that the power of the Barkhausen noises from INCONLE plates changed after applying the thermal fatigue. However, it was very difficult to quantitative and qualitative the relationship between the Barkhausen noise and the fatigue level, because the Barkhausen noise is the complicated nonlinear signal. Therefore we examined the chaotic behavior of the rotational Barkhausen noise to evaluate the fatigue level of the magnetic materials.

Barkhausen Noise Analysis for Stress Field Evaluation on Bearing Raceway Used in Aeronautic Engine

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---Bearings in aeronautic engines are submitted to very severe running conditions. The loading zones between balls or rollers and raceways sustain mechanical stresses leading to hertzien fatigue phenomena. At end of this phenomena, micro-cracks may appear on loading zone. There are capable of developing until the bearing failure which may cause the engine stop. It is therefore indispensable to keep quality of loading zone in aeronautic motor bearings. Preoccupations are metallurgical aspect (avoiding grinding abuse), and stress state (targeting compressive residual stresses) for any loading zones of bearings. From which the necessity to validate a method capable to introduce residual stresses and to develop a NDT method in the same way to ensure the follow up of associated residual stress profiles. So the intention of our work is to present a NDT method based on the phenomenon of the Barkhausen noise to identify the stress profiles of loading zones between balls or rollers and raceways. This method is adapted to the industrial imperatives bound to lineally measurements. Indeed, this solution presents the advantage to be without contact, rapid and suitable for the circular geometry's rings. By leaning on the X ray diffraction as method of reference, we showed the efficiency of the Barkhausen noise to estimate the residual stress profiles on raceways after machining operations, after specific pre-stressing treatment and after running of engine. Today the advancement of our works permits us to consider, in a near future, the transfer of this method toward the industrial environment.

A Comparison of Theory and Experiment for the Effects of Stress on Magnetic Hysteresis and Barkhausen Activity in Stainless Steel

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---It is of practical interest to infer residual-stress information from stainless steel gas turbine blade shrouds using nondestructive methods. The residual stresses built up as the blades were welded into place. Magnetic hysteresis and Barkhausen effect measurements are particularly suitable for this purpose due to their high sensitivities to the stress induced magnetic anisotropies. However, due to the complex nature of the magnetic interactions, a more fundamental study (calibration) must be carried out prior to quantitative analysis of the measurement results. Magnetic hysteresis loops and Barkhausen effect signals were measured on 410 stainless steel laboratory specimens under various applied loads. The maximum applied stress was about 90% of the yield strength and was applied using an Instron testing machine. The resulting calibration curves were used to estimate the residual stresses in the turbine blade shrouds from the on-site measurement data. Good agreement was observed between the residual stresses determined by the magnetic NDE measurements and by hole-drilling. The measured results were compared with predictions made using the hysteresis model and the extended Barkhausen model. The comparison forms part of an ongoing validation and refinement procedure for the model. Further refinements will be made to the models to eliminate the need for performing experiment-based calibrations.---The authors would like to acknowledge Siemens-Westinghouse Power Corporation, Quadrangle Building, 4400 Alafaya Trail, Orlando, FL 32826-2399, for the financial and technical support of this work.

Neutron Fluence Effects on the Magnetic Parameter Changes in Linde 80 High Copper Weld

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---The changes in magnetic parameters due to irradiation have been recently investigated within the efforts to find reliable nondestructive evaluation (NDE) techniques in predicting, for example, fracture toughness of embrittled reactor pressure vessel (RPV) steels. In the present study, neutron fluence effects on the magnetic parameters, i.e. Barkhausen noise amplitude (BNA), saturation magnetization (Ms), susceptibility (¥ö) and coercivity (Hc) were investigated for surveillance specimens made of Linde 80 high copper weld of reactor pressure vessel (RPV) in view of the need for additional experimental data regarding the magnetic NDE of neutron irradiated reactor structural steel. These specimens are in three different conditions, i.e. unirradiated and irradiated to two different neutron fluence (1.23E + 19 n/cm2, 9.94E + 19 n/cm2, EÃ 1 MeV, 290 É). The changes in the magnetic parameter due to irradiation in the present study were roughly the same as the results reported earlier: The hysteresis loop appeared to turn clockwise further as fluence increased, resulting in further decrease in BNA and susceptibility, and the increase in the coercivity for the Linde 80 high copper weld. The fluence effects on the changes in BNE and coercivity (Hc) appeared differently to YS, BNA and susceptibility (¥ö). Since this observation regarding the coercivi ty is contrary to the previous observation for unirradiated RPV steels, further systematic investigation may be needed with regard to the observation on the coercivity made in the current study. An inter-comparison between the changes in magnetic parameters and yield strength due to irradiation show that, of those five magnetic parameters investigated, the BNA and susceptibility (¥ö) appeared to show a relationship for the Linda 80 high copper weld.

A Magnetic Method in the Testing of Ferromagnetic Materials

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---Electromagnetic nondestructive evaluation (NDE) of materials and structures is concerned with either the measurement of some material property or the detection and characterization of material flaws. The use of magnetoresistive sensors for electromagnetic NDE has grown considerably in the last few years. In this paper we describe a probe with the magnetoresistive sensor which enables inspection of plates made of magnetic steels. With magnetic methods of testing, a magnetic field is applied to the object under test and any resulting changes of magnetic flux in the region of interest are observed. The probe considered in the paper includes an exciting coil wound around a hollow cylindrical ferrite core and supplied with a direct current. The magnetoresistive sensor is placed inside the core over the surface of the plate under test. Such a location of the magnetoresistive sensor protects the sensor from the working magnetic field and results in higher sensitivity to small changes in the magnetic field caused by surface and subsurface defects. Simplified theoretical analysis of the output voltage of the transducer as well as results of measurements for steel plates are given.

Characterization of Complex Parameters for a Piezoelectric Thin Film Deposited on a Substrate

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---Piezoelectric thin films deposited on proper substrates have been widely applied for fabricating devices. For improving the performance of the devices, the material parameters of the film are very important, which determine the piezoelectric response of the thin film. The real parts of the material parameters have been obtained by a series of approximate equations. In this paper, a method to extract both the real and imaginary parts of stiffed elastic constants C_{33}^D, piezoelectric constant h_{33}, dielectric constant $?_{33}^S$, and electro-mechanical coupling constant k_1^2 of the thickness extensional mode of a piezoelectric thin film deposited on a substrate is presented. The elastic constant C_s^D of the substrate is also can be determined by the method. Based on the measured electric impedance curve of the composite resonator consisting of the thin film and substrate, a merit-value function $?^2(C_{33}^D, ?_{33}^S, h_{33}, C_s^D)$ is defined, which defines the deviation between the measured impedance curve and the calculated impedance curve under the given values of $C_{33}^D, ?_{33}^S, h_{33}, C_s^D$. Then a nonlinear multi-parameter data fitting technique is used to extract the complex material constants $C_{33}^D, ?_{33}^S, h_{33}, C_s^D$ of the film and substrate by taking the value of the function $?^2$ in a minimum. The proper initial values of $C_{33}^D, ?_{33}^S, h_{33}, C_{33}$ are very important for the multi-parameter data fitting technique. A series of approximate equations are also deduced by using the spectrum structure of the measured impedance curve. The accuracy of the method is demonstrated by numerical simulation for two typical samples: a sol-gel PZT film deposited on a stainless steel plate and a commercial PZT film deposited on an aluminum plate. The results show the errors of the extracted complex material constants are less than 0.5%.---The authors would like to thank Professor Z. Wang of the Department of Physics, Concordia University, for his inspiring discussions.

Evaluation of Residual Stress Distribution Using SAW

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---In this study, the dispersion relation and the propagation characteristics of the Rayleigh surface wave are investigated indirectly by measuring the profile(angular dependency) and frequency spectrum of the backward radiation. The radiation is the longitudinal wave leaked from the surface wave that is converted from the incident ultrasonic wave and doubly propagates the scuffing region in the scuffing specimens(Averaging Method). The profile and the spectrum then are compared to the residual stress distribution determined by X-ray diffraction. The width of the backward radiation profile increases and the peak intensity decreases as the increase of variational rate of residual stress distribution for the scuffing specimen. The peak angle represents the amount of residual stress and plastic deformation, etc. The spectrum of backward radiated wave shows that the surface wave is scattered by micro-fatigues during the propagation leading to severe missing of high frequency component. The result observed in this study demonstrates high potential of the backward radiated ultrasound as a tool for the nondestructive evaluation of the subsurface gradients of materials.

Theoretical and Experimental Determination of the Natural and Initial Acoustoelastic Coefficients

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---The main effect of stresses on the propagation of ultrasonic wave is the variation of its velocity. Generally, the relative change of wave velocity due to the stress is proportional to the latter and the proportional coefficient is known as the acoustoelastic coefficient. For most of ultrasonic methods, the knowledge of the value of these acoustoelastic coefficients is necessary to evaluate stress field. The theoretical determination of these coefficients is more or less complex in function of the degree of symmetry of the material and the development can be realized from different coordinates systems (natural or initial). Experimentally, it is usually easier to obtain the coefficients defined with regard to the natural coordinates because the length of propagation of the wave to be taken into account in the determination of these coefficients remains constant. When residual stresses in a material have to be measured, this latter is already in the initial state and consequently the access to its natural state is not possible. This paper is devoted to the evaluation of the error introduced by the use of acoustoelastic coefficients defined with the natural coordinates for the estimation of residual stresses. The differences between the acoustoelastic coefficients expressed with the natural and initial coordinates are theoretically and experimentally determined and compared. It is shown that the value of some coefficients can vary significantly according to the used system of coordinates and that the consequence on the estimation of residual stresses can be important.

Rapid Transmission Coefficient Reconstruction and Material Property Estimation in Plates

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---Rapid reconstruction of the transmission coefficient (TC) of an infinite plate across a wide frequency band and over a large angular range is achieved by scanning a highly focused transducer along the plate to collect its transmitted field in a fluid-coupled setup. A temporal and spatial Fourier transform is applied to transform the acquired data from the x-t (spatial coordinate and time) domain to the k-f (wave number-frequency) domain. With the aid of a reference scan to measure beam profiles, the extrinsic effects of both the transducer beams and the electronic system responses are removed from the k-f domain result to reveal the intrinsic material property related TC. The reconstructed TC is then used to evaluate the elastic behavior of the plate. For isotropic plates, both longitudinal and shear constants are determined directly from the plate-wave mode cut-off frequencies mapped in a single transducer scan at low orientation angle. For anisotropic plates, elastic constants are reconstructed through an inversion algorithm operating on the data selected from the different parts of the measured TC in a stepwise, targeted fashion based on sensitivity studies. We have also developed a complex transducer point model for the interpretation of the measurement results. Experiments on both isotropic and anisotropic plates show a measurement error of less than 5% from the contact acoustic estimates for most of the elastic constants.---This work was supported in part by the Institute for Physical Research and Technology at Iowa State University.

Non-Contact System to Measure the Material Properties of a Layered Viscoelastic Medium

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---This study investigates a method to determine the material constants of a layered viscoelastic medium. A mathematical model in a double transformed space is first set up to describe ultrasonic wave propagation in a semi-infinite layer with two stress-free boundaries. This model is solved numerically for individual Fourier-components with the material parameters as variable parameters. These results are compared to Fourier-components of experimentally measured data. The in-plane and out-of-plane surface displacements are measured with a fiberoptic, interferometric detection system. A time-of-flight analysis is used to estimate the material properties that are then optimized with a Downhill-Simplex Algorithm to minimize the error between the theoretical solution and the measurements.

Material Characterization Using Nonlinear Wave Propagation

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---The objective of this research is to develop an understanding of the underlying mechanics of nonlinear waves in order to develop quantitative techniques capable of interrogating damaged materials. Previous theoretical simulations revealed that harmonic waves propagating through a nonlinear elastic material generate higher harmonic frequencies. The current study uses high-fidelity laser ultrasonic techniques to experimentally investigate nonlinear effects in materials. Specific experiments include generation with a single harmonic input or with two superposed harmonic waves. Material systems under investigation include hysteretic, nonlinear materials like rocks, and cement-based materials, as well as polymers. One goal of this research is to verify behavior predicted by a numerical model, as well as provide physical interpretation of nonlinear wave propagation.

A Two-Dimensional Reconstruction Theory of Thermal Conductivity Profiles Based on Thermal Wave Technique

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---For the nondestructive evaluation of the thermal properties of the materials, the problem of inverse calculations of thermal conductivity profiles from the measured surface temperature has attracted considerable interest. Many one-dimensional reconstruction theories were established to determine the thermal conductivity profiles etc., but two-dimensional reconstruction theory has not been reported. In this paper, a two-dimensional reconstruction theory is firstly presented, in which a solid material with a boundary width, thickness and a semi-finite extension in length is employed as a sample. The surface of the sample is illuminated by a modulated laser beam as a thermal line source and the surface temperature of the sample is detected by a thermal wave technique. Then, two-dimensional heat conduction equation and the related boundary conditions, including other boundaries are assumed adiabatic, are used for reconstructing inhomogeneous thermal conductivity profiles ?(*x,y*) of the sample. By using a pulse spectrum technique and a Newton-like iterative method, the two-dimensional inverse problem is expressed by a first kind of Fredholm integral equation. Further, the integral equation is approximated by ill-posed linear algebra equations. In order to overcome the singularity of the ill-posed linear algebra equations, a regularization method is introduced and an error function is defined to choice the regularization parameter automatically. Numerical simulations are performed according to photothermal signals on several samples. The results demonstrate that this approach is effective and stable even the signals are with 5% random noise disturbance.

Anisotropic Effects in Noncontacting Thermoelectric Materials Characterization

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---Inclusions and other types of imperfections in metals can be nondestructively detected by noncontacting magnetic measurements that sense the thermoelectric currents that appear when the specimen is subjected to directional heating and cooling. The detectability of small imperfections is ultimately limited by the intrinsic thermoelectric anisotropy and inhomogeneity of the material to be inspected. Only noncubic materials such as titanium alloys exhibit crystallographic anisotropy, though a much weaker morphological anisotropy can be also exhibited by textured cubic materials. An analytical method for calculating the magnetic field produced by thermoelectric currents in anisotropic materials under two-dimensional directional heating and cooling has been developed. Experimental results from a textured Ti-6Al-4V titanium-alloy plate are shown to be in very good agreement with the predictions of this model. These results clearly indicate that the earlier observed strange background signatures in textured specimens can be attributed to the thermoelectric anisotropy of the material. In such specimens the best flaw detectability can be achieved by rotating the heating/cooling direction so that the anisotropic effect averages out. The results also indicate that noncontacting thermoelectric inspection can be used to characterize the macroscopic texture of materials by evaluating their magnetic signatures under external heating and cooling.

A Study on the Splitting of the Valence Band for a AgInS2/GaAs Epilayer Using Photocurrent Measurement

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---The chalcopyrite AgInS2 epilayers were grown on the GaAs substrate by using a hot-wall epitaxy (HWE) method. The temperature dependence of the energy band gap of the AgInS2 obtained from the absorption spectra was well described by the Varshni's relation. In addition, we obtained the free exciton binding energy, 0.1115 eV, for the chalcopyrite AgInS2/GaAs by using Shay's result. The crystal field and the spin-orbit splitting energies for the valence band of the AgInS2 have been estimated to be 0.1541 eV and 0.0129 eV, respectively, by means of the photocurrent spectra and the Hopfield quasicubic model. These results indicate that the splitting of the ¥Äso definitely exists in the Ã5 states of the valence band of the AgInS2/GaAs epilayer. The three photocurrent peaks observed at 10 K are ascribed to the A1-, B1-, and C1-exciton peaks for n = 1. Also, we obtained the exciton peaks from the PC spectrum at 293 K. Therefore, we conclude that the peaks observed by the photocurrent measurement are the free exciton peaks or peaks due to band-to-band transitions.

Ultrasonic NDE and Mechanical Testing of Fiber Placement Composites

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---Fiber placement is a tow-based, automated manufacturing method for composites that is poised to replace the traditional hand layup. Being tow-based, the internal structure of a fiber placed composite, especially when there is also fiber steering, is considerably more complex than a laminate laid up from unidirectional prepreg tapes. In this work we report ultrasonic imaging of fiber placed composite laminates, both with and without fiber steering, with an eye toward developing a tool for evaluating their quality. Ultrasonic scan images are used for mapping out the gaps and overlaps of fiber tows at the boundary of adjacent courses. Mechanical short beam shear tests were conducted to measure the interlaminar shear strength for comparison with the NDE results and to examine the failure behavior of fiber placed composites with and without steering. Ultrasonic scan images of the panels were used to guide the extraction of specimens from regions with anomalies and from clear regions. The mechanical test data and the comparison with ultrasonic results will be described.---This work was supported by the NSF Industry/University Cooperative Research Center for NDE at Iowa State University.

Characteristic Evaluation of CFRP Composites Under Falling Weight Impact Loading

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---This paper describes a method for the falling weight impact test in order to estimate the impact energy absorbing characteristics and impact strength of CFRP laminate plates in consideration of stress wave propagation theory. Delamination area of impacted specimens for the different ply orientation was measured with ultrasonic C-scanner to find correlation between impact energy and delamination area. Absorbed energy of quasi-isotropic specimen having four interfaces was higher than that of orthotropic laminates with two interfaces. The more interfaces, the more absorbed energy. Hybrid specimen containing GFRP layer was higher than that of normal specimens. Also, a system of falling weight impact tester introduced here has been successful in evaluating the characteristics and impact strength of CFRPs.

Investigation of the Influence of Fraction of SiC Particles on the Elastic Model of SiC_p/Aluminum by Laser Ultrasonic Method

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---We investigate the influence of the volume fraction of silicon carbide particles (SiC_p) in an Al matrix composite on the elastic modeli of composites by using laser ultrasonic method. A series of silicon carbide particles reinforced LY12 aluminum alloy (SiC_p/LY12Al) composites with six volume fractions of SiC_p (10 %, 15 %, 20 %, 35 %, 45 % and 55 %) are used as samples. The grain sizes of SiC particles are of 7 ?m for 5 samples, except for the sample with volume fractions 15% of SiC_p. The grain size of the sample with SiC_p volume fraction 15% is about 3.5 to 5 ?m. The results show that the value of the elastic model increases linearly with the increasing of the volume fraction of SiC particles. The relative elastic model changes can be reached to 124.88% for Shear model and to 125% for Young model. We also calculate the elastic modeli of composite based on the elastic theory for two phase system. The detailed results and discussions will be presented.

Influence of Fraction of SiC Particles on the Thermal Diffusivity of Composite SiC_1/Aluminum by Mirage Effect

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---We investigate the influence of the volume fraction of silicon carbide particles (SiC_p) on the thermal diffusivity of Al matrix inforced by SiC_p particles composite by using mirage effect. A series of silicon carbide particles reinforced LY12 aluminum alloy (SiC_p/LY12Al) composites with six volume fractions of SiC_p (10 %, 15 %, 20 %, 35 %, 45 % and 55 %) are used as samples. The grain sizes of SiC particles are of 7 ?m for 5 samples, except for the sample with volume fractions 15% of SiC_p. The grain size of the sample with SiC_p volume fraction 15% is about 3.5 to 5 ?m. The results show that the value of the thermal diffusivity decreases linearly with the increasing of the volume fraction of SiC particles. The relative thermal diffusivity changes can be reached to 33 %. We also calculation the thermal diffusivities for those composites based on several theoretical models. The detailed results and discussions will be presented.

Thermal Wave Determination of the Thermal Diffusivity of Composite ZrO_2/Aluminum

---S. Lin[1], X. R. Zhang[1], M. Zhou[2], and J. He[1], [1]Laboratory of Modern Acoustics and Institute of Acoustics, Nanjing University, Nanjing 210093, China; [2]College of Mechanical Engineering, Jiangsu University, Zhenjiang 212003, China

---We improve our mirage detection system including the hardware and software respectively. Then we investigate the thermal diffusivity of Al matrix inforced by ZrO_2 particles composite by using mirage effect. A series of ZrO_2 particles reinforced A356 aluminum alloy (ZrO_2/A356Al) composites with four weigh fractions (wt%) of ZrO_2 (5 %, 10 %, 12 %, 15 %) are used as samples. The average grain size of the ZrO_2 particles is of 4 ?m for those samples. The results show that the value of the thermal diffusivity decreases with the increasing of the weigh fraction of ZrO_2 particles. The relative thermal diffusivity changes can be reached to 28.6%. We also calculation the thermal diffusivities for those composites based on several theoretical models. The detailed results and discussions will be presented.

Acoustic Emission Characteristics on Microscopic Damage Behavior of Carbon Fiber Sheet Reinforced Concrete

---Jin-Kyung Lee, Department of Mechanical Engineering, Dong-Eui University, Pusan 614-010, Korea; Joon-Hyun Lee, School of Mechanical Engineering, Pusan National University, Pusan 609-735, Korea

---It is well recognized that the damage associated with the aging of civil infrastructures is one of the most serious threats to the assurance of public safety. Recently, carbon fiber sheet (CFS) has been widely used for reinforcement and rehabilitation of damaged concrete beams since they offer many advantages when compared to conventional steel bar. In order to safely apply to damaged concrete structures, however, the reinforcement effect of CFS for concrete beams and the microscopic damage behavior of CFS reinforced concrete must be understood completely. In this study, a three-point bend test has been carried out to understand the damage progress and micro-failure mechanism of CFS reinforced concretes. For these purposes, four kinds of specimens were used; unreinforced concrete, steel bar reinforced concrete, CFS reinforced concrete, and concrete reinforced by both steel and CFS. Two-dimensional AE source location was performed to monitor crack initiation and propagation processes for the four types of specimens of reinforced specimens.

Velocity Measurement on Asphalt and Nondestructive Inspection of Pipe Under the Asphalt

---O. Kobori, Osaka Sangyo University, 3-1-1, Nakagaito, Daito City, Osaka Prefecture, 574-8530, Japan; Y. Udagawa, Imaging Supersonic Laboratories Co., Ltd., 12-7, Tezukayama-Nakamati, Nara City, Nara Prefecture, 631-0063, Japan

---Asphalt concrete is composed of sand, coal-tar, and fine gravel. When an ultrasonic wave, such as 5 MHz frequency is transmitted into the asphalt, sound waves travel making a detour around gravel and decrease in frequency because of scattering and/or camping. We can only observe the low frequency component of about 500 kHz in receiving echoes. On the other hand, most ultrasonic testers with transducer and pulser-receiver are designed to have the efficiency in the range of resonant frequency of the transducer. Effective sensitivity of 5 MHz transducer, for example, is settled in from 2.5 MHz to 10 MHz. In this case, we cannot observe the waves of less than 2 MHz frequency because of a lack in sensitivity in receiving. For this reason, ultrasonic measurement is not effective to the materials with high damping and/or scattering such as asphalt, composite, firebrick, and forming ones. We use digital wideband ultrasonic testers (UCT 12 db) with active transducer for the measurement that is developed by the co-author. Ultra wideband uni-pole wave is generated by step-function pulser in the active transducer and transmitted sound frequency range from DC to 5 MHz. The sound waves passed through the media are received by another ultra wideband receiver in the active transducer. Its effective frequency range is from 20 kHz to 3 MHz at ISL-N02020R transducer. Experiment is achieved to the asphalt model of which size is 300 mm square and 105 mm inches thick and which has a 300 mm long pipe with 22 mm diameter in the 54 mm depth. Sound waves are transmitted normally on each date point to the model and the time of flight is measured by transmission technique and echo method. Experimental results show that average velocity is 3734 m/s in longitudinal and 2467 m/s in share wave. Pipe under the asphalt is found within the error of 1 mm.

A Study on Annealing Effects of AgInS2/GaAs Epilayer Obtained from Photoluminescence Measurement

---K. J. Hong, J. W. Jeong, and H. W. Baek, Department of Physics, Chosun University, 375, Sosok-dong, Kwangju 501-759, Korea; K. H. Im, Department of Automotive Engineering, Woosuk University, 490 Hujung-ri, Samrae-up, Wanju-kun, Chonbuk 565-701, Korea

---The AgInS2 epilayers with a chalcopyrite structure grown using a hot-wall epitaxy (HWE) method have been confirmed to be a high quality crystal. From the optical absorption measurement, the temperature dependence of the energy band gap on AgInS2/GaAs was found to be Eg(T) = 2.1365 eV - (9.89-10-3 eV) T2/(2930 £« T). After the as-grown AgInS2/GaAs was annealed in Ag-, S-, and In-atmospheres, the origin of point defects of AgInS2/GaAs has been investigated by using the photoluminescence (PL) at 10 K. The native defects of VAg, VS, Agint, and Sint obtained from PL measurements were classified as a donors or acceptors type. And we concluded that the heat-treatment in the S-atmosphere converted AgInS2/GaAs to an optical p-type. Also, we confirmed that In in AgInS2/GaAs did not form the native defects because In in AgInS2 did exist in the form of stable bonds.

Collaboration for Education in Nondestructive Testing – Extending the Reach

---Brian Larson, Sam Wormley, and Lester Schmerr, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011; Bruce Crouse, Cowley County Community College, Arkansas City, KS 67005; Randy Walbridge and Bill Wiley, Southeast Community College, Milford, NE 68405

---The development of NDT related educational materials has been the focus of the North Central Collaboration for NDE Education for the past four years. The Collaboration was started as a National Science Foundation (NSF) Advanced Technology Education (ATE) program and united four Midwest community colleges and Iowa State University. The Collaboration developed advanced teaching methods and new materials that have allowed students to learn NDT concepts better and in less time. These materials have been made freely available over the Internet and have been well received. The Collaboration has recently received a second NSF ATE grant to become a national focal point for NDT education and has expanded to include more educational institutions. In this second phase of activities, the collaboration will develop a coordinated, multi-level approach that 1) promotes NDT as a career field to students, teachers and counselors in junior and senior high schools, 2) servers as an educational resource for students and instructors of two-year NDT programs and their graduates who are working in the industry, and 3) supplies educational materials that will allow educators in other technology programs (such as manufacturing and welding) to introduce their students to NDT methods. This paper will review the current activities of the Collaboration for Education in Nondestructive Testing.---Support for this work was provided by the National Science Foundation's Advanced Technology Education (ATE) Program through grant #DUE 9602370.

Vertically Integrated Engineering Design for Combined Research and Curriculum Development in Materials Engineering and Nondestructive Evaluation

---D. C. Jiles [1,2,6], M. Akinc[2,6], S. B. Biner[2,6], K. Constant[2], J. N. Gray[3], M. Huba[4], S. W. Martin[2], L. W. Schmerr[5] and R. Bruce Thompson [1,2,5], [1]Center for NDE, [2]Department of Materials Science & Engineering, [3]Department of Mechanical Engineering, [4]Department of Educational Leadership and Policy Studies, [5]Department of Aerospace Engineering and Engineering Mechanics, [6]Ames Laboratory, US DoE, Iowa State University, Ames, Iowa 50011

---As part of a new grant from the National Science Foundation, the Center for NDE is providing industrial design project opportunities for students throughout their undergraduate careers. These projects combine traditional materials characterization with advanced computer simulations for determining the suitability of engineering designs for NDE. Traditionally, engineering students have taken a capstone senior design course; however the conventional senior design approach is no longer able to meet the needs of high technology industries. Engineering graduates now need a diverse range of technical skills, including an understanding of the interplay between materials properties, design, manufacturing, inspection, degradation and failure. These needs can better be met by providing research opportunities throughout the students' undergraduate careers. The goal is to incorporate engineering design experience into the curriculum through the concept of “vertically integrated design”. The curriculum includes a two-credit sophomore level lecture/laboratory course, a two-credit junior level laboratory/lecture course and four credits of design experience in the senior year. Students begin in their sophomore years. During their junior and senior years, they progress to become team leaders. In the 2000-2001 academic year we had 16 design projects during the fall semester with 54 students, and 5 design projects during the spring semester with 14 students. Projects are set up with industrial partners and are selected to be multi-year investigations with lifetimes that extend beyond the normal one semester capstone design project. These projects provide continuity to the investigations and allow a more ambitious scope of work to be addressed.---This research is supported by the National Science Foundation under grant number EEC-9980331.

SESSION 29
UT TRANSDUCERS AND FIELDS
C. Valle, Chairperson
Cleaveland 151 (Druckenmiller)

3:30 PM **Practical Application of Modeling at Ultrasonic Probe and Inspection Design**
---H. Wüstenberg, R. Boehm, and D. Tscharntke, BAM, Berlin, Germany

3:50 PM **Quantitative Evaluation of Defects in Anisotropic Media Using the Far-Field Radiation Characteristics of Vibrating Sources**
---M. Spies, Fraunhofer-Institute for Nondestructive Testing, IZFP, University Building 37, 66123 Saarbrucken, Germany

4:10 PM **Prediction of Angle Beam Ultrasonic Testing Signals Using Multi-Gaussian Beams**
---H.-J. Kim and S.-J. Song, Sungkyunkwan University, School of Mechanical Engineering, 300 Chunchun-dong, Jangan-ku, Suwon, Kyungggi-do, 440-746, Korea

4:30 PM **Development of a Smart Flexible Transducer to Inspect Component of Complex Geometry: Modeling and Experiment**
---O. Roy, S. Mahaut, and O. Casula, CEA/DRT/LIST, CEA Saclay, 91191 Gif-sur-Yvette Cedex, France; G. Cattiaux, CEA/IPSN, Fontenay aux Roses, France

4:50 PM **Effects of Surface Irregularities of Components on Wideband Radiation of Ultrasonic Beams by Contact Transducers**
---A. Lhémery, S. Chatillon, and P. Calmon, French Atomic Energy Commission, CEA/LIST, CEA-Saclay, bât. 611, 91191 Gif-sur-Yvette cedex, France

5:10 PM **A Study on Development of an EMAT Sensor for the High Temperature Measurement**
---I.-S. Kim, Y.-J. Jung, and B.-S. Sung, Mokpo National University, Department of Mechanical Engineering, Chungkye-myun, Muan-gun, 534-729, Korea

5:30 PM **Use of Acoustic Emission for Optimal Poling and Quality Checking of PZT Ceramics**
---K. M. Rao and S. P. M. Rao, Osmania University, Physics Department, University College of Science, Hyderabad-500 007, India

Practical Application of Modeling at Ultrasonic Probe and Inspection Design

---H. Wüstenberg, R. Boehm, D. Tscharntke, BAM, Berlin, Germany

---Most of the suddenly occurring actual NDT problems require an urgent solution with few time and possibilities to carry out basic investigations to find out the optimal solution for the probes and the whole inspection concept. This has nevertheless in the past been the origin of many new probe designs and concepts based more on intuition than on pure scientific rationales. The theory went afterwards. But this has been also the origin of many valuable modelling approaches growing by the years with the experience and the practical needs. As well as for the ultrasonic probe design as for the modelling of inspection situations we have at our institute developed approximate modelling tools, which have been practically applied and validated at various occasions. This contribution will outline the basic aspects of the modelling approaches for the soundfield at the probe design for focussing and phased array probes applied at various surface geometries. All desired wave modes, pulse shapes and different forms of beam profiles of a probe concept are modelled and also the interaction with different type of defects at positions near to the surface or within the volume in components with a simplified surface geometry. This enables the simulation of inspection problems and the optimal choice of the most important parameters e.g. for a mechanized UT inspection. Since the approximations are selected to assure a fast and sufficiently exact calculation of A-scans or B-scans, the use of this approach for an interactive adaptation of modelling results to measured ones is possible. Examples for the application of this concept for the technical justification of a probe arrangement for a specific case and the critical evaluation of UT and RT inspections will be given.

Quantitative Evaluation of Defects in Anisotropic Media Using the Far-Field Radiation Characteristics of Vibrating Sources

---Martin Spies, Fraunhofer-Institute for Nondestructive Testing, IZFP, University Bldg. 37, 66123 Saarbrucken, Germany

---Understanding the nature of wave radiation and propagation within anisotropic materials, such as fiber-reinforced composites, columnar-grained weld structures and certain ceramic materials, is an essential step in the development of efficient NDE techniques. However, many models require extensive computational efforts due to the increasing complexity of analytical expressions and to numerical difficulties. Also, relationships which would allow to exploit analogies to the isotropic material case are generally not available. In this contribution, explicit far-field formulations for wavefields generated by vibrating planar sources are presented, applicable to both transducer radiation and wave scattering at defects. Integral equations for circular and rectangular sources are solved using a far-field approximation. For the propagating bulk waves with single-valued group velocities, expressions are obtained similar to the isotropic case and validated via comparison with exact calculations using point source superposition. On this basis, the scattering behavior of globular and crack-like defects is examined using explicit expressions for pulse-echo amplitude locus curves. Quantitative defect evaluation, where? in addition to the times-of-flight and the maximum amplitudes? the dynamic behavior of the flaw signal is used, is performed in the following way: first, spherical and disk-shaped defects are discriminated with the help of their isolated directivities, then the amplitude locus curves are inverted to yield the respective defect dimensions. This procedure is illustrated using simulated as well as experimental data for a unidirectional composite material.

Prediction of Angle Beam Ultrasonic Testing Signals Using Multi-Gaussian Beams

---Hak-Joon Kim and Sung-Jin Song, School of Mechanical Engineering, Sungkyunkwan University, 300 Chunchun-dong, Jangan-ku, Suwon, Kyungggi-do, 440-746, Korea

---The angle beam ultrasonic testing is the one of the fundamental testing methods those are widely used for the nondestructive evaluation of various materials or structures including especially weldments. The quantitative prediction of the testing signals, however, is rather difficult. This paper will describe an efficient approach that can provide a robust remedy to such a difficult problem. In this work, using the multi-Gaussian beam, produced are the necessary elements to form a complete angle beam ultrasonic testing model, including the radiation beam from circular plane transducers, the reflected/refracted beams from/through interfaces, the scattering beam from a flaw, and the reception by receiving transducers. Combining these elements, proposed are the two models: 1) the reflection from the circular part of the IIW standard block that can be served as the reference model for the estimation of the system efficiency factor, and 2) the flaw responses from which the angle beam testing signals are predicted. The accuracy of the proposed models will be validated by the initial experiments.

Development of a Smart Flexible Transducer to Inspect Component of Complex Geometry: Modeling and Experiment

---Olivier Roy, Steve Mahaut, and Olivier Casula, CEA/DRT/LIST, CEA Saclay, 91191 Gif-sur-Yvette Cedex, France; G. Cattiaux, CEA/IPSN, Fontenay aux Roses, France

---Ultrasonic nondestructive testing of component of irregular geometry carried out with contact transducer must faces several difficulties: sensitivity losses due to unmatched contact, inaccurate localization of defects due to transducer disorientation, uncovered scan area in the component. To improve the performances of such inspections, the CEA, supported by the safety authorities (IPSN), has developed a new concept of phased array transducer. The phased array radiating surface is flexible to optimise the contact and the sensitivity of the testing, while the characteristics of the transmitted beam are preserved during the scanning, thanks to adapted delay laws. The delay computation requires the actual position of the elements, so a specific instrumentation is coupled to the transducer to measure its radiating surface distortions. Thus, this smart flexible transducer becomes self-adaptive. Recent studies have been made to obtain further performances improvements of this system, including instrumentation development and a new phased array design. Both longitudinal and shear waves focused beams can therefore be generated and mastered with this smart transducer. Inspections have been performed on a specimen containing artificial defects under a realistic profile, with an adaptive mode to compensate the effect of the irregular profile. Experimental results, displayed using specific imaging, show the ability of this system to detect and characterize defects under irregular profiles, using longitudinal or shear waves in a fully mastered beam.

Effects of Surface Irregularities of Components on Wideband Radiation of Ultrasonic Beams by Contact Transducers

---Alain Lhémery, Sylvain Chatillon, and Pierre Calmon, French Atomic Energy Commission, CEA/LIST, CEA-Saclay, bât. 611, 91191 Gif-sur-Yvette cedex, France

---Methods of NDT by contact ultrasonic transducer (angle beams) are widely used in industry. When a method is proposed, it is necessary to demonstrate its performances. Typically, it is needed to demonstrate the ability of a given transducer to radiate a beam of wanted characteristics whatever its position relatively to the component (zone coverage). When the component is of irregular surface, the transducer wedge cannot be directly coupled to it. A volume between the wedge and the component (filled by water or oil used as a coupling) is created that fundamentally modifies transducer radiation behavior. The paper addresses this problem. At first, it describes a model developed at CEA to account for the main effects observable in such a situation (beam spreading, skewing, splitting, unexpected contributions leading to false alarms). It is shown that the main effect is the co-existence of wave modes propagating directly from the wedge to the component with others involving a double refraction phenomenon (wedge / liquid coupling / component). Then, predicted fields are compared to measured results. This concerns displacement fields measured at the surface opposite to that (irregular) on which the transducer acts. The very good agreement obtained proves the validity of our approach.

A Study on Development of an EMAT Sensor for the High Temperature Measurement

---Ill-Soo Kim, Young-Jae Jung, and Back-Sub Sung, Department of Mechanical Engineering, Mokpo National University, Chungkye-myun, Muan-gun, 534-729, Korea

---Knowledge of the liquid core location during continuous casting operation has important implications from the standpoint of product qualify and caster operation. An understanding of this phenomenon is extremely important because mechanical interactions between the strand and the machine in the containment zone impact significantly on both the machine operation and product quality. To solve the above problems EMAT (Electro Magnetic Acoustic Transducer) has been designed and fabricated with elongated spiral coil with permanent magnetic core and simulators with 2, 4, 8, 16, 32 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 quality of the productivity of the machine.

Use of Acoustic Emission for Optimal Poling and Quality Checking of PZT Ceramics

---K. Mallikarjuna Rao and S. P. Mallikarjun Rao, Osmania University, Physics Department, University College of Science, Hyderabad-500 007, India

---Acoustic Emission (AE) signals are captured during poling and dc field application on PZT-5A ceramic disc samples. Auto regressive (AR) modeling of AE signals was done and the resultant AR coefficients were used in the Pattern recognition of AE source mechanisms. Based on this, AE signals due to domain alignment during poling could be easily discriminated against non domain signals. Thus, the results suggest use of AE methods, to find the optimal poling parameters and check the quality of PZT sample vis-a-vis microcracking in the body of the ceramic. The results are supported by fractographs.

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SESSION 30
X-RAYS
R. E. Green, Chairperson
Smith Auditorium (Sills)

3:30 PM **New X-ray Inspection Microscope Magnifies 3000X with 0.4 Micron Resolution**
---M. Watanabe, H. Kai, K. Ohashi, K. Yada, and B. Willis, X-ray Systems R&D Department, TOHKEN Company Limited, Dai-ichi Seimei Building (10F), 2-7-1 Nishishinjuku, Shinjuku-ku, Tokyo 163-0710, Japan

3:50 PM **Impact of the Low Energy Scattering in the Radiography Simulations**
---F. Inanc, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

4:10 PM **Image Reconstruction of Multisurface Objects from Strongly Limited X-Ray Perspective Angle**
---V. Vengrinovich[1], S. Zolotarev[1], A. Kuntsevich[1], G.-R. Tillack[2], U. Ewert[2], and B. Redmer[2]; [1]Institute of Applied Physics, Akademicheskaya str. 16, 220072, Minsk, Belarus; [2]Bundesanstalt für Materilforschung and Prüfung, Unter den Eichen 87, 12205, Berlin, Germany

4:30 PM **Energy Dispersive Investigation of Lead Screen Intensification**
---S. Wendt, Iowa State University, 209W Nuclear Engineering Laboratory, Ames, IA 50011; J. N. Gray, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

4:50 PM **Computational Determination of Absorbed Dose Distributions from Multiple Volumetric Gamma Ray Sources**
---C. Zhou and F. Inanc, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

5:10 PM **Studies of Dynamic Failure of Steel Pipes Using X-Ray Radiography**
---M. B. Aufderheide, III, T. J. Orzechowski, J. D. Molitoris, A. Sunwoo, A. E. Schach von Wittenau, D. M. Slone, J. A. Jackson, H. E. Martz, Jr., and D. M. Goodman, Lawrence Livermore National Laboratory, L-096, P. O. Box 808, Livermore, CA 94551

New X-ray Inspection Microscope Magnifies 3000X with 0.4 Micron Resolution

---Masaru Watanabe, Hiromi Kai, Kenji Ohashi, Keiji Yada, and Brian Willis, X-ray Systems R&D Department, TOHKEN Company Limited, Dai-ichi Seimei Building (10F), 2-7-1 Nishishinjuku, Shinjuku-ku, Tokyo 163-0710, Japan

---Non-destructive inspection of minute internal structures is required in many scientific, engineering and manufacturing sectors. Previously developed, so called "micro-focus", X-ray systems improved magnification to about 100X, and improved image resolution down to about 10 microns. But, finer detailed inspections are required in such fields as electronics, biology, nano-technology and medical engineering. Resolution of output images is highly dependent on a small, highly bright X-ray spot source from the X-ray target. Production of a small but high brightness electron beam spot for X-ray generation is a prime limiting factor of image resolution. Development of a new X-ray inspection microscope will be presented, having a 25-fold improvement in image resolution by reducing X-ray source spot size to 0.4 microns. High brightness and small spot size has been realized by the development of unique components within the X-ray tube, such as electron-beam emitter, focus coils, and X-ray target. To accommodate samples of various densities, the applied X-ray tube voltage has been made adjustable between 40kV and 120kV. Output images of 640x486 pixels (~VGA) are obtainable with magnification as high as 3000X, and resolution of detail down to 0.4 microns has been made possible.

Impact of the Low Energy Scattering in the Radiography Simulations

---Feyzi Inanc, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---Modeling and simulation has recently acquired significant popularity in the radiography circles for various purposes. Although there are various physical mechanisms that need to be covered in the conventional radiography simulations, most of the attention seems to be devoted to the photoelectric absorption. While some modeling efforts ignore all types of scattering, some try to deal with the issue through various approximations. Almost all simulation efforts ignore coherent scattering and electron binding effects in their work. Electron binding can suppress the incoherent scattering totally at zero degree scattering cases. In addition, it will decrease the incoherent scattering for small degree scattering case. Although coherent scattering is usually important for lower energy levels, it is basically a forward scattering case and it can surpass incoherent scattering angle in the vicinity of zero degree scattering even at significant energy levels. In this work, we will demonstrate inclusion of coherent scattering into simulations and then we will provide several examples for various energy levels and material types.---This material is based upon work supported by the Federal Aviation Administration under Contract #DTFA03-98-D-00008, Delivery Order #IA003 and performed at Iowa State University's Center for NDE as part of the Center for Aviation Systems Reliability program.

Image Reconstruction of Multisurface Objects from Strongly Limited X-Ray Perspective Angle

---V. Vengrinovich[1], S. Zolotarev[1], A. Kuntsevich[1], G.-R. Tillack[2], U. Ewert,[2] and B. Redmer[2]; [1] Institute of Applied Physics, Akademicheskaya str.16, 220072, Minsk, Belarus; [2] Bundesanstalt für Materilforschung und Prüfung, Unter den Eichen 87, 12205, Berlin, Germany

---In the problem of image reconstruction from incomplete X-ray data, a problem can be isolated, in which, due to the mathematical degeneration, an X-ray perspective angle for object observation is too small for obtaining an unambiguous result of restoration. A solution is described which enables finally the precise measurement of internal object dimensions. The general formulation and the practical application are considered in this article. The image restoration of a pipe's longitudinal cross section is obtained from a set of projections taken with a mechanized X-ray data acquisition system with planar geometry. The mathematical concept is based upon the solution of the inverse problem in Bayesian formulation. The first approximation step for strongly reducing the configuration space of interest is implemented with a specially developed technique named "wall thickness increments counting method". The algorithm and a user based software were developed. A feasibility study was carried out, which allows conclusions about the estimation of reconstruction errors by simulation of the measurement parameters deviation from nominated values. It is shown that the specified restored wall thickness error of ?0.5 mm is achieved within a reasonable range of scattering for the experimental data. The technique was validated, using results of a series of experiments performed with the new mechanized planar data acquisition system, which has shown its practicability for smooth surface image restoration of welds.

Energy Dispersive Investigation of Lead Screen Intensification

---S. Wendt, Iowa State University, 209W Nuclear Engineering Laboratory, Ames, IA 50011; J. Gray, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---Research has been completed to better explain the interactions of x-ray photons and lead intensifying screens. The objective was to differentiate between the direct effects from electrons originating in the lead screen and the indirect effects from scattered x-rays. The goal was to develop quantitative relationships that describe the intensification process. The lead screen intensification was studied with various thicknesses of aluminum and iron attenuators. The energy spectra of the emitted x-rays was investigated to determine if there was a correlation to the observed film intensification factors. A high precision motion control system coupled with a high purity germanium detector was used to study the energy spectra. X-ray generator settings from 75 to 300 kvp were samples. Results to date will be reported.---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 through the Airworthiness Assurance Center of Excellence.

Computational Determination of Absorbed Dose Distributions from Multiple Volumetric Gamma Ray Sources

---Chuanyu Zhou and Feyzi Inanc, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---Interstitial brachytherapy is a medical procedure that involves insertion of many radioactive seeds into a sick gland for eliminating sick tissue. For such implementations, the spatial distribution of absorbed dose is very important. The current practice used in the brachytherapy planning is to superimpose the absorbed dose distributions computed for a single seed to find the overall distribution for multiple seed environments. In such an approach, the heterogeneity induced by the presence of many volumetric radioactive seeds go unnoticed. Some of the seeds used in the brachytherapy are made from metallic cores or metallic shell structures. Such metallic structures are very efficient in attenuating the low energy gamma rays emitted by the radioisotopes typically used in the interstitial brachytherapy implementations. The shadowing effect caused by this may results some locations to receive doses that are under what is typically prescribed. In this presentation, we are going to show how we compute the absorbed dose distributions from volumetric sources and then use that algorithm for multiple volumetric radioactive seeds. We will present the results for both superposition method and our method and show that there is medically significant difference between two methods for some locations.---This work was funded by the Roy J. Carver Charitable Trust.

Studies of Dynamic Failure of Steel Pipes Using X-Ray Radiography

---Maurice B. Aufderheide III, Thaddeus J. Orzechowski, John D. Molitoris, Anne Sunwoo, Alexis E. Schach von Wittenau, Dale M. Slone, Jessie A. Jackson, Harry E. Martz, Jr., and Dennis M. Goodman, Lawrence Livermore National Laboratory, L-096, LLNL, P. O. Box 808, Livermore, CA 94551

---The response of metals to the dynamic loading of high explosive detonation is a subject of interest because it is a probe of the equation of state and constitutive model of metals. In order to study these issues, a series of experiments are planned in which steel pipes are filled with high explosive, detonated, and the process of disassembly observed with NDE techniques such as X-Ray radiography and Fabry-Perot velocimetry. In this paper we describe the steps taken to quantify the radiographic imaging, compare the resulting images with simulations performed with the HADES radiographic simulation code, and use the HADES-CCG tomography code to study the accuracy of our reconstructions.---This work was performed under the auspices of the U.S. Department of Energy by the University of California, Lawrence Livermore National Laboratory under Contract No. W-7405-Eng-48.

SESSION 31
INFRASTRUCTURE NDE
J. Harris, Chairperson
Druckenmiller 016

3:30 PM **Ultrasonic Stress Measurements in Prestressing Tendons**
---G. A. Washer, Federal Highway Administration, HRDL-10, NDE Validation Center, 6300 Georgetown Pike, McLean, VA 22101; R. E. Green, Johns Hopkins University Center for NDE, 3400 N. Charles Street, Baltimore, MD 21218-2689

3:50 PM **An Ultrasonic Method for Measuring Tensile Forces in a Seven-Wire Prestressing Strand**
---R. H. L. Chen and K. Wissawapaisal, West Virginia University, Department of Civil and Environmental Engineering, P. O. Box 6103, Morgantown, WV 26506-6103

4:10 PM **Nondestructive Evaluation of FRP Composite Bridge Components Using Infrared Thermography**
---U. B. Halabe, H. V. S. GangaRao, P. Klinkhachorn, and E. S. Sazonov, West Virginia University, Constructed Facilities Center, Room 645 Engineering Sciences Building, Morgantown, WV 26506-6103; H. AlQennah, RBA Group, Bridgeville, PA

4:30 PM **Effect of Soil Properties on Acoustic Wave Propagation in Buried Water Pipes**
---R. Long, K. Vine, and P. Cawley, Imperial College, Department of Mechanical Engineering, Exhibition Road, London, SW7 2BX, United Kingdom

4:50 PM **Development of a Guided Wave Inspection Technique for Rock Bolts**
---M. D. Beard, M. J. S. Lowe, and P. Cawley, Imperial College of Science, Department of Mechanical Engineering, Technology and Medicine, London, SW7 2BX, England

5:10 PM **An Automated Damage Detection System for AVLB**
---E. S. Sazonov and P. Klinkhachorn, West Virginia University, Department of Computer Science and Electrical Engineering, P. O. Box 6109, Morgantown, WV 26506-6109; H. V. S. GangaRao and U. B. Halabe, West Virginia University, Constructed Facilities Center, Morgantown, WV 26506-6109

5:30 PM **Acoustic Emission Study of Fatigue Cracks in Materials Used for AVLB**
---R. H. L. Chen and J.-H. Choi, West Virginia University, Department of Civil and Environmental Engineering, Morgantown, WV 26506

Ultrasonic Stress Measurements in Prestressing Tendons

---Glenn A. Washer, Federal Highway Administration, HRDL-10, NDE Validation Center, 6300 Georgetown Pike, McLean, VA 22101; Robert E. Green, Johns Hopkins University Center for NDE, 3400 N. Charles Street, Baltimore, MD 21218-2689

---There are currently more than 130,000 prestressed concrete bridges in the United States and approximately 37,000 of these bridges are more than 30 years old. Steel tendons that are pretensioned to counteract the effect of design loads are critical to structural performance of these bridges. However, there are currently no accepted nondestructive evaluation techniques to evaluate the condition of these tendons. The goal of this research was to examine ultrasonic stress measurement techniques for the condition assessment of prestressing tendons. Acoustoelastic measurements were made in prestressing rods and strands, and constants are reported that relate the change in ultrasonic velocity to the change in stress. The effects of dispersion in prestressing tendons, which act as circular wave guides for ultrasonic waves, were measured and evaluated. For this research, narrow-band, non-contact Electromagnetic Acoustic Transducers (EMATs) were designed to launch and receive ultrasonic waves propagating within the tendons.

An Ultrasonic Method for Measuring Tensile Forces in a Seven-Wire Prestressing Strand

---Roger H. L. Chen[1] and Komwut Wissawapaisal[2], [1]Professor and [2]Ph.D. Student, Department of Civil and Environmental Engineering, West Virginia University, P. O. Box 6103, Morgantown, WV 26506-6103

---Because initial prestress forces applied to prestressing strands undergo a progressive process of reduction over many years of their service lives, reductions of the prestress forces have, in many cases, caused failures of prestressed concrete structures. For this reason, it is important to periodically measure the tensile force in the strands to ensure the serviceability of the existing concrete members. The main objective of this study is to develop a nondestructive evaluation method for measuring prestress forces in the seven-wire prestressing strands. The strands of this type are widely used in various types of prestressed concrete structures. The experiment is conducted by measuring the traveling time of an ultrasonic wave propagating through the entire length of a ½ inch diameter seven-wire strand, which is subjected to different levels of tensile forces. Theoretical analysis is conducted by taking into account the acoustoelastic effect and dispersive behavior of a longitudinal transient wave traveling through a long, prestressed, circular bar. Results indicate that the velocity (or traveling time) of each frequency component of the traveling wave can be related to tensile force level in the strand. The Wigner-Ville Transform is used as a signal-processing tool in order to identify the arrival times of different frequency components of the detected waveforms. The analytical and experimental results correlate well, and high measurement accuracy is observed. This technique proves to be an efficient tool for measuring tensile forces in the seven-wire steel strands for post-tensioning concrete members.

Nondestructive Evaluation of FRP Composite Bridge Components Using Infrared Thermography

---Udaya B. Halabe, Hota V. S. GangaRao, Powsiri Klinkhachorn, and Edward Sazonov, Constructed Facilities Center, West Virginia University, Room 645 Engineering Sciences Building, Morgantown, WV 26506-6103; Hasan AlQennah, RBA Group, Bridgeville, PA

---This paper presents the results of an experimental study on the use of infrared thermography for detection of subsurface delaminations in Fiber Reinforced Polymer (FRP) composite bridge decks and concrete columns wrapped with FRP jackets. Composite bridge deck specimens were constructed in the laboratory with varying subsurface delamination conditions such as different sizes, thicknesses and filler materials. These simulated delaminations were placed between the 3/8" thick wearing surface and the top of the FRP deck. The laboratory specimens were tested using an infrared imaging system. The infrared images from the delaminated specimens were compared with solid (undamaged) specimens to study the effect of subsurface delaminations on the infrared images under controlled laboratory conditions. In addition, field tests were conducted using infrared thermography on the FRP composite decks of two bridges (Wickwire Run and Laurel Lick) located in West Virginia. The field tests were used to detect subsurface delaminations and study the effect of environmental parameters on the infrared images. As an additional example, infrared testing was conducted to evaluate FRP wrapping and detect debonding between the FRP wrap and the underlying concrete column in the Pond Creek Bridge in West Virginia. This study shows that the infrared thermography technique can be used effectively for rapid evaluation of subsurface condition of FRP composite bridge decks and wrapped columns. The study also shows how the environmental conditions (e.g., shadow, oil spill, and angle of reflection of solar rays) can affect the output infrared images.

Effect of Soil Properties on Acoustic Wave Propagation in Buried Water Pipes

---R. Long, K. Vine, and P. Cawley, Department of Mechanical Engineering, Imperial College, Exhibition Road, London, SW7 2BX, United Kingdom

---Leak detection in buried water pipes is often done using correlators which determine the position of a leak from measurements of the sound it generates at two or more locations. We are currently studying the characteristics of acoustic wave propagation in buried cast iron water mains; by improving our understanding, we hope to make recommendations that will allow the improvement of acoustic leak location techniques. We are also investigating whether examination of the dispersion curves extracted from test data can give information on pipe characteristics such as diameter, material and wall thickness. For this, we need to understand the effect of soil properties on the velocity and attenuation dispersion curves. The soil shear and longitudinal velocities are strong functions of the soil type and overburden pressure. This paper reports a theoretical study of the effect of these properties on the dispersion curves. An experimental investigation involving the measurement of the bulk soil properties adjacent to the pipe using a novel wire waveguide technique and the measurement of guided wave propagation along the pipe is also described. Results have been obtained from operational water mains in the London area and comparisons with the theoretical predictions are presented.

Development of a Guided Wave Inspection Technique for Rock Bolts

---M. D. Beard, M. J. S. Lowe, and P. Cawley, Department of Mechanical Engineering, Imperial College of Science, Technology and Medicine, London, SW7 2BX, United Kingdom

---Rock bolting is a technique for supporting mine roadways, in which a steel bolt is fixed into the surrounding rock with an epoxy resin. The rock bolt confines movement and expansion of the rock strata, thus making the roof more stable. Previous work has investigated the use of high frequency, low-leakage guided waves to inspect these bolts non-destructively for defects and failure. This technique has proved successful for straight rock bolts, but is unable to reliably inspect rock bolts that have become deformed due to ground movement. This paper focuses on the use of the low-frequency L(0,1) mode, which has a good degree of sensitivity to surface defects and epoxy conditions, for such a test. Modelling techniques are used to predict the wave properties under varying epoxy, rock and contact conditions, and test results are presented from large laboratory test specimens and a working mine. Suggestions are put forward for instrumentation development to allow the industrial use of this technique alongside the high frequency test already developed.

An Automated Damage Detection System for AVLB

---Edward S. Sazonov and Powsiri Klinkhachorn, Department of Computer Science and Electrical Engineering, West Virginia University, P. O. Box 6109, Morgantown, WV 26506-6109; Hota V. S. GangaRao and Udaya Halabe, Constructed Facilities Center, West Virginia University, Morgantown, WV 26506-6109

---This paper presents an overview of an automated damage detection system for the Armored Vehicle Launched Bridge (AVLB). The damage detection process for this system is completely automated and all steps, including data acquisition, signal processing, and damage detection and location, can be performed without the operator's intervention. The system utilizes a non-contact laser vibrometer mounted on a computer-controlled robotic gantry as the measurement sensor. The gantry may be programmed to scan the bridge at a desired spatial resolution, thus accommodating a trade-off between test time and precision of damage location. Modal data such as frequency response functions or deflection mode shapes of the specimen can be acquired using different types of excitation, providing additional flexibility of experiments. Acquired data is automatically processed to obtain strain energy mode shapes, which are used as the damage indicator. The analysis of the strain energy mode shapes is performed by a fuzzy expert system. The fuzzy expert system produces the final result of the test, which is represented both as a graph showing damaged locations and a text report summarizing test settings and detected damages. This system was tested on a full-scale AVLB with different damage scenarios simulated by temporarily removing some components of the bridge. The damage detection system was able to detect all damage cases that impaired structural integrity of the bridge.

Acoustic Emission Study of Fatigue Cracks in Materials Used for AVLB

---Hung-Liang (Roger) Chen and Jeong-Hoon Choi, Department of Civil and Environmental Engineering, West Virginia University, Morgantown, WV 26506

---The Armored Vehicle Launch Bridge (AVLB) is subjected to cyclic loading during launching as well as during tank crossings. The cyclic loading causes cracks to initiate in critical bridge components, and then to propagate. Unless these cracks are detected and repaired before they rapidly grow to reach their critical stage of propagation, the failure of bridge components can occur. Three AVLB components, the splice doubler angle, the splice plate, and the bottom chord are susceptible to fatigue damage. In the present study, laboratory fatigue tests on the materials used for the components, aluminum 2014-T6, aluminum 7050-T765, and ASTM A36 steel, were conducted using the acoustic emission (AE) fatigue crack monitoring technique. A total of fourteen compact-tension specimens were prepared in this study: six aluminum 2014-T6, four aluminum 7050-T76511, and four ASTM A36 steel specimens. The characteristics of AE signals associated with the stress intensity factor (K) were obtained to understand AE behavior corresponding to the fatigue crack growth in the materials. Several AE parameters, such as AE counts, energy, and hit, have been shown to be useful tools for detecting cracks, providing early warnings, and preventing failure of bridge structures. The major jump in AE count rate occurred when Kmax reached a value of about 27 ksi*sqrt(in) (30 MPa*sqrt(m)) for aluminum 2014-T6 specimens and about 46 ksi*sqrt(in) (50 MPa*sqrt(m)) for aluminum 7050-T76511 specimens; this major jump for ASTM A36 steel specimens could not be found because the number the true AE signals was not sufficient enough for proper AE characterization. The identical results were also observed in the study of AE hit rate. In addition, the 3-D and 2-D AE source location techniques were able to successfully locate the path of crack propagation using the proper setup of threshold level and wave velocity.

SESSION 32
MATERIALS CHARACTERIZATION
K. Lipetzsky, Chairperson
Sills 117

3:30 PM **Viscoelastic Property Identification from Waveform Reconstruction**
---N. Leymarie, B. Audoin, and S. Baste, Université Bordeaux 1, UMR CNRS n?5469, Laboratoire de Mécanique Physique, Ecole MATMECA, 351, Cours de la Libération, 33405-TALENCE Cedex, France; C. Aristegui, Université Claude Bernard Lyon 1, Laboratoire MECAL, Bât. W, 43, bd du 11 Novembre 1918, 69622-VILLEURBANNE Cedex, France, INSERM Unité 556, 151, Cours Albert Thomas, 69424 LYON Cedex 03, France

3:50 PM **Study of Mechanical Properties and Boundary Conditions of Ceramic Candle Filters Using Vibration Measurements**
---R. H. L. Chen and A. C. Kiriadikis, West Virginia University, Morgantown, WV 26506-6103

4:10 PM **Structure of Meteorites and Tektites**
---C. Wert, University of Illinois at Urbana, Illinois, 1708 West Green Street, Champaign, IL 61821; M. Weller, Max Planck Institute, 92 Seestrasse, Stuttgart, D70 174, Germany

4:30 PM **Microscopic Thermal Diffusivity Distribution Measurement Using a Photoreflectance Experiment**
---J. Jumel, J.-C. Krapez, and F. Lepoutre, MECS/DMSE, Onera Centre de Chatillon, 29 Avenue de la division Leclerc, BP 72, 92322, Chatillon Cedex, France; O. Arnould, LMT, Cachan, France

4:50 PM **Nondestructive Characterization of Lattice Block Material**?
---K. G. Lipetzky and J. M. Warren, Naval Surface Warfare Center Carderock Division, Welding and NDE Branch, Code 615, 9500 MacArthur Boulevard, West Bethesda, MD 20817-5700

5:10 PM **NDE and the Microgravity Sciences at NASA**
---D. J. Roth, MS 6-1, NASA Glenn Research Center, 21000 Brookpark Road, Cleveland, OH 44135

Viscoelastic Property Identification from Waveform Reconstruction

---Nicolas Leymarie, Bertrand Audoin, and Stéphane Baste, Université Bordeaux 1, UMR CNRS n°5469, Laboratoire de Mécanique Physique, Ecole MATMECA, 351, Cours de la Libération, 33405-TALENCE Cedex, France; Christophe Aristegui, Université Claude Bernard Lyon 1, Laboratoire MECAL, Bât. W, 43, bd du 11 Novembre 1918, 69622-VILLEURBANNE Cedex, France, INSERM Unité 556, 151, Cours Albert Thomas, 69424 LYON Cedex 03, France

---Nondestructive evaluation of material viscoelastic properties opens promising prospects for knowledge of materials and structure behavior. A new inverse method is proposed for the determination of the viscoelastic properties of composite material plates from the plane-wave transmitted acoustic field. Innovations lie in a two-step inversion scheme based both on the well-known maximum-likelihood principle and on analytic signal formulation. Establishing analytical formulations both of the plate transmission coefficient and of its first and second derivatives allowed us to define a slightly noise-sensitive process suited to both very thin plates and strongly dispersive media. The reliability of the inversion process for viscoelastic property identification is demonstrated using simulated data for composite materials with different anisotropy and damping degrees. The method works equally well for thin or thick specimens, and for dispersive as well as non-dispersive media. Finally, two experiments are performed on an isotropic and an anisotropic thin plates in order to examine the suitability of the modeling used in the inverse process for experimental identification of viscoelastic properties.

Study of Mechanical Properties and Boundary Conditions of Ceramic Candle Filters Using Vibration Measurements

---Hung-Liang (Roger) Chen and Alejandro C. Kiriakidis, West Virginia University, Morgantown, West Virginia 26506-6103

---Dynamic characterization tests were employed to investigate the material properties and boundary constraints of ceramic candle filters. The ceramic candle filters are hollow cylindrical structures made of porous ceramic materials and are actually clamped on one end in the field. This paper describes the testing of full-size ceramic candle filters. Fixed-free boundary conditions were used to simulate an in-situ candle filters condition. All filters were nondestructively tested to simulate a fixed-free or a free-free boundary condition. The filters were subjected to an excitation force using an instrumented hammer, and the responses were picked up by an accelerometer and/or a laser vibrometer (LV). The experimental results were analyzed to determine vibration parameters such as natural frequencies, mode shapes and frequency response functions of each candle filter. Results from this study indicated that the vibration signature could be used as a tool to evaluate both the boundary restraints and the material properties of the ceramic candle filters. The results further proved that the measurements from LV (non-contact) and the accelerometer (contact) were comparable. These measurements can be used to calculate the boundary restraints and Young's modulus of the filter, using the filter's second and third bending modes.

Structure of Meteorites and Tektites

---Charles Wert, University of Illinois at Urbana, Illinois, 1708 West Green Street, Champaign, IL 61821; Manfred Weller, Max Planck Institute, 92 Seestrasse, Stuttgart, D70 174, Germany

---A great deal of matter is found on the earth which has come from outer space. Part of this is composed of inorganic minerals, similar in composition to rocks found on the earth. Part is metallic alloys, mainly of iron and nickel, similar to stainless steels. Part is glassy matter, similar to both volcanic glass, obsidian, and to commercial manufactured glass. Some of these materials have organic constituents, which has led to speculation that complex hydrocarbons (or even life itself) may have formed in space or on Mars. A great deal of this matter fell in prehistoric times, but a lot arrives even now, some 500 tons per day. Many chemical, physical, and geological measurements have been reported for all types of these materials. We have applied acoustical and dielectric measurements of materials science to elucidate additional features of these materials.

Microscopic Thermal Diffusivity Distribution Measurement Using a Photoreflectance Experiment

---J. Jumel, J.-C. Krapez, and F. Lepoutre, MECS/DMSE, Onera Centre de Chatillon, 29 Avenue de la division Leclerc, BP 72, 92322, Chatillon Cedex, France; O. Arnould, LMT, Cachan, France

---Functionally gradient materials needs sophisticated methods to measure their thermal properties distribution. For instance, recent methods have been developed to measure in-depth diffusivity gradients in hardened steel. In this paper, we study a functionally gradient material whose thermal properties variations are parallel to the surface. To interpret the measurements, we propose a finite element type model to calculate the periodic temperature increase generated in a photothermal experiment whatever is the thermal property distribution at the sample surface. Detailed study of linearly varying thermal properties permits to reconstruct, from the phase of the periodic temperature increase, the thermal diffusivity distribution along the scanning direction. This measurement is sensitive both to the thermal diffusivity distribution and to thermal effusivity relative variations. A theoretical study is presented in the case of linearly varying thermal diffusivity, in order to give physical interpretation of the thermal wave propagation in an inhomogeneous but continuous media. From this study, a simple extraction scheme is proposed to determine the thermal diffusivity variation at the surface of the sample. Experimental results performed on a Nickel/Copper/Nickel assembly with continuous diffusion profile will illustrate the performances of the method.

Nondestructive Characterization of Lattice Block Material?

---Kirsten G. Lipetzky and Jeffrey M. Warren, Naval Surface Warfare Center Carderock Division, Welding and NDE Branch, Code 615, 9500 MacArthur Boulevard, West Bethesda, MD 20817-5700

---The principles of Naval architecture consider weight distribution and weight effects to be a major parameter governing design. Naval architects are always looking for ways to minimize weight, thereby allowing the architect grater flexibility for selection and placement of weight-critical, performance-improving components. One initiative that has been pursued is the manufacture of lightweight watertight doors using Lattice Block Material.? Lattice Block Material? (LBM?) is the name given to a new class of materials which makes use of the well-understood principles of trusses and space frames to create a variety of components having high strength-to-weight ratios. Differences in product design, materials selection, and manufacturing process, however, can lead to uncertainty as to the overall performance of a given end product. For this reason, a variety of nondestructive methods were utilized to characterize LBM? for watertight door applications including visual inspection, x-ray radiography, x-ray computed tomography, and infrared thermography.

NDE and the Microgravity Sciences at NASA

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

---This talk will focus on the microgravity sciences at NASA and 1) what role NDE has played in this area to date, 2) what role NDE may play in future experiments, and 3) specific experiment concepts that investigate how microgravity affects fundamental processes related to NDE performance. A review of basic microgravity concepts will be provided including the various facilities that NASA has to create a microgravity environment (including drop towers, aircraft, rockets, space shuttle, and the International Space Station). The logistics of how the NDE community can get involved in future microgravity sciences research at NASA will also be discussed. The basic science disciplines investigated within the microgravity area at NASA, as well as evolving thematic areas, will be provided.

SESSION 33
IMAGING TECHNIQUES
J.-P. Monchalin, Chairperson
Cleaveland 151 (Druckenmiller)

8:30 AM **Laser-Ultrasonic Inspection of Steel Slabs Using SAFT Processing**
---B. Campagne, D. Lévesque, A. Bouin, and J.-P. Monchalin, Industrial Materials Institute, National Research Council of Canada, Boucherville, Quebec, Canada

8:50 AM **Accuracy of Fatigue Crack Characterization Using Ultrasonic Scanning**
---I. N. Komsky, Northwestern University, Center for Quality Engineering and Failure Prevention, 2137 N. Sheridan Road, Evanston, IL 60208

9:10 AM **Crack Detection Enhancement in Lap Joint Aircraft Structures Using Lamb Waves and SAFT Imaging**
---R. Sicard[1,2], A. Chahbaz[1], A. Cyr[1], and J. Goyette[2], [1]Tektrend International, NDT Technology and Development, 2001 St. Regis Blvd., Montreal Quebec, H9B 2M9; [2]Institut de Recherche sur l'Hydrogène, Université du Quebec à Tois-Rivières, C. P. 500, Trois-Rivières, Quebec, Canada, G9A 5H7

9:30 AM **Scanning Laser Source Technique for Ultrasonic Imaging of Surface-Breaking Defects: Experiments and Modeling**
---P. A. Fomitchov, Y. Sohn, A. K. Kromine, J. D. Achenbach, and S. Krishnaswamy, Northwestern University, Center for Quality Engineering and Failure Prevention, 2137 Sheridan Road, Catalysis Building, Evanston, IL 60208

9:50 AM **Guided Waves EMATs for the Inspection of Complex Aircraft Structures**
---A. Chahbaz, R. Sicard, A. Cyr, and M. Brassard, Tektrend Intl., NDT Technology and Development, 2001 St. Regis, Montreal, Quebec, Canada H9B 2M9

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

10:30 AM **Laser/EMAT Measurement Systems for Ultrasound B-scan Imaging**
---R. J. Dewhurst and P. R. Murray, Department of Instrumentation and Analytical Science, UMIST, P. O. Box 88, Manchester, M60 1QD

10:50 AM **Nondestructive Evaluation of Repairs on Composite Aircraft Structures**
---D. K. Hsu and D. J. Barnard, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

11:10 AM **Defect Selective Imaging by Scanning Laser Vibrometry**
---N. Krohn and G. Busse, University of Stuttgart, IKP-ZFP, Pfaffenwaldring 32, 70569 Stuttgart, Germany

11:30 AM **Thermoelectric SQUID-Based Method: Conditions for Application**
---G. S. Krivoy, Y. Tavrin, and J. H. Hinken, FINO AG, TecCenter, Bad Salzdetfuerth, D-31162, Germany

11:50 AM **An Optical Approach to the Characterizations of Surface Flaws Induced by Fretting**
---F. Inanc, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

12:10 PM ***Lunch and Adjourn***

Laser-Ultrasonic Inspection of Steel Slabs Using SAFT Processing

---B. Campagne, D. Lévesque, A. Blouin, and J.-P. Monchalin, Industrial Materials Institute, National Research Council of Canada, Boucherville, Quebec, Canada

---In the steel industry, there is a need to detect the presence of inclusions or small defects below the surface of cast slabs. A technique is presented in this paper combining laser-ultrasonics with numerical focusing and processing that allows such a detection on descaled slabs. Laser-ultrasonics is a non-contact inspection technique based on lasers for the generation and detection of ultrasound. For the numerical focusing, an improved Synthetic Aperture Focusing Technique (SAFT) algorithm operating in the Fourier domain and recently developed at IMI is used. In addition to increasing speed, the improved method (F-SAFT) includes temporal deconvolution, control of the aperture, as well as spatial interpolation. The last two features allow a reduction in the sampling requirements decreasing both data acquisition time and processing time, therefore making the technique more attractive for industrial use. Also, a further improvement in F-SAFT reconstruction is made when taking into account the surface variations measured by a surface profiler. The performance of the technique will be demonstrated on samples taken from a steel slab having flat-bottom holes at different depths. Also, evidence of the detection of real inclusions will be reported.

Accuracy of Fatigue Crack Characterization Using Ultrasonic Scanning

---Igor N. Komsky, Center for Quality Engineering and Failure Prevention, Northwestern University, 2137 N. Sheridan Road, Evanston, IL 60208

---As a part of aircraft inspection, characterization of fatigue cracks around fasteners is a vital task to ensure airworthiness of airplane structures. Fracture mechanics is widely used to predict possible premature failures that are due to fatigue cracks initiation and growth. The increasing use of failure prediction methods has motivated the rapid growth of ultrasonic techniques to measure the length and depth of the cracks. Conventional techniques for crack characterization are based on either echo-amplitude measurements or time-of-flight evaluation. Application of more advanced imaging or scanning techniques significantly improves the accuracy and resolution of ultrasonic measurements. However, these techniques usually require high-cost instrumentation and training. A novel imaging technique has been developed at Northwestern University to characterize fatigue cracks in the internal layers of multi-layer aircraft structures. The technique is based on the combination of B-scan images. All data can be acquired and processed using portable low-cost ultrasonic units. Accuracy and effectiveness of various approaches for ultrasonic crack characterization in aircraft structures are addressed in this paper. The techniques and instrumentation were tested on the Boeing, Fairchild, and Cessna aircraft structures. The influence of crack size and orientation on the accuracy of measurements was evaluated.

---This material is based upon work supported by the Federal Aviation Administration under Contract # DTFA03-98-D-00008, Delivery Orders # 98-IA005 and #98-IA007 and performed at Northwestern University as part of the Center for Aviation Systems Reliability program through the Airworthiness Center of Excellence.

Crack Detection Enhancement in Lap Joint Aircraft Structures Using Lamb Waves and SAFT Imaging

---R. Sicard[1,2], A. Chahbaz[1], A. Cyr[1], and J. Goyette[2], [1]Tektrend International, NDT Technology and Development, 2001 St. Regis Blvd., Montreal, Quebec, H9B 2M9; [2] Institut de Recherche sur l'Hydrogène, Université du Quebec à Trois-Rivières, C.P. 500, Trois-Rivières, Quebec, Canada, G9A 5H7

---Guided waves have great inspection potential due to the variety of available propagating modes. In this work, we use Lamb wave on lap joint structures to detect crack-like defects at the faying surface between the lower skin and the upper skin/doubler assembly. For each guided wave test, a single line of data is collected by moving the probe along the inspected specimen. Our objective is to enhance the sensitivity of a guided Lamb wave inspection for the detection of flaws as small as 0.1" long and 0.033" deep by processing the data with a suitable artificial focusing technique. For this purpose, a SAFT algorithm in the Fourier domain has been modified to take into account the dispersive nature of Lamb waves. The results of the inspection are presented as a comparison between color-coded two-dimensional raw B-scans and SAFT processed images. Defect separation and characterization enhancement is evaluated from these results.

Scanning Laser Source Technique for Ultrasonic Imaging of Surface-Breaking Defects: Experiments and Modeling

---Pavel A. Fomitchov, Yunghoon Sohn, Alexei K. Kromine, Jan D. Achenbach, and Sridhar Krishnaswamy, Center for Quality Engineering and Failure Prevention, Northwestern University, 2137 Sheridan Road, Catalysis Building, Evanston, IL 60208

---The Scanning Laser Source (SLS) technique is a promising new tool for detection of surface breaking defects. The SLS approach is based on monitoring the changes in laser generated ultrasound as a laser source is scanned over a defect. Changes in amplitude and frequency content are observed for ultrasound generated by the laser over uniform and defective areas. SLS offers several advantages over conventional PZT approaches including ability to detect defects: (i) that are sub-wavelength, (ii) that have various orientations with respect to the ultrasonic detector, and (iii) which are on structures with complex surfaces such as turbine disk slots. The SLS scanning system includes a portable Nd-YAG laser, a fiber optic scanner, and an ultrasonic detector that can be either a conventional PZT transducer or a laser interferometer. High resolution ultrasonic images of small EDM notches and fatigue cracks on flat, curved and thin specimens including real-world structures such as aircraft turbine disk are presented. These images allow easy detection, localization and characterization of small defects up to 0.125 mm length and 0.06 mm depth. The paper also presents an elastodynamic model of laser-generated ultrasound and its interaction with surface-breaking flaws. The laser source is modeled as a distribution of surface stress dipoles. Ultrasonic propagation is modeled using mass-spring lattice simulations. The interaction of the moving dipole distribution with a surface-breaking crack is shown to adequately capture all the experimentally observed features of SLS, including characteristic changes in ultrasonic amplitude and spectral content.

Guided Waves EMATs for the Inspection of Complex Aircraft Structures

---A. Chahbaz, R. Sicard, A. Cyr, and M. Brassard, Tektrend Intl., NDT Technology and Development, 2001 St. Regis, Montreal, Quebec, Canada H9B 2M9

---Traditional nondestructive testing and monitoring methods all have specific drawbacks when applied to complex structures. However, guided wave EMATs have great detection potential and are more sensitive to common and hidden defects. In conductive or magnetic materials, guided modes are generated more efficiently using EMAT probes. With no couplant, EMATs bring new flexibility and capabilities for reliable and fast inspection of large multilayered structures. In this work, we use guided wave EMATs for crack and corrosion detection on lap joint structures. We experimentally investigate the sensitivity of EMATs and guided modes to detect and image small flaws. To this end, we designed and tuned suitable EMAT probes with optimized wavelength to eliminate the paint effect, corrosion-inhibiting compounds and sealant between the lower and upper skin layers. For each guided wave test, a single line of data is collected by moving the EMAT probe along the inspected specimen. Signals are then presented in color-coded two-dimensional C-scan format.

Laser/EMAT Measurement Systems for Ultrasound B-scan Imaging

---R. J. Dewhurst and P. R. Murray, Department of Instrumentation and Analytical Science, UMIST, P. O. Box 88, Manchester, M60 1QD

---For non-contact nondestructive evaluation (NDE), a laser/EMAT system is an alternative to a more expensive all optical laser-ultrasound system. Several design options of the electromagnetic acoustic transducer (EMAT) are available, permitting inspection of electrically conducting materials. In this paper, we describe a system capable of monitoring variation in sample thickness or defects, with time-of-flight diffraction arising from mode-converted ultrasonic waves. In a B-scan imaging configuration, quantitative time-of-flight analysis of laser-generated acoustic waves is shown to be an effective method for measurement. Various images will be presented together with an interpretation of their features. For these images, transient laser pulses with typical energies of ~18 mJ have been delivered to the material surface via an optical fiber and focused to a line source by a cylindrical lens. Acoustic waves arising from this excitation propagated through the sample to be reflected from the far surface. Waves returning to the surface, including L-S and S-L mode-converted waves, were detected using an EMAT sensitive to in-plane motion. B-scans have been generated as the sensor head moved along the material's surface, forming a 2-D intensity profile that made changes in plate thickness easy to visualize. Both L-S and S-L mode-converted waves provided a method of simultaneously monitoring two different points on the far surface enabling any changes in the material thickness to be clearly identified. Performance levels will be compared with those that are possible with all optical systems.

Nondestructive Evaluation of Repairs on Composite Aircraft Structures

---David K. Hsu and Daniel J. Barnard, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---Composite structures on aircraft can incur damages that require repair. To ensure structural integrity and flight safety, such repairs should be nondestructively inspected. For honeycomb sandwich structures, the repair procedure often involves scarfing, core splicing and potting that can significantly modify the mechanical property of the repaired region. An NDE method for assessing composite repair should therefore be capable of detecting improper repairs as well as characterizing the altered mechanical response of the repair zone. In this work we used the Computer Aided Tap Tester (CATT) for inspecting repairs on honeycomb sandwich composite components. The CATT system generates an image for the local stiffness of the repaired region. Such images reveal voids and unbonds as areas of anomalously low stiffness and core potting and splicing as regions of increased stiffness. A number of examples of composite repairs will be described, including good repairs on engine cowling, a rejected repair on a B747 trailing edge, and a void in a repair on a helicopter blade. For repairs on solid composite laminates, a fieldable ultrasonic scanning technique was used for detecting defects at various depth in the repair.---This material is based upon work supported by the Federal Aviation Administration under Contract No. DTFA03-98-D-00008, Delivery Order IA016 and performed at Iowa State University's Center for NDE as part of the Center for Aviation Systems Reliability program.

Defect Selective Imaging by Scanning Laser Vibrometry

---N. Krohn and G. Busse, IKP-ZFP, University of Stuttgart, Pfaffenwaldring 32, 70569 Stuttgart, Germany

---Vibrometry is well known as an integral method for damage detection. The defects are represented as local changes in the mechanical transfer function (frequency shift, increase of damping). The interpretation of these results is difficult and a localization is impossible for symmetrical samples. It is more promising to use nonlinearity as another feature of the defect: Damping does not only broaden a resonance, it is also a highly nonlinear process as it is amplitude dependent. But also the out-of-plane movement of loose interfaces behaves nonlinearly and results in "clapping". Therefore the excitation of a sample by injection of a sinusoidal wave produces higher harmonics at the damaged area. By using these harmonics defect selective imaging is performed where only the defect itself appears. This contribution shows the applicability of this new technique to modern composite materials that are used in safety relevant areas. Advances resulting from the use of bandwidth limited pulses and modulated excitation will be presented as well.

Thermoelectric SQUID-Based Method: Conditions for Application

---Gennady S. Krivoy, Yury Tavrin, and Johann H. Hinken, FINO AG, TecCenter, Bad Salzdetfuerth, D-31162, Germany

---Last year on QNDE 2000 we have reported about our new thermoelectric method based on superconducting magnetic field sensors (SQUID) to detect weak inhomogeneities like segregations, small metallic inclusions, fatigue and structural changes due to local overheating during manufacturing of metal parts. Here we consider results of further experiments using the thermoelectric method. A temperature gradient in the specimen to be measured is generated during the measurements. Due to different thermoelectric properties of the base material and included inhomogeneities a thermoelectric current inside the specimen is generated. This current induces a magnetic field which is measured with the SQUID gradiometer outside the specimen. Different kinds of the specimen surface scanning were used: the radial scanning by rotation and the XY-scanning. The conditions and limitations of the measuring system when performing the different kinds of the scanning are discussed.

An Optical Approach to the Characterizations of Surface Flaws Induced by Fretting

---Feyzi Inanc, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---The mechanical vibrations present in the jet engines can cause turbine blades to scratch turbine disk surfaces. The surface flaws resulting from fretting may cause crack initiation and they should be kept under surveillance for avoiding crack propagation. These surface flaws are usually at the places where the accessibility is limited and conventional imaging techniques are not adequate for imaging these surface flaws for quantification purposes. The current practice to evaluate such surface flaws is to use manual methods and to rely on inspectors' judgment. In this work, we developed an image acquisition system that is capable of acquiring images from limited access locations with one dimensional background gradient. We implemented dark and light field specular reflection techniques to be able to characterize scratch and area type flaws. We also implemented some simple image processing techniques for enhancing the images. In our presentation, we will introduce our image acquisition system and then provide some examples regarding light and dark field implementations.---This work has been funded by the AFOSR under Grant #F49620-991-1-0148.

SESSION 34
GUIDED WAVES MODELING
A. McNab, Chairperson
Sills 117

8:30 AM **Guided Waves in Curved Pipes**
---A. Demma, M. J. S. Lowe, and P. Cawley, Imperial College, Department of Mechanical Engineering, Exhibition Road, London, SW7 2BX, United Kingdom

8:50 AM **A Model for High Frequency Guided Wave Inspection of Curved Shells**
---R. Roberts, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011; A. Pardini and A. Diaz, Pacific Northwest National Laboratory, Battelle Boulevard, P. O. Box 999, MS K5-26, Richard, WA 99352

9:10 AM **Detection of Damage in a Ship Hull Using Ultrasonic Guided Waves**
---W.-J. Song and J. L. Rose, Penn State University, Engineering Science and Mechanics Department, University Park, PA 16802

9:30 AM **Model and Methodology for Crack Detection on a Cylindrical Hole Containing an Elastic Insert**
---J. C. Aldrin, Computational Tools, 6797 Roanoake Ct., Gurnee, IL 60031; J. D. Achenbach, Northwestern University, 2137 N. Sheridan Road, Evanston, IL 60208

9:50 AM **Orthogonality of Elastic Wave Modes in Two-Layered Plate with Weak Interface**
---J. Du and J. C. Cheng, Nanjing University, National Lab of Modern Acoustics, Nanjing 210093, P. R. China

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

10:30 AM **Elastic Guided Waves in a Layered Rectangular Waveguide: Effect of the Aspect Ratio**
---Y. M. Desai, Department of Civil Engineering, IIT-Bombay, Powai, Mumbai-4000067, India; O. Mukdadi and S. K. Datta, University of Colorado, Department of Mechanical Engineering, Boulder, CO 80309-0427; A. H. Shah, University of Manitoba, Department of Civil and Geological Engineering, Canada R3T 5V6; A. J. Niklasson, Department of Mechanics, Chalmers University of Technology, S-412 96, Sweden

10:50 AM **Measurement and Finite Element Analysis for Wedge Waves Propagating Along Piezoelectric Wedges**
---C.-H. Yang and K. Y. Tsai, Chang Gung University, Department of Mechanical Engineering, 259 Wen-Hua 1st Road, Kwei-Shan, Taoyuan, China

11:10 AM **Quantitative Potentials in a Wave Guide with Lamb and Shear Horizontal Waves**
---X. Zhao, J. L. Rose, and S. Pelts, The Pennsylvania State University, Engineering Science and Mechanics Department, University Park, PA 16802

11:30 AM **Dispersion and Excitability of Guided Acoustic Waves in Isotropic Beams with Arbitrary Cross Section**
---P. Wilcox, M. Evans, O. Diligent, M. J. S. Lowe, and P. Cawley, Imperial College, Department of Mechanical Engineering, Exhibition Road, London, SW7 2BX, United Kingdom

11:50 AM **Lamb Wave Scattering by Defects. A Hybrid Boundary Element-Finite Element Formulation**
---J. M. Galan and R. Abascal, Mecanica Medios Continuos (Estructuras), Escuela Superior de Ingenieros (Universidad de Sevilla), Sevilla, Spain

12:10 PM ***Lunch and Adjourn***

Guided Waves in Curved Pipes

---A. Demma, M. Lowe, and P. Cawley, Department of Mechanical Engineering, Imperial College, Exhibition Road, London, SW7 2BX, United Kingdom

---Guided wave propagation in hollow cylinders is a topic of great interest in long range inspection of pipes and tubes. The propagation of Lamb waves is well understood in the case of straight pipes. However, it is frequently desirable to test regions of pipe beyond a bend so it is necessary to understand the reflection and transmission characteristics of the bend. This paper summarizes the improvement in the understanding of Lamb wave propagation through pipes with bends. The effects of a bend on the transmission of both the longitudinal L(0,2) and the torsional T(0,1) modes have been studied. At the 2000 QNDE conference, we reported initial results on the mode conversion due to the presence of a bend in a pipe network. The effect of bend radius on the reflection and mode conversion characteristics is now understood. This was achieved by obtaining the dispersion relationship for a curved pipe and thereby identifying the velocities and mode shapes of the modes propagating in the bend. A numerical modal solution (FE) was used to obtain the dispersion curves for toroidal structures. The characteristics of the modes in curved pipes are shown. The effect of frequency on mode conversion is also reported.

A Model for High Frequency Guided Wave Inspection of Curved Shells

---R. Roberts, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011; A. Pardini and A. Diaz, Pacific Northwest National Laboratory, Battelle Boulevard, P. O. Box 999, MS K5-26, Richard, WA 99352

---The work reported here supports an ongoing development of a measurement to detect and size stress corrosion cracking in a ~25mm thick curved shell using a transducer access ~1m from the crack site. The measurement is using 3.5 MHz shear waves launched at an angle of ~70 degrees. Propagation between transducer and flaw occurs as a series of multiple reflections between the shell walls, and in this sense is viewed as a guided wave, but at a sufficiently high frequency to temporally resolve individual wall reflections. The received signals in this measurement display considerable structure, and are not easily interpreted in terms of discreet scattering events. This paper reports on the development of a computer model to aid in this interpretation. The model seeks to employ a Green function scattering formulation, where the point response of the shell is evaluated via ray theory. Considerations in the formulation of the problem are summarized, along with problematic issues that can occur in the curved geometry. Predicted signals are presented for canonical geometries, and compared with available experimental results.

---This work was conducted under the collaborative sponsorship of the Safety Program of the Tanks Focus Area, and the Characterization, Monitoring, and Sensors Technology Crosscut Program, both of the Office of Science and Technology, Office of Environmental Management, USDOE. The work was performed at the Ames Laboratory in cooperation with the Center for NDE. Ames Laboratory is operated by Iowa State University for the USDOE under Contract W-7405-ENG-82.

Detection of Damage in a Ship Hull Using Ultrasonic Guided Waves

---Won-Joon Song and Joseph L. Rose, Engineering Science & Mechanics Department, Penn State University, University Park, PA 16802

---A technique to detect damage in a ship hull using guided waves is presented. A defect boundary image (Defect Locus Map) is constructed using reflected guided waves obtained at different test locations. The location and the size of a defect are determined based on Defect Locus Map. In the experiments, shear horizontal waves and Lamb waves are used and the experimental results are compared. Experimental tests are conducted on a ship hull and steel plates containing a defect with different shapes and sizes. The potential of the defect locus map method to detect and quantify damage in a ship hull is discussed.

Model and Methodology for Crack Detection on a Cylindrical Hole Containing an Elastic Insert

---John C. Aldrin, Computational Tools, 6797 Roanoake Ct., Gurnee, IL 60031; Jan D. Achenbach, Northwestern University, 2137 N. Sheridan Road, Evanston, IL 60208

---Prior work has shown the means of generating 'leaky' Rayleigh waves about C-141 weep holes and the subsequent measurement of the resulting circumferential body waves to determine the existence of surface breaking cracks. Ultrasonic inspection techniques are also desired for the C-141 rib clip holes and the C-130 beam cap holes, which contain fasteners. The focus of this study is to examine the possibility of crack detection for holes containing elastic inserts. A BEM model was formulated for the scattering response of an incident shear wave transducer signal by a cylindrical hole with a radial notch, an elastic insert, and a stiffness interface between the hole and the insert. Through comparisons with experimental data, characterization of the interface condition between the hole and the insert was made. Due to the interface conditions for these two hole cases, significant 'leaky' Rayleigh waves can be generated and subsequently used for inspection purposes. A feasible ultrasonic inspection strategy was determined from the simulated and experimental studies. Validation of the approach is presented for both simulated and experimental data. A discussion of the sensitivity of the inspection technique to variation in measurement, geometric and material parameters is also presented.

Orthogonality of Elastic Wave Modes in Two-Layered Plate with Weak Interface

---J. Du and J. C. Cheng, National Lab of Modern Acoustics, Nanjing University, Nanjing 210093, P.R. China

---It is known that ultrasonic guided waves are powerful in the characterization of the cohesive quality in bonded plates. But its success in measuring bond strength largely depends on the understanding of the nature of the imperfect interface and propagating characteristics of ultrasonic guided waves. In most studies on the guided waves propagating in a sandwich plate, main works are concerned with effects of spring or density model on dispersion of guided waves. In this paper, we pay attention to the guided wave modes in such sandwich plate for the spring or density model. Especially, we have discussed in detail orthogonality of guided wave modes, and results show that the guided wave modes are orthogonal to each other for weak interface with spring model, and are not orthogonal to each other for interface with the density model. The analytical results are also supported by numerical simulations.

Elastic Guided Waves in a Layered Rectangular Waveguide: Effect of the Aspect Ratio

---Y. M. Desai, Department of Civil Engineering, IIT-Bombay, Powai, Mumbai-4000067, India; O. Mukdadi and S.K. Datta, Department of Mechanical Engineering, University of Colorado, Boulder, CO 80309-0427; A.H. Shah, Department of Civil and Geological Engineering, University of Manitoba, Winnipeg, Canada R3T 5V6; A.J. Niklasson, Department of Mechanics, Chalmers University of Technology, S-412 96, Sweden

---Guided waves in a plate of finite width having arbitrary thickness to width ratio (h/b) has been analyzed in this paper. Although there is some work on rectangular elastic waveguide, no systematic study of the effect of the change in the width for a given plate thickness and the anisotropy of the material properties of the constituents has been reported in the literature. The objective of this model study is to demonstrate that the increase in the ratio h/b changes the guided wave dispersion dramatically. The effects of the edges of the plate are seen in the dispersion of guided wave modes as lowering of cutoff frequencies, clustering of modes that tend asymptotically to the case of an infinite plate. The emergence of the surface waves and their interactions with the edges are significantly dependent upon the anisotropy and the presence of thin interface or surface layers.

Measurement and Finite Element Analysis for Wedge Waves Propagating Along Piezoelectric Wedges

---C.-H. Yang and K. Y. Tsai, Department of Mechanical Engineering, Chang Gung University, 259 Wen-Hua 1st Road, Kwei-Shan, Taoyuan, China

---Wedge waves are guided waves propagating along the tip of sharp wedges, with energy tightly confined near wedge tips. Wedge waves propagating along isotropic wedges have been studied regarding to the effects of material properties, apex angles, truncations, and curvature effect of wedge tips. These studies include theoretical approximations, piezoelectric based measurements, laser ultrasonic measurements, and finite element analysis. In the area of anisotropic wedge problem, especially piezoelectric wedges, very little research result is available. The purpose of this research is to investigate the wave propagation behavior of wedge waves propagating along the tip of piezoelectric wedges simultaneously with experiments and numerical analysis. In the experiment, a laser ultrasonic technique is used to measure the dispersion behavior of wedge waves propagating along LiNbO3 wedges with apex angle of either 7.5? or 15?. Besides the laser ultrasound measurements, the wave propagation behavior is also analyzed with finite element method. The results show good agreement between the measurement and numerical results for various aspects of piezoelectric wedge waves including orientation of wedge wave propagation, apex angle, and the dispersion due to apex truncations. Krylov's theoretical model for the prediction of anisotropic wedge wave speed is evaluated with the current measurement results. The results of the current research will provide the basis for future development in sensor, including micro-sensor and biosensor, based on piezoelectric wedge waves.

Quantitative Potentials in a Wave Guide with Lamb and Shear Horizontal Waves

---Xiaoliang Zhao, Joseph L. Rose, and Sam Pelts, Engineering Science and Mechanics Department, The Pennsylvania State University, University Park, PA 16802

---Wave scattering analysis implemented by Boundary Element Method and normal mode expansion was used to study the sizing potential of defects on a wave-guide. Three shapes of defects in a 10mm thick steel plate of though wall depth of 10% to 90% were considered. Mode conversion and reflection and transmission coefficient of both Lamb and Shear Horizontal waves at frequency range 0.05 to 2 MHz were calculated. Numerical results showed for low-frequency S0 Lamb wave and certain frequency range of Horizontal mode, a monotonic change in signal amplitude with the defect sizes can be observed. Some experiments with EMAT (electro-magnetic transducers) are also discussed.

Dispersion and Excitability of Guided Acoustic Waves in Isotropic Beams with Arbitrary Cross Section

---P. Wilcox, M. Evans, O. Diligent, M. Lowe, and P. Cawley, Department of Mechanical Engineering, Imperial College, Exhibition Road, London, SW7 2BX, United Kingdom

---The successful use of guided acoustic waves for long range inspection is highly dependent upon being able to accurately model guided wave propagation in the structure under inspection. Guided wave propagation in certain structures can be solved by analytical means, but this is not the case for slender structures of irregular cross section such as 'I' beams, railway track and so forth, all of which are potentially ideally suited to guided wave inspection. Acoustic wave propagation in such structures may be modeled numerically using 3-dimensional, time-marching finite element (FE) techniques. However, this is a slow process and extracting the dispersion characteristics of individual guided wave modes from the results is difficult. A technique for predicting guided wave properties in railway track has been proposed by Gavric that uses modified finite element code to create a special 2-dimensional model, the eigenvalues of which may be related to points on the dispersion curves. In this paper, a similar method for rapidly predicting the dispersion behavior of guided waves in a beam of arbitrary cross section is presented, with the advantage that it can be readily implemented on any standard FE package that includes multi-order, axi-symmetric modeling and an eigen solver routine. The model is also used to predict the excitability of any mode when a harmonic force is applied in an arbitrary direction at any position in the cross section.

Lamb Wave Scattering by Defects. A Hybrid Boundary Element-Finite Element Formulation

---Jose M. Galan and Ramon Abascal, Mecanica Medios Continuos (Estructuras), Escuela Superior de Ingenieros (Universidad de Sevilla), Sevilla, Spain

---A hybrid Finite Element (FE) - Boundary Element (BE) Formulation is applied to study Lamb wave scattering by defects in homogeneous isotropic plates. In this technique, a BE model of the neighborhood of the defect is combined with a semi-analytical FE non-reflecting boundary condition which accurately models the radiation condition in the plate. This formulation is provided with a meshing criterion that guarantees the accuracy of the results. The numerical results satisfy energy flux conservation and reciprocity within a very tight margin. In addition, the BE model size has no influence on the results, which is an advantage over previous techniques. The accuracy of the code is verified by a series of benchmark problems from the literature. The interaction with long delaminations, which was first solved by Rokhlin (1979), is studied. The scattering by square and elliptical surface defects, which were studied respectively by Alleyne and Cawley (1992) and Cho and Rose (1997), is also considered. Parametric studies are performed in order to show mode sensitivities. This numerical formulation represents a flexible and general tool to solve the direct problem of Lamb wave scattering by defects of complex geometry. The results can be used for defect identification and characterization purposes.

SESSION 35
NDE FOR MATERIAL PROPERTIES AND FATIGUE DAMAGE
B. Raj, Chairperson
Druckenmiller 016

8:30 AM **Ultrasonic Maps of Porosity in Aluminum Castings**
---B. Ghaffari, T. J. Potter, and G. Mozurkewich, Ford Motor Company, Scientific Research Laboratory, MD 3028/SRL, P. O. Box 2053, Dearborn, MI 48121-2053

8:50 AM **Quantitive Measurements of Ultrasonic Attenuation and Velocity in Liquids and Slurries for Determination of Particle Size Distribution**
---R. W. Reed, East Stroudsburg University, Physics Department, Gessner Science Hall, East Stroudsburg, PA 18301; J. G. Dos Ramos and T. Oja, Matec Instruments/Matec Applied Sciences, 56 Hudson Street, Northborough, MA 01532

9:10 AM **Measuring Graphite Size by Ultrasonic Attenuation in Cast Irons**
---J. M. A. Rebello, S. E. Kruger, and J. Charlier, Metallurgy and Materials Department, Federal University of Rio de Janeiro, COPPE/EE/UFRJ, P. O. Box 68505 CEP 21945-970, Rio de Janeiro, RJ Brazil

9:30 AM **Monitoring Microstructure Evolution of Nickel at High Temperature**
---S. E. Kruger, S. Bolognini, G. Lamouche, and A. Moreau, Industrial Materials Institute, National Research Council, 75, Boul. De Mortagne, Boucherville, Quebec, Canada

9:50 AM **A Study of Ultrasonic Property Variations Within Jet-Engine Nickel Alloy Billets**
---P. Haldipur, F. J. Margetan, and R. B. Thompson, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

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

10:30 AM **Survey of Ultrasonic Properties of Aircraft Engine Titanium Forgings**
---L. Yu, F. J. Margetan, and R. B. Thompson, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011; A. Degtyar, United Technologies Pratt & Whitney, East Hartford, CT 06108

10:50 AM **Thermography Detection of Early Thermal Effects During Fatigue Tests on Steel and Aluminum Samples**
---J.-C. Krapez, D. Pacou, and G. Gardette, Solid and Damage Mechanics Department, ONERA, 29 Ave. de la Division Leclerc, Chatillon 92320, France

11:10 AM **Evaluation of Plane Bending Fatigue Damage in Metallic Plates Using the Thin-Film Flux-Gate Magnetic Sensor**
---M. Oka and T. Yakushjii, Oita National College of Technology, 1666 Maki, Oita, 870-0152, Japan; Y. Tsuchida and M. Enokizono, Oita University, 700 Dannoharu, Oita, 870-1192, Japan

11:30 AM **Characteristics of Elastic Waves Generated by Fatigue Crack Penetration and Growth in an Aluminum Plate**
---K. Nam, Pukyong National University, Department of Materials Science and Engineering, Namgu, Pusan, 608-739, Korea; A. Mal, University of California, Mechanical and Aerospace Engineering Department, Los Angeles, CA 90095-1597

12:10 PM ***Lunch and Adjourn***

Ultrasonic Maps of Porosity in Aluminum Castings

---Bita Ghaffari, Timothy J. Potter, and George Mozurkewich, Ford Motor Company Scientific Research Laboratory, MD 3028/SRL, P. O. Box 2053, Dearborn, MI 48121-2053

---The use of cast aluminum in the automotive industry has grown dramatically in recent years. This has lead to an increased need for quantitative characterization of porosity in aluminum castings. As previously reported in the literature, measuring the attenuation of ultrasound is a promising approach. The magnitude and frequency dependence of attenuation provides information about the volume fraction of porosity and the mean pore size. We have built an immersion ultrasound scanning system to utilize this technique in pulse-echo mode. A focused 10-MHz transducer, moved by a 3-dimensional translation stage, is used to scan castings that have two parallel surfaces. Maps of attenuation locate areas of varying porosity readily and reliably. To obtain the porosity volume fraction and pore size, the spectral shape of attenuation is fit at each location. In this talk we present the latest results from this sytem.

Quantitive Measurements of Ultrasonic Attenuation and Velocity in Liquids and Slurries for Determination of Particle Size Distribution

---Robert W. Reed, East Stroudsburg University, Physics Department, Gessner Science Hall, East Stroudsburg, PA 18301; J. Gabriel Dos Ramos and Tonis Oja, Matec Instruments/Matec Applied Sciences, 56 Hudson Street, Northborough, MA 01532

---Instrumentation and software have been developed for making precise measurements of the attenuation and velocity, at ultrasonic frequencies in the 1 to 100 MHz range, in liquids and slurries. The measurements are made using a pulse echo method with high fidelity tone bursts and highly linear electronics. A very precise motion stage is used to position a reflector in the liquid cell. Signal processing methods are applied to waveforms, digitized at a 1 GHz rate, for making attenuation and velocity measurements with respective accuracies better than 1% and 0.01%. Example data for several liquids will be presented. The attenuation data for slurries is inverted to determine the particle size distribution. Particle sizes in the range of 10 mn to 100 ?m can be determined from the data. Example results for several particle size distributions will be presented.

Measuring Graphite Size by Ultrasonic Attenuation in Cast Irons

---Joao M. A. Rebello, Silvio E. Kruger, and Jacques Charlier, Metallurgy and Materials Department, Federal Univerisity of Rio de Janeiro, COPPE/EE/UFRJ, P. O. Box 68505 CEP 21945-970, Rio de Janeiro, RJ Brazil

---Precipitated graphite geometry is one of the main microstructural parameters that contribute to cast iron mechanical properties. In this paper we address the measurement of the graphite size by ultrasonic attenuation. Samples of different cast iron microstructures were characterized by quantitative metallographic techniques and further correlated with ultrasonic parameters. Longitudinal ultrasonic waves were generated and detected by commercial broadband piezoelectric transducers on direct contact and the signals were processed in order remove system effects. For surface acoustic waves, a large aperture lens-less focalized piezoelectric transducer was used. The experimental attenuation spectra were fitted with simple scattering models and both longitudinal and surface wave techniques showed very good quantitative correlations with graphite size, independent of its geometry.

Monitoring Microstructure Evolution of Nickel at High Temperature

---Silvio E. Kruger, Stephane Bolognini, Guy Lamouche, and Andre Moreau, Industrial Materials Institute, National Research Council, 75, Boul. De Mortagne, Boucherville, Quebec, Canada

---Laser ultrasonics was used to monitor the evolution of the microstructure of commercial pure nickel from room temperature up to 1000°C. The objective is to characterize the response of ultrasonic velocity, attenuation and absorption to recrystallization and grain growth. These parameters were measured during the applied thermal cycle and for different magnetic fields. The attenuation and velocity were measured by classical broadband pulse-echo technique. The absorption was measured by a laser ultrasonic reverberation technique on small samples as an attempt to separate the relative contribution of absorption and scattering to the total attenuation. Below the Curie temperature, the recrystallized microstructure showed strong magnetoelastic effects. Above this temperature, the ultrasonic attenuation is dominated by grain scattering, allowing the characterization of grain growth. A relationship between the grain size and attenuation at high temperatures was established.

A Study of Ultrasonic Property Variations Within Jet-Engine Nickel Alloy Billets

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

---Nickel-alloy material intended for the fabrication of rotating jet engine components is ultrasonically inspected prior to use. The inspection is performed on a cylindrical billet formed by casting and forging operations. Defect detection limits are determined, in part, by the metal microstructure, which controls the ultrasonic properties of the billet. As part of its effort to improve billet inspections, the Engine Titanium Consortium is undertaking a survey of the ultrasonic properties of Nickel-alloy billets. Ultrasonic velocity, attenuation, and back-scattered grain noise are being measured in rectangular coupons cut from representative 10"-diameter billets of IN718 and Waspaloy. The measurements are being made for three sound propagation directions (radial, axial, and hoop) in order to form a coherent picture of the manner in which ultrasonic properties vary within billets. The sonic properties will then be correlated with grain size and shape data obtained from optical metallography at adjacent sites in the billet. Initial studies indicate that the ultrasonic properties vary significantly with radial depth, but have little dependence on inspection direction at a given site. This latter result is in sharp contrast to prior observations on titanium billet specimens and is likely caused by the greater role of recrystallization in the processing of nickel-based superalloys. It suggests an approximately equiaxed, untextured microstructure in which the average grain size varies with radial position. A summary of the results to date from this ongoing study will be presented.---This material is based upon work supported by the Federal Aviation Administration under Contract #DTFA03-98-D-0008, Delivery Order IA029 and performed at Iowa State University's Center for NDE as part of the Center for Aviation Systems Reliability program.

Survey of Ultrasonic Properties of Aircraft Engine Titanium Forgings

---Linxiao Yu, F. J. Margetan, and R.Bruce Thompson, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011; Andrei Degtyar, United Technologies Pratt & Whitney, East Hartford, CT 06108

---Titanium alloys used in the construction of rotating jet-engine components have complicated duplex microstuctures in which the elastic properties vary on several length scales. These microstructures influence ultrasonic pulse/echo inspections in three basic ways: (1) the attenuation of sound energy acts to decrease the amplitude of echoes from possible defects; (2) backscattered noise from grain boundaries acts to mask echoes from small or subtle echoes; and (3) velocity inhomogeneities cause distortions of propagating sound beams, which in turn lead to fluctuations in echo amplitudes. As part of its effort to improve forging inspections, the Engine Titanium Consortium is surveying the ultrasonic properties of representative Ti 6-4 forgings. The principal goal is to document the manner in which ultrasonic velocity, attenuation, backscattered grain noise, and signal fluctuation levels depend upon position and inspection direction within forgings. In addition efforts will be made to correlate the measured ultrasonic properties with available microstructural and forging-strain data. This information will be used to help design improved forging inspections, and to more accurately assess inspection capabilities. The presentation will provide a summary of the work to date on this ongoing project.---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 Center for Aviation Systems Reliability program.

Thermography Detection of Early Thermal Effects During Fatigue Tests on Steel and Aluminum Samples

---J.-C. Krapez, D. Pacou, and G. Gardette, Solid and Damage Mechanics Department, ONERA, 29 Ave. de la Division Leclerc, Chatillon 92320, France

---It is known for some years that there is a correlation between the fatigue limit of some metallic materials and the appearance of heat dissipation measurable by IR thermography. This approach unfortunately fails for aluminum alloys. Our objective was to analyze more deeply the temperature signal obtained during fatigue tests and to check if there is any other damage-dependant signature. We performed several fatigue tests on steel (XC48, 316L) and an aluminum alloy (7010) and simultaneously measured with a focal plane array camera the modulated surface temperature. For each value of the stress amplitude, we calculated a series of three images corresponding to the local linear "drift" of temperature, the temperature amplitude at frequency f, and the one at 2f. For steel samples, three phenomena were observed when we reached the fatigue limit: the emergence of a measurable temperature drift, an increase of the slope of the temperature amplitude at frequency f, and the emergence of a temperature harmonic at 2f. For 7010 alloy, only one phenomena was clearly observed at the corresponding fatigue limit: a slope increase of the thermoelastic component. There is thus a clear evidence, both for steel and aluminum, that the thermoelastic coefficient changes when the fatigue limit is reached, i.e. when damage and/or plasticity appears at the microscopic level, which finally leads to failure. This thermal signature of fatigue damage is obtained in a very short time as compared to conventional fatigue tests: typically less than a couple of hours.

Evaluation of Plane Bending Fatigue Damage in Metallic Plates Using the Thin-Film Flux-Gate Magnetic Sensor

---Mohachiro Oka and Terutoshi Yakushiji, Oita National College of Technology, 1666 Maki, Oita, 870-0152, Japan; Yuuji Tsuchida and Masato Enokizono, Oita University, 700 Dannoharu, Oita, 870-1192, Japan

---The conventional magnetic sensors cannot estimate the amount of fatigue damage. If we can estimate it, the service life of a structure can be extended and accidents can be prevented. Then, we have measured magnetic flux density 1 mm above a specimen caused by residual magnetization in order to estimate the amount of plane bending fatigue damage on austenitic stainless steel plates such as SUS304 using a thin-film flux-gate magnetic sensor. Our experiments are carried out in the following procedure: At first, cyclic stress is applied by a plane bending fatigue testing machine. Partial transformation from austenite to martensite is induced by plane bending fatigue at the center. Secondly, specimens are excited by a static magnetic field. Then, the area of martensite is magnetized by the external exciting magnetic field. Next, the distribution of magnetic flux density caused by residual magnetization above specimens is measured. From our experiments, it can be said that the magnetic flux density caused by residual magnetization is clearly dependent on an increase of stress and the number of cycles. Fatigue dependence of residual magnetization on austenitic stainless steel plates will be discussed. And, distribution of residual magnetization on steel plate (SS400) will be shown.

Characteristics of Elastic Waves Generated by Fatigue Crack Penetration and Growth in an Aluminum Plate

---Kiwoo Nam, Department of Materials Science and Engineering, Pukyong National University, Namgu, Pusan, 608-739, Korea; Ajit Mal, Mechanical and Aerospace Engineering Department, University of California, Los Angeles, CA 90095-1597

---Existing surface defects in structural members often act as sites of fatigue crack initiation, and if undetected, these cracks may grow through the thickness of the member, leading to catastrophic failure of the structure. Thus, in-service monitoring of fatigue cracks through reliable and effective nondestructive techniques is an important ingredient in the leak-before-break (LBB) design and safe operation of defects critical structures. As advanced, waveform-based, acoustic emission (AE) technique has been used in this paper to study the characteristics of the signals emanating from the initiation, growth, and through-the-thickness penetration of a surface fatigue crack in a 6061 aluminum plate. The goal of this experimental study is to determine whether the evolution of the fatigue cracks could be identified from the properties of the waveforms produced during the tests. The AE waveform signals detected at different stages of crack growth was found to have different temporal and spectral characteristics. The data analytic technique presented here can be applied to real-time monitoring of the initiation and propagation of fatigue cracks in structural components.

SESSION 36
SIGNAL PROCESSING
E. Henneke, Chairperson
Smith Auditorium (Sills)

8:30 AM **Ultrasonics Without a Source, Waveforms Arising from the Correlations of Thermal Noise**
---R. L. Weaver and O. I. Lobkis, University of Illinois, Department of Theoretical and Applied Mechanics, 104 S. Wright Street, Urbana, IL 61801

8:50 AM **An Approach to Robust Deconvolution of Ultrasonic Pulse-Echo Signals**
---T. Olofsson and T. Stepinski, Signals and Systems Group, Department of Material Science, P. O. Box 528, 751 20 Uppsala, Sweden

9:10 AM **Pulse-Echo TOF Measurement Using the Wavelet Off-Center Frequency Slicing Technique**
---S.-C. Wooh and J.-W. Hong, Department of Civil and Environmental Engineering, Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, MA 02139

9:30 AM **Study of Acoustic Emission Sources and Signals**
---M. I. López Pumarega[1,2], M. Armeite[1,2], M. Oliveto[1,2], R. Piotrkowski[2,3,4], H. Galicer[2,4], and J. E. Ruzzante[1,2,4], [1]ENDE, Comisión Nacional de Energía Atómica, Avenida General Paz 1499, 1650 San Martín, Buenos Aires, Argentina; [2]GLEA Members (Grupo Latinoamericano de Emisión Acústica); [3]Universidad Nacional de General San Martín, Buenos Aires, Argentina; [4]Universidad Tecnólogica Nacional, Regional Buenos Aires, Argentina

9:50 AM **Learn++: A Versatile Incremental Learning Algorithm for Classification and Characterization of NDE Signals**
---R. Polikar, Rowan University, Department of Electrical and Computer Engineering, 136 Rowan Hall, 201 Mullica Hill Road, Glassboro, NJ 08028

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

10:30 AM **Lift-off Invariance Transformations for Eddy Current Nondestructive Evaluation Signals**
---D. Kim, L. Udpa, and S. S. Udpa, Iowa State University, Department of Electrical and Computer Engineering, Materials Assessment Research Group, Ames, IA 50011

10:50 AM **Flaw Recognition in Presence of Interferences from Fasteners and Subsurface Structures**
---T. Chady and R. Sikora, Technical University of Szczecin, Faculty of Electrical Engineering, Szczecin, Poland; M. Enokizono, Oita University, Faculty of Engineering, Oita, Japan

11:10 AM **Nonlinear Mixing Algorithms for Suppression of TSP Signals in Bobbin Coil Eddy Current Data**
---L. Udpa, S. S. Udpa, K. Arunachalam, and P. Ramuhalli, Iowa State University, Materials Assessment Research Group, Department of Electrical and Computer Engineering, Ames, IA 50011

11:30 AM **An Adaptive Wiener Filter Based Technique for Automated Detection of Defect Locations from Bobbin Coil Eddy Current Data**
---M. Das[1], P. Ramuhalli[2], H. Shekhar[2], L. Udpa[2], S. S. Udpa[2], [1] Oakland University, Department of Electrical and Systems Engineering, Rochester, MI 48309; [2]Iowa State University, Material Assessment and Research Group, Department of Electrical and Computer Engineering, Ames, IA 50014

12:10 PM ***Lunch and Adjourn***

Ultrasonics Without a Source, Waveforms Arising from the Correlations of Thermal Noise

---Richard L. Weaver and Oleg I. Lobkis, Department of Theoretical and Applied Mechanics, University of Illinois, 104 S. Wright Street, Urbana, IL 61801

---A transducer in contact with a non-insonified solid body generates a noise signal. Some of the noise is due to thermal fluctuations in the amplifier, some ambient acoustic noise, and some of it is due to thermal fluctuations in the sample. By comparing the spectral power density of the noise from a high-sensitivity Acoustic Emission transducer with the spectral power density consequent to the application of a calibrated broken capillary source, we show that a significant fraction of the noise in that transducer is due to thermal fluctuations in the body. Such elastic wave thermal fluctuations may be conceptualized as consisting of a random gas of thermal phonons. A derivation is presented showing that the autocorrelation function of that noise should equal the pulse-echo signal generated by that transducer. The thesis is investigated by constructing that autocorrelation function (The auto-correlation appears to converge after only a few 10's of msec of data collection.) and comparing it with the pulse/echo signal. The two waveforms are found to be substantially identical. Less sensitive transducers, although they require more data and longer autocorrelations before convergence is achieved, produce similar results. Possibilities for application are considered.---Work supported by NSF.

An Approach to Robust Deconvolution of Ultrasonic Pulse-Echo Signals

---Tomas Olofsson and Tadeusz Stepinski, Signals and Systems Group, Department of Material Science, P. O. Box 528, 751 20 Uppsala, Sweden

---The received signal in ultrasonic pulse-echo data in NDT can be modeled as a convolution between the transducer's impulse response and the reflection sequence which is the impulse characteristic of the inspected object. The deconvolution problem is typically formulated as estimation of the reflection sequence. The estimation task is often solved using linear minimum mean square error (MMSE) estimators that require accurate measurements of the transducer's impulse response. Measurement errors caused by non-ideal transducer measurement setup may degrade accuracy of the reflection sequence estimates. This paper describes a way of designing linear minimum mean squared error (MMSE) estimators with improved robustness against transducer impulse response measurement errors. The presented approach is based on the assumption that the impulse response can be determined with an error within a so-called uncertainty set, defined based on a physical model of the impulse response measurement, prior knowledge about the inaccuracies usually present in the measurement setup, and the available knowledge about the transducer. Robust linear MMSE estimators for the reflection sequence are proposed that minimize the mean squared error averaged over the uncertainty set. It is verified experimentally, using real signals, that the robust estimators outperform candidate estimators on the average.

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Pulse-Echo TOF Measurement Using the Wavelet Off-Center Frequency Slicing Technique

---Shi-Chang Wooh and Jung-Wuk Hong, Department of Civil and Environmental Engineering, Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, MA 02139

---A method based on the concept of the off-center frequency slicing of the wavelet transform coefficients in the time-frequency domain is introduced to detect pulse signals propagating in a nondispersive system. A closed form solution is derived to represent the continuous wavelet transform of a Gaussian signal using the Morlet wavelet. From that solution, it is proved that the resulting wavelet coefficient is symmetric around the temporal center, but asymmetric along the frequency axis. More specifically, it is shown that the width of the wavelet coefficient becomes narrower as the frequency increases. Consequently, it is shown that slicing at a higher frequency can improve the temporal resolution than that at the center frequency of the signal. Based on this observation, an echo detection scheme is proposed with a criterion to choose the slicing frequency. The analytical expressions are compared with the results obtained from the simulation and experimental studies.

Study of Acoustic Emission Sources and Signals

---M. I. López Pumarega[1,2], M. Armeite[1,2], M. Oliveto[1,2], R. Piotrkowski[2,3,4], H. Galicer[2,4], and J. E. Ruzzante[1,2,4], [1]ENDE, Comisión Nacional de Energía Atómica, Avenida General Paz 1499, 1650 San Martín, Buenos Aires, Argentina; [2]GLEA Members (Grupo Latinoamericano de Emisión Acústica); [3]Universidad Nacional de General San Martín, Buenos Aires, Argentina; [4]Universidad Tecnólogica Nacional, Regional Buenos Aires, Argentina

---This paper presents the studies carried out on Acoustic Emission (AE) signals from different tests. Some of them were produced with a hand driven machine to exert the stress, on pieces of seamless steel tubes, with oxide layer and without it. Two AE sensors were used as “guards” to avoid noise. AE signals were captured with a wide band sensor and digitized. The other tests were performed on seamless Zry-4 tubes, stressed up to rupture with a specially constructed hydraulic system. A wide band AE sensor was used to capture the AE. In all tests, the signal treatment was different according to the type of signal: either continuous or burst type. In burst type signal, their parameters were statistically studied as Amplitude, Duration and Risetime distributions, finding some differences between pieces owing to the oxide layer. Also AE temporal distributions were studied, discussing Poisson and Polya distributions. Thee instants preceding burst type signals were analyzed with wavelets techniques finding different patterns. In continuous type signals 1/f noise was analyzed. Obtained results are presented and discussed.

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Learn++: A Versatile Incremental Learning Algorithm for Classification and Characterization of NDE Signals

---Robi Polikar, Department of Electrical and Computer Engineering, 136 Rowan Hall, Rowan University, 201 Mullica Hill Road, Glassboro, NJ 08028

---An incremental learning algorithm is introduced, which allows additional information to be learned from new data, even when new data include examples corresponding to previously unseen classes. The algorithm, called Learn++, takes advantage of synergistic generalization performance of an ensemble of simple classifiers. Each simple classifier is trained with a strategically chosen subset of the training database, such that it learns a different subset of the overall decision boundary. As new data become available, new classifiers are generated, which are then combined through weighted majority voting. The weights are determined based on the estimated likelihood of each classifier to correctly classify an instance of unknown class. The voting procedure also allows Learn++ to estimate the confidence level in its own decision. The need for an incremental learning algorithm arises often in nondestructive evaluation, since large volumes of data are typically acquired at different times, and individual databases may include instances of different classes. Simulation results on various NDE signals, in particular on ultrasonic weld inspection data, are presented to demonstrate the feasibility of the proposed approach.

Lift-off Invariance Transformations for Eddy Current Nondestructive Evaluation Signals

---D. Kim, L. Udpa, and S. S. Udpa, Iowa State University, Department of Electrical and Computer Engineering, Materials Assessment Research Group, Ames, IA 50011

---Eddy current testing methods are widely used in a variety of applications including steam generator tubes in nuclear power plants, aircraft parts and airframes. An Eddy Current (EC) signal consists of changes in coil impedance, measured as the probe scans the specimen surface. A key factor that affects the EC signal is lift-off or distance between the test object and the probe. In practice, it is difficult to keep track of the actual value of the lift-off which is essential for accurate interpretation of the signal. Hence it is necessary to have a scheme to render the eddy current signal invariant to the effects of lift-off. In this paper, we use the concept of invariance transformation to compensate eddy current signals for variations in lift-off. The signals are transformed to obtain a zero lift-off equivalent signal that can be subsequently used for defect characterization. Results showing the validity of the approach will be presented.

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Flaw Recognition in Presence of Interferences from Fasteners and Subsurface Structures

---Tomasz Chady and Ryszard Sikora, Faculty of Electrical Engineering, Technical University of Szczecin, Szczecin, Poland; Masato Enokizono, Faculty of Engineering, Oita University, Oita, Japan

---The objectives of this paper are to detect and identify flaws in conducting elements surrounded partially by subsurface structures. Signals from eddy current sensors are frequently contaminated by noise due to the presence of such elements. When employing single frequency testing it is very difficult to discriminate between the various factors, which cause the signal changes. To deal with this problem, application of a multi-frequency technique and newly developed identification procedure is proposed. The flaw identification algorithm is based on the approximation of frequency characteristic of the sensor. Numerical simulations and extended experiments with various (magnetic and nonmagnetic) interfering structures were performed. Results of numerical simulations as well as results of experiments confirmed usability of the proposed method. Selected results will be presented in the paper.

Nonlinear Mixing Algorithms for Suppression of TSP Signals in Bobbin Coil Eddy Current Data

---L. Udpa, S. Udpa, Kavitha Arunachalam, and Pradeep Ramuhalli, Materials Assessment Research Group, Department of Electrical and Computer Engineering, Iowa State University, Ames, IA 50011

---Multi-frequency eddy current techniques are commonly used in inspecting steam generator tubes in nuclear power plants. The measurement usually contains strong signals from external tube support plates (TSP) that tend to mask signals from defects. It is therefore required to suppress the TSP contributions in signals prior to signal analysis using a process referred to as 'mixing'. Conventional methods combine measurements taken at different frequencies using linear transformations to suppress TSP signals. In mixing, a signal at a low excitation frequency (35 kHz) is transformed to the corresponding signal at high frequency (400 kHz), and the transformed signal is subtracted from the measured high frequency signal. In reality, the transformation required to convert a low frequency signal to the corresponding high frequency signal is non-linear, and the use of linear mixing algorithms results in a large residual TSP signal. This paper proposes the use of a non-linear mixing technique using radial basis function (RBF) neural networks. The RBF neural network uses a non-linear mapping to transform signals at low excitation frequencies to the corresponding signals at high frequency. Comparison of initial results using the neural network approach indicate that the proposed method performs better than existing commercial linear mixing algorithms.

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An Adaptive Wiener Filter Based Technique for Automated Detection of Defect Locations from Bobbin Coil Eddy Current Data

---M. Das[1], P. Ramuhalli[2], H. Shekhar[2], L. Udpa[2], S. Udpa[2], Materials Assessment and Research Group, Iowa State University; [1]Department of Electrical and Systems Engineering, Oakland University, Rochester, MI 48309; [2]Material Assessment and Research Group, Department of Electrical and Computer Engineering, Iowa State University, Ames, IA 50014

---This paper presents a new adaptive Wiener filter based technique for detection of defect locations from (noisy) bobbin coil eddy current data. Basically a two step enhancement and detection strategy is proposed here. In the first step, the noisy eddy current data is processed through an improved adaptive Wiener filter that reduces the background noise and significantly enhances the defect signals. Next, a generalized likelihood ratio test is used to detect the probable defect points from the enhanced data. The performance of the proposed detection technique is tested on several real world data sets collected from the steam generator tubes of some nuclear power plants. The experimental results indicate that the method is quite promising and useful for automated processing and classification of eddy current data.---This work was sponsored by the Electric Power Research Institute.

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