

REVIEW OF PROGRESS IN QUANTITATIVE NDE

Western Washington University
Bellingham, Washington

July 14-19, 2002

PROGRAM

Monday, July 15, 2002

PLENARY SESSION 1 ADVANCES IN INFORMATION TECHNOLOGY R. B. Thompson, Chairperson PAC

9:00 AM *Opening Remarks*

9:15 AM **Recent and Anticipated Advances in Scientific Computing**
---G. O. Strawn, Division of Computer Info. Science & Engineering, National Science Foundation,
4201 Wilson Boulevard, Arlington, VA 22230

10:10 AM *Coffee Break*

PLENARY SESSION 2 OVERVIEW OF IMPORTANT ADVANCES D. E. Chimenti, Chairperson PAC

10:30 AM **NDE of Material Degradation by Embrittlement and Fatigue**
---I. Altpeter and G. Dobmann, Universitat des Saarlandes, Institut fur zerstörungsfreie, D-6600
Saarbrücken, Gebäude 37, West Germany

11:15 AM **Practical Long Range Guided Wave Inspection – Managing Complexity**
---P. Cawley, Department of Mechanical Engineering, Imperial College, London SW7 2BX, United
Kingdom

12:10 PM *Lunch*

Recent and Anticipated Advances in Scientific Computing

---G. O. Strawn, Division of Computer Info. Science & Engineering, National Science Foundation, 4201 Wilson Boulevard, Arlington, VA 22230

---The last decade saw major advances in information technology (IT). The Internet emerged from research laboratories to become a revolutionary infrastructure, making one huge heterogeneous IT system out of millions (soon to be billions) of previously isolated component systems. An underreported aspect of this revolution is that there is now "one huge heterogeneous data base" residing on those component systems. And it is getting big. In 1980, \$1 million would buy perhaps 10 gigabytes of storage (10^{10}); today, \$1 million will buy almost a petabyte (10^{15}). And, of course, supercomputers have seen floating point operations per second (flops) grow from gigaflops to teraflops, enabling, among other things, ever more realistic simulations of complex systems. Spectacular advances in performance such as these are expected to continue for at least another decade. Interesting questions present themselves, such as: can the software keep up? Can science keep up? This talk will give a perspective on these developments and questions as the National Science Foundation considers how it might best help accelerate scientific and engineering use of these increasingly important IT tools.

NDE of Material Degradation by Embrittlement and Fatigue

---I. Altpeter and G. Dobmann, Universitat des Saarlandes, Institut fur zerstörungsfreie, D-6600 Saarbrücken, Gebaude 37, West Germany

--- This abstract presents an overview on current activities and results concerning NDE of material degradation by embrittlement and fatigue. Service induced degradation of reactor pressure vessels according to licensing rules is the main limiting factor of the operating life time of nuclear power plants. Degradation of reactor pressure vessel material mechanical properties includes a decrease in fracture toughness, an increase in strength and an increase in the fracture appearance transition temperature (FATT). The vessel operating factors, primarily neutron irradiation and thermal aging have an effect on intrinsic material properties (microstructure) that affect both mechanical and electromagnetic properties. The magnetic and electrical properties determine electromagnetic NDT-quantities, that may be used to monitor the condition of reactor pressure vessel materials so far NDT results reliably correlate with mechanical properties and relevant components are accessible. The strength of a material is mainly influenced by impeding dislocation movement under mechanical load. Similar to the pinning of dislocation movement is the pinning of magnetic domain walls under magnetic load. Therefore the potential of electromagnetic techniques for characterization of mechanical strength is based on the analogy between dislocation and domain wall movement. The low-alloy, heat-resistant WB 36 (15 NiCuMoNb 5) is used as piping and vessel material in fossil-fuel power plants as well as in boiling water reactor and pressurized water reactor nuclear power plants in Germany. However, after long-term service exposure at temperatures above 320° C, failure was observed during operation only in fossil-fuel plants. The reason was thermal embrittlement, i.e. toughness reduction and FATT enhancement. Small-angle neutron scattering (SANS) measurements concluded that the service-induced precipitation causes the hardening decrease in toughness due to copper particles ranging from 1 to 3 nm in size. Investigations by MPA Stuttgart have shown that Vickers hardness is a suited parameter for quantification of the embrittlement. As conventional Vickers hardness measurements are not repetitively and area-wide applicable and as spot tests require information about critical test areas, non-destructive early-detecting of the hardness increase is a most favorable solution of this problem. Therefore, the suitability of micromagnetic NDE techniques for the characterization of the Vickers hardness was investigated. A measurement system was successfully calibrated for the prediction of HV 10 by Barkhausen noise and upper harmonics analysis of the magnetic field. The practical applicability of this approach was shown by proving its independence on side-effects like plastic deformation and tensile loads. In all cases, high correlation coefficients and accuracy were achieved. The evaluation of early fatigue damage and thus the remaining lifetime is a task of practical relevance for example in the chemical, nuclear or in the aircraft industry. For example austenitic stainless steels are in widespread application, mainly because of their high toughness and insensitivity to corrosion attack. However, under static as well as fatigue load the material has the tendency to respond with localized phase transformations from the non-magnetic γ - to the martensitic and ferromagnetic α' - phase. Magnetic permeability changes are observed by the martensitic structure development and by residual stress effects, whereas the electrical conductivity is influenced by the changing dislocation density and arrangement. Concerning on-line fatigue monitoring of austenitic stainless steels, new measuring results by using a GMR-Sensor will be presented. Furthermore, a new thermal NDE method for fatigue damage characterization of Ti 6Al 4V will be presented. This method is based on dissipated heat evaluation. Important advantages of the presented thermal method are the locally resolved evaluation of the thermal parameter using an infrared camera, the low time consumption of the measurements (few seconds), and the simplicity of the method. Relevant results from other research institutes will also be presented.

Practical Long Range Guided Wave Inspection – Managing Complexity

---P. Cawley, Department of Mechanical Engineering, Imperial College, London SW7 2BX, United Kingdom

---The inspection of large structures using conventional ultrasonic bulk wave techniques is slow because the inspection region is limited to the area immediately surrounding the transducer, so scanning is required if the whole structure is to be tested. Ultrasonic guided waves potentially provide an attractive solution to this problem because they can be excited at one location on the structure and will propagate many metres, returning echoes indicating the presence of corrosion or other defects. However, guided wave testing is complicated by the presence of many possible wave modes, most of which are dispersive. These guided wave characteristics offer a wealth of opportunities for the extraction of information about the structure, but it is crucial to manage this complexity if the test is to be useable in industrial practice. Guided waves can be used in three regimes, which have been discussed extensively at previous QNDE meetings by several groups: short range ($\ll 1\text{m}$, e.g. leaky Lamb wave inspection of composite materials and high frequency surface wave scanning), medium range (up to about 5m, e.g. SH and Lamb waves in the 250 kHz to 1 MHz frequency range for plate and tube inspection), and long range (up to 100m, e.g. testing of pipelines). This paper concentrates on long range testing using frequencies below 100 kHz. The progress from research work to a robust, commercial pipe testing system will be discussed, together with more recent research on applications to plates and railroad rails. There are many remaining research issues to be addressed, notably the inspection of more complex structures, and those where attenuation is significant. These will be discussed, together with a review of opportunities in the smart structures field.

Monday, July 15, 2002

SESSION 3
MICROWAVE NDE
R. Zoughi, Chairperson
SMATE 140

- 1:30 PM** **The Nondestructive Evaluation Toolbox: Where Does Microwave NDT Fit?**
---G. W. Carriveau, SAIC, 16701 West Bernardo Drive, San Diego, CA 92127
- 2:10 PM** **Nano Spatial Resolution with 60 MHz Near-Field Scanning Millimeter-Wave Microscope**
---M. Kim, K. Lee, J. Kim, and H. Kim, Department of Physics, Sogang University, C. P. O. 1142, Seoul 121-742, Korea
- 2:30 PM** **Near-Field Nondestructive Detection of Small Corrosion Precursor Pits Under Paint in Aluminum Panels**
---D. Hughes¹, R. Zoughi¹, and Russell Austin², ¹Applied Microwave Nondestructive Testing Laboratory (*amntl*), Electrical and Computer Engineering Department, University of Missouri-Rolla, Rolla, MO 65409, ²Texas Research Institute at Austin (TRI Austin), 9063 Bee Caves Road, Austin, TX 78733-6201
- 2:50 PM** **A Millimeter-Wave Near-Field Scanning Probe with a Resonant Waveguide Probe**
---K. Lee, J. Kim, H. Kim, and M. Kim, Department of Physics, Sogang University, C. P. O. 1142, Seoul 121-742, Korea
- 3:10 PM** **Coffee Break**
- 3:30 PM** **Influence of Cyclical Soaking and Drying of Mortar in Chloride Bath on its Microwave Reflection: The Forward Model**
---K. Muñoz and R. Zoughi, Applied Microwave Nondestructive Testing Laboratory (*amntl*), Electrical and Computer Engineering Department, University of Missouri-Rolla, Rolla, MO 65409
- 3:50 PM** **Near-Field Scanning Microwave Microscope Using a Dielectric Resonator**
---J. Kim, H. Kim, M. Kim, and K. Lee, Department of Physics, Sogang University, C. P. O. 1142, Seoul 121-742, Korea
- 4:10 PM** **Near-Field Microwave and Embedded Modulated Scattering Techniques for Dielectric Characterization of Materials**
---D. Hughes and R. Zoughi, Applied Microwave Nondestructive Testing Laboratory (*amntl*), Electrical and Computer Engineering Department, University of Missouri-Rolla, Rolla, MO 65409

**The Nondestructive Evaluation Toolbox:
Where Does Microwave NDE FIT?**

---G. W. Carriveau, SAIC, 16701 West Bernardo Drive, San Diego, CA 92127

---Because of the variety of materials used and the nature of manufacturing processes it is often very difficult to effectively inspect and characterize complex composite structures. It is expected that no single NDE technology might be expected to totally provide the inspection information required. This paper describes a series of tests that have been performed on a variety of thick composite structures using a wide variety of NDE methods. The measurements were performed to assess the efficacy of these methods when looking for typical flaws and defects found in this type of material. Those that were addressed include: delaminations between plies, resin rich and resin poor areas, porosity, inclusions, contact and correct filling between laminate and adhesive, thickness of adhesive, correct placement of components and assemblies, foreign materials, impact damage, etc. Inspection methods that were surveyed and evaluated include: conventional through transmission and inverse geometry radiography, eddy current, single probe scanning and two-dimensional array ultrasonics, laser trans-illuminescence, microwave NDE, and time delayed thermal imaging. Microwave results will be compared with the other methods and the overall results will be reviewed and discussed.

Nano Spatial Resolution with 60 GHz Near-Field Scanning Millimeter-Wave Microscope

---Myungsick Kim, Kiejin Lee, Jooyoung Kim, and Hyun Kim, Department of Physics, Sogang University, C.P.O. 1142, Seoul 121-742, Korea

---We report a millimeter-wave imaging technique for the various sample using a near-field scanning millimeter-wave microscope by using a resonant standard waveguide at operation frequency $f=60$ GHz. The metallic probe tip in the resonant waveguide was design to couple the resonant waveguide. By tuning a coupling coefficient of the probe tip in a resonant standard waveguide, we could achieve a maximum sensitivity and spatial resolution. By the monitoring the change of quality factor in the near field zone as the probe scanned over the object, we obtain quantitative near-field images of the metal, organic and oxide thin films with nano spatial resolution. We also visualize an image of carrier density of ITO thin film depends on dc bias voltage.

Near-Field Nondestructive Detection of Small Corrosion Precursor Pits Under Paint in Aluminum Panels

---Dana Hughes¹, Reza Zoughi¹, and Russell Austin², ¹Applied Microwave Nondestructive Testing Laboratory (*amntl*), Electrical and Computer Engineering Department, University of Missouri-Rolla, Rolla, MO 65409, ²Texas Research Institute at Austin (TRI Austin), 9063 Bee Caves Road, Austin, TX 78733-6201

---Detection of corrosion under paint and composite laminate coatings is an important concern in many applications. The appearance of small pits in a metal substrate covered with a thin layer of paint is the precursor to corrosion of the substrate. The earlier these pits are detected the higher the potential for preventing corrosion in the substrate. Near-field microwave nondestructive testing and evaluation techniques have shown great potential for detecting corrosion under thin paint and composite laminates. The substrates used in these investigations have included steel and aluminum panels. The current investigation involves the detection of small manufactured and salt-chamber grown pits in aluminum panels. These panels are then primed and painted and in one case the pits are covered with a thin layer of applique. This paper describes the pit properties in these panels as well as the results of using near-field microwave NDT techniques, primarily using open-ended rectangular waveguide probes, at several different microwave frequency bands. The results are raster scan images of the panels showing the relative location of the pits as well as the influence of their size on the measured signal/image. In addition, a method for increasing the spatial resolution of the microwave system while keeping the operating frequency relatively low is also described.

A Millimeter-Wave Near-Field Scanning Probe with a Resonant Waveguide Probe

---Kiejun Lee, Jooyoung Kim, Hyun Kim, and Myungsick Kim, Department of Physics, Sogang University, C.P.O. 1142, Seoul 121-742, Korea

---We report a near-field scanning imaging technique using a millimeter-wave scanning microscope with a resonant standard waveguide probe at operating frequency of 30-39 GHz and 60 GHz. The metallic probe tip in resonant waveguide with a tunable short was designed to couple energy into and out of the resonant waveguide. By tuning the resonant waveguide probe using a tunable short, we could obtain improved sensitivity and spatial resolution of evanescent image of electronic, organic, ferromagnetic, superconductor, and biological materials. By measuring the shift of resonance frequency and the change of quality factor, we obtained near-field scanning millimeter-wave images with a spatial resolution better than 200 nm. The principal factors of near-field scanning millimeter-wave microscope affecting the sensitivity and the spatial resolution, such as the sample-tip separation, the impedance matching, the radius of the probe-tip, and the quality factor of resonant waveguide, are discussed.

Influence of Cyclical Soaking and Drying of Mortar in Chloride Bath on its Microwave Reflection: The Forward Model

---Kristen Muñoz and R. Zoughi, Applied Microwave Nondestructive Testing Laboratory (*amntl*), Electrical and Computer Engineering Department, University of Missouri-Rolla, Rolla, MO 65409

---Intrusion of chloride ions is a major cause of deterioration in reinforced concrete structures. Chloride-induced corrosion of steel rebar can significantly compromise integrity of these structures. In recent years, near-field microwave nondestructive testing techniques have been used for detection and evaluation of chloride ingress in cement-based materials, with much success. One of the most important issues associated with this problem is the gradient and depth to which chloride may penetrate in a cement-based material after successive exposure to a chloride solution. Consequently, it has been proposed to cyclically soak mortar samples, made-to-fit inside of waveguide sample holders, to salt water and then oven-dry them. In this way, after every cycle more and more free salt is left behind in the sample. The distribution of salt in the sample is not expected to be uniform. Electromagnetically, this corresponds to a dielectric material with varying dielectric properties. In order to evaluate the utility of this approach the process is modeled using a discrete layered dielectric approach in which the sample is assumed to be made of thin layers of dielectric materials with varying dielectric properties corresponding to their respective salt content. Subsequently, the magnitude and phase of reflection coefficient of such as sample is calculated for when the sample is placed inside a short-circuited. The change in the reflection properties as a function of various distribution functions, representing salt penetration into the samples, is then studied. This information can then be used to determine evaluate the dielectric property gradient of the material and hence the salt content distribution (i.e., the inverse formulation). This paper presents the modeling of the forward problem and discusses the results of several representative cases.

Near-Field Scanning Microwave Microscope Using a Dielectric Resonator

---Jooyoung Kim, Hyun Kim, Myungsick Kim, and Kiejun Lee, Department of Physics, Sogang University, C.P.O. 1142, Seoul 121-742, Korea

---We report a near-field scanning microwave microscope by using a high quality dielectric resonator with a tunable screw at an operating frequency of $f = 4.5$ GHz. The probe tip is mounted in a cylindrical resonant cavity coupled to a dielectric resonator. By tuning the tunable screw coming through the top cover, we could improve sensitivity, signal-to-noise ratio, and spatial resolution to better than 1.5 mm. To demonstrate the ability of local microwave characterization, the surface resistance of metallic thin films has been mapped.

Near-Field Microwave and Embedded Modulated Scattering Techniques for Dielectric Characterization of Materials

---Dana Hughes and Reza Zoughi, Applied Microwave Nondestructive Testing Laboratory (*amntl*), Electrical and Computer Engineering Department, University of Missouri-Rolla, Rolla, MO 65409

---Near-field microwave nondestructive testing techniques, using open-ended waveguide probes, have been extensively used for inspection of a wide variety of structures and composites. Modulated scattering techniques, using PIN diode-loaded resonant dipole antennas been used at microwave frequencies for nondestructive testing, antenna pattern measurement, electromagnetic field mapping and radar cross-section measurement applications. In this approach, the PIN diode is forward and reverse biased using a rectangular pulse train. Consequently, the dipole antenna is loaded with a short or a near-open load as a function of time. When a dipole antenna is embedded inside of a dielectric material, its impedance is not only a function of frequency and dipole dimensions, but also a function of the dielectric properties of the medium in which it is embedded. The periodic impedance loading of the PIN diode changes the dipole impedance during the forward and reserve stages of the diode. The diode impedance is not a function of the dielectric properties of the material, however the dipole impedance is. Thus, the forward and reverse reflection properties of the dipole scatterer change as a function of changes in the material dielectric properties. Subsequently, the comparison between the reflection coefficient of the dipole antenna between the forward and reverse cases may be used to evaluate the dielectric properties of the material. This results in a rapid, nondestructive and sensitive dielectric measurement technique. The derivation of the loaded dipole current density, from which its reflection coefficient may be determined, has already been accomplished. This paper presents the results of specific measurements for the purpose of evaluating the dielectric properties of mortar samples using this embedded MST approach.

Monday, July 15, 2002

SESSION 4
COMPOSITE MATERIALS
N. Gengembre, Chairperson
SMATE 150

- 1:30 PM** **Ultrasonic Assessment of Thermoset Cure: Dependence of Tg and Crosslink Density on Thermal History and Stoichiometric Ratio**
---M. E. Unwin and R. E. Challis, School of Electrical and Electronic Engineering, University of Nottingham, University Park, Nottingham, NG7 2RD, United Kingdom
- 1:50 PM** **Prediction of Ultrasonic Fields into Composite Multi-Layered Structures: Homogenization Approach for the Direct Field and Statistical Approach for the Inner Reflections**
---N. Gengembre, P. Calmon, and S. Chatillon, CEA/LIST, French Atomic Energy Commission, CEA-Saclay bat. 611, 91191 Gif-sur-Yvette Cedex, France; O. Petillon, EADS-CCR, EADS, 12 rue Pasteur BP 76, 92152 Suresnes Cedex, France
- 2:10 PM** **Baseline NDE Data for Ceramic Matrix Composite Materials**
---R. E. Martin and L. M. Harmon, Cleveland State University, Cleveland, OH 44135; G. Y. Baaklini, NASA Glenn Research Center, Cleveland, OH
- 2:30 PM** **Optimizing Test Flaws for New Inspection Methods: Why Test Specimen-Optimized for Traditional Ultrasonic Inspection May Fail**
---W. J. Bisle and D. Scherling, Airbus Deutschland GmbH, Testing Technology, Bremen, Germany
- 2:50 PM** **Development of Nondestructive Methods for Composite Repair Inspection**
---D. K. Hsu, D. J. Barnard, J. J. Peters, and V. Dayal, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011
- 3:10 PM** **Coffee Break**
- 3:30 PM** **Continuous Health Monitoring of Graphite-Epoxy Rocket Motor Cases**
---M. Luzio, R. D. Finlayson, and R. K. Miller, Physical Acoustics Corporation, 195 Clarksville Road, Princeton Junction, NJ 08550
- 3:50 PM** **Global and Local NDI Characterization of Fiber Reinforced Materials**
---R. M. Aoki, German Aerospace Center DLR, Institute of Structures & Design, Pfaffenwaldring 38-40, 70569 Stuttgart, Germany; K. Eberle, Institute for Statics and Dynamics of Aerospace Structures, University of Stuttgart, Pfaffenwaldring 27, 70569 Stuttgart, Germany
- 4:10 PM** **Transmission and Reflection of Guided Waves in a Plate Overlap**
---W.-J. Song and J. L. Rose, Department of Engineering Science and Mechanics, Pennsylvania State University, 412 Earth and Engineering Science Building, University Park, PA 16802-6812; J. M. Galan and R. Abascal, Grupo de Estructuras, Escuela Superior de Ingenieros, Camino de los Descubrimientos, s/n, E-41092, Sevilla, Spain
- 4:30 PM** **Imaging of Fatigue Damage in CFRP Materials Using Nonlinear Harmonic Generation**
---C. Mattei and P. Marty, CSM Materialteknik AB, Saab Aerospace Group, Linkoping, Sweden

Ultrasonic Assessment of Thermoset Cure: Dependence of Tg and Crosslink Density on Thermal History and Stoichiometric Ratio

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

---Assessment of the cure state of thermoset materials is important for process and quality control in the manufacture of composite components and adhered structures. Production procedures often involve cure schedules where a component undergoes a complicated thermal history. Dynamic mechanical analysis (DMA) studies of the variation of glass transition temperature (Tg) and crosslink density (Mc) indicate that post cure stages cause significant changes to the macromolecular structure of a thermoset. Ultrasonic cure monitoring technique, which have the advantage of being relatively inexpensive and applicable in an industrial setting, have already been developed. However, detailed studies of ultrasound measurements in terms of the chemistry of a cured thermoset have yet to be achieved. Here we investigate the extent to which ultrasonic attenuation and velocity measurements can be interpreted in terms of the molecular structure of the thermoset. The WLF equation and theory of rubber elasticity have been applied to ultrasonic modulus data to give estimations of Tg and Mc. Results for epoxy samples cured under different thermal conditions and with different stoichiometric ratios show good agreement with equivalent data from DMA techniques. Initial results indicate that ultrasonic techniques may ultimately provide detailed chemical on-line cure state assessment and monitoring in an industrial setting.

Prediction of Ultrasonic Fields into Composite Multi-Layered Structures: Homogenization Approach for the Direct Field and Statistical Approach for the Inner Reflections

---Nicolas Gengembre, Pierre Calmon, and Sylvain Chatillon, CEA/LIST, French Atomic Energy Commission, CEA-Saclay bat. 611, 91191 Gif-sur-Yvette cedex, France; Odile Petillon, EADS-CCR, EADS, 12 rue pasteur BP76, 92152 Suresnes cedex, France

---The simulation of ultrasonic fields into composite materials is growing important for aeronautic applications, since it allows to assist the settings and interpretations of non destructive tests. In this paper, attention is paid to multi-layered composite structures, such as Carbon epoxy materials. Such materials are constituted of disoriented anisotropic planar layers (plies). A method is proposed to evaluate the field radiated into such components by means of a homogenization approach: effective stiffness constants are evaluated for the whole layers, thereafter considered as one anisotropic and homogeneous material. Such a description of the component can then be introduced into CEA's software Champ-Sons dealing with such configurations. This approach allows to predict the field transmitted through the inner interfaces. Anyhow, the signal coming back from these inner interfaces is not negligible and can be of some interest in the evaluation of the quality of the components. Therefore, another model has been developed that addresses the prediction of the noise due to reflections on the inner interfaces and also to the presence of scatterers such as porosities and to the electronic gain applied. The formulation is established as a function of the attenuation into the material, the Depth Amplitude Compensation function (DAC) applied and the thickness of the layers. Examples and comparisons with experiments are shown.

Baseline NDE Data for Ceramic Matrix Composite Materials

---Richard E. Martin and Laura M. Harmon, Cleveland State University, Cleveland, OH, 44135; George Y. Baaklini, NASA Glenn Research Center, Cleveland, OH

---Ceramic Matrix composite materials are seen as a promising technology for use in high temperature applications such as the next generation reusable launch vehicle. These materials offer a high strength to weight ratio and excellent high temperature performance. However, for these materials to be used to their potential, nondestructive evaluation (NDE) methods must be established to determine the presence of manufacturing and in-service defects that can lead to early and unexpected failures. The work presented is intended to investigate the benefits of a number of NDE methods for the location of critical material variations and defects in SiC/SiC composite coupons. These coupons are scheduled for fatigue testing and will be re-examined later using the same methods in order to measure the damage progression within the material and to correlate NDE data with fatigue life and failure locations. The methods used include microfocus x-ray, acousto-ultrasonics and thermal imaging techniques.

Optimizing Test Flaws for New Inspection Methods: Why Test Specimen-Optimized for Traditional Ultrasonic Inspection May Fail

---Wolfgang J. Bisle and Dieter Scherling, Airbus Deutschland GmbH, Testing Technology, Bremen, Germany

---Often test specimens are used for development of new test methods, which were already helpful used for qualification/validation of traditional NDT methods/procedures like Ultrasonic. Especially in case of fiber reinforced plastics it is usual to simulate flaws using inserts like foils etc. These simulated flaws work for instance very well blocking ultrasound. This made them widespread in laboratories and one tends to use them also as references to check other inspection methods. But already the production of parts with flaw simulations by foils is critical - occasionally they bond with the structure and partially they show no interfaces. In case of optical and thermo optical inspection methods these flaw simulations by inserts now make more trouble than they help - their behavior shows completely different effects than natural flaws. Having had this problem with shearography as well as with pulse thermography and ultrasonic burst excited thermography we looked for other simulation methods which behave more realistic. We will report about a new approach and its results.

Development of Nondestructive Methods for Composite Repair Inspection

---D. K. Hsu, D. J. Barnard, J. J. Peters, and V. Dayal, Center for Nondestructive Evaluation, Iowa State University, 1915 Scholl Road, Ames, IA 50011

--- This paper describes the progress of an FAA-funded project aimed at developing nondestructive inspection methods for evaluating the condition and quality of repairs made on composites, especially honeycomb sandwich structures. The goal is to establish the relationship between the internal features and conditions of a composite repair and the image of the repair formed by nondestructive methods. The techniques chosen for inspecting composite repairs are the Computer Aided Tap Test (CATT) and air-coupled ultrasonic testing (ACUT). The former is a time-proven old method made quantitative and image-capable with the help of electronics and laptop computer. The latter is a new, maturing technique that has distinct advantages and a potential for becoming a practical tool for inspecting composite repair. Using the two methods, several repairs on composite aircraft parts were imaged and evaluated. To verify the aforementioned relationship, one of the repaired panel was sectioned to reveal the internal construction and defects. Both the CATT image and the ACUT image correlated well with the core splice, scarfed ply region and delamination in the repair. Future work will include one-sided inspection of solid laminates using air-coupled Lamb waves and applying air-coupled ultrasonic scans in the field.---This material is based upon work supported by the Federal Aviation Administration under Contract #DTFA03-98-D-00008, Delivery Order #IA047 and performed at Iowa State University's Center for NDE as part of the Center for Aviation Systems Reliability program. The technical monitor was Cu Nguyen.

Continuous Health Monitoring of Graphite-Epoxy Rocket Motor Cases

---M. Luzio, R. D. Finlayson, and R. K. Miller, Physical Acoustics Corporation, 195 Clarksville Road, Princeton Junction, NJ 08550

---Following the explosion of Delta 241 (IIR-1) on January 17th, 1997, the failure investigation board concluded that the Graphite Epoxy Motor cases (GEMs) should be inspected for damage throughout their life and just prior to launch. Subsequent investigations and feedback from industry led to an Aerospace Corporation recommendation to instrument the entire fleet of GEMs with a health monitoring system. The results presented in this paper contributed significantly to the understanding of the acoustic properties of the GEM casing, and make a substantial advancement in the development of the theoretical basis of location algorithms for Acoustic Emission (AE) sources. These AE sources include impacts and other sources of high mechanical and thermal stresses. Prior testing has shown that impacts with energies equal to or greater than 5 foot-pound will damage the GEMs. When the composite material undergoes damage, it is important to detect it rapidly, avoiding the possible use of an unsuitable motor case during launch. Based on the nature of the situation, AE methods were used to approach the problem. The tests discussed in this paper were designed to find a method of AE analysis that will classify impacts according to their energy content delivery, and to determine if they are potential initiators of damage to the GEMs. In addition to impact energy determination, the location of an impact was also determined within an acceptable range.

Global and Local NDI Characterization of Fiber Reinforced Materials

---R. M. Aoki, German Aerospace Centre DLR, Institute of Structures & Design; Pfaffenwaldring 38-40, 70569 Stuttgart, Germany; K. Eberle, Institute for Statics and Dynamics of Aerospace Structures, University of Stuttgart, Pfaffenwaldring 27, 70569 Stuttgart, Germany

---Development in processing technology may improve productivity and product reliability especially for advanced fiber reinforced structural aerospace and terrestrial applications. Changes in final properties of these materials can be correlated to processing variables through Non-Destructive Inspection (NDI) after different steps during its manufacturing and may also identify the more sensitive processing parameters. Results of an ongoing research program on characterization of fiber reinforced materials beginning with manufacturing of CFRP laminates up to fiber reinforced ceramic matrix material C/C-SiC will be presented. The synergetic evaluation of the NDI (global/local) e.g. mechanical vibration and ultrasonic results together with a correlation to destructive testing results show the potentials for better understanding of the material in the meso- and macro scale and build the basis for further theoretical model development. During the destructive testing (tensile and 3 point bending tests) strain measurements with help of advanced photogrammetry based on 3D image correlation was used. Fundamental information of the nature of the defect or damage states, e.g. crack pattern, fiber/matrix debonding, delamination, porosity, etc., their effect on thermo-mechanical properties of the material, or the expected performance of the structure in service environment are the principal aims of these investigations.

Transmission and Reflection of Guided Waves in a Plate Overlap

---W.-J. Song and J. L. Rose, Department of Engineering Science and Mechanics, Pennsylvania State University, 412 Earth and Engineering Science Building, University Park, PA 16802-6812; J. M. Galan and R. Abascal, Grupo de Estructuras, Escuela Superior de Ingenieros, Camino de los Descubrimientos, s/n, E-41092, Sevilla, Spain

---Lamb and SH wave propagation in a plate overlap is investigated. Transmission and reflection coefficients for incident Lamb waves of A0 and S0 modes and SH n=0 waves across the overlap region are numerically calculated using a hybrid BEM method. Transmission and reflection coefficients of the Lamb and SH waves across the overlap region are studied as a function of incident mode, frequency, and overlap length. In addition, mode conversion phenomena from the incident waves within the overlap region are also included in the numerical study. A few experiments were also conducted for measurements of transmission and reflection coefficients for incident S0, A0, and SH n=0 mode waves in overlap-shaped steel plates with two different overlap areas. The experimental results are in good agreement with the numerical calculations. The numerical and experimental results can be used to establish guidelines for NDE in overlapped plates and in multi-layer structures with various joints by selecting modes and tuning frequency.

Imaging of Fatigue Damage in CFRP Materials Using Nonlinear Harmonic Generation

---Christophe Mattei and Pierre Marty, CSM Materialteknik AB, Saab Aerospace Group, Linköping, Sweden

---The increasing use of composite material in demanding loading and environmental conditions calls for nondestructive techniques that can be instrumental in evaluating the structure's residual life. As Graphite/Epoxy composite materials are known for their good response to fatigue, they also present very few measurable sign of damage before the onset of delaminations. In this paper, experimental evidence is presented which suggests a strong nonlinear interaction between acoustic wave and micro-structural damage before the onset of delaminations in fatigued CFRP samples. Sample used were 32 plies quasi-isotropic graphite/epoxy laminate fatigued with a four point bending fatigue. Monitoring of the aging process with Acoustic Emission was used to stop the loading when the first signs of degradation preceding delamination occurred. Measurements were made in immersion using focused transducer in through transmission. Narrow band excitation was applied to the transmitter. First Harmonic Images were constructed from the amplitude of the first harmonic normalized by the amplitude of the fundamental. Harmonic imaging technique (HIT) shows a much higher sensitivity to micro-damage than amplitude C-scan. Correlations are established between the image zone where the nonlinear parameter is high and the region where delamination eventually occurred.

Monday, July 15, 2002

SESSION 5
NEW TECHNIQUES AND SYSTEMS I
J. Posakony, Chairperson
FRASER 4

- 1:30 PM** **Ultrasound Burst Phase Thermography for Applications in the Automotive Industry**
---T. Zweschper, G. Riegert, A. Dillenz, and G. Busse, Institute of Polymer Testing and Polymer Science (IKP) – Department of Nondestructive Testing, University of Stuttgart, D-70569 Stuttgart, Germany
- 1:50 PM** **Determination of Dispersion Curves of Phase and Group Velocities Using Backward Radiated Leaky Lamb Waves**
---Y. H. Kim and S.-J. Song, School of Mechanical Engineering, Sungkyunkwan University, Suwon 440-746, Korea; S.-D. Kwon, Department of Physics, Andong National University, Andong 760-749, Korea
- 2:10 PM** **Laser Ultrasonic Applications of Multiplexed Two-Wave Mixing Interferometry**
---Y. Zhou, F. Zhang, and S. Krishnaswamy, Center for Quality Engineering and Failure Prevention, Northwestern University, 2137 N. Sheridan Road, Evanston, IL 60208-3020
- 2:30 PM** **Nonlinear Laser Ultrasonic Measurements of Localized Fatigue Damage**
---J. L. Blackshire, AFRL/MLLP, Wright Patterson Air Force Base, OH 45433; S. Sathish, University of Dayton Research Institute, Dayton, OH 45469-0127; J. K. Na, Veridian Engineering, Dayton, OH 45440
- 2:50 PM** **Development of an Acousto-Ultrasonic Scan System**
---D. J. Roth¹, L. M. Harmon², R. E. Martin², and A. L. Gyekenyesi³, ¹NASA Glenn Research Center, MS 6-1, 21000 Brookpark Road, Cleveland, OH, 44135; ²Cleveland State University; ³Ohio Aerospace Institute
- 3:10 PM** **Coffee Break**
- 3:30 PM** **Acoustic Interferometer for Localized Rayleigh Wave Velocity Measurements**
---R. W. Martin¹, S. Sathish¹, R. Reibel¹, T. J. Moran, and M. P. Blodgett, Metals, Ceramics and NDE Branch, Materials and Manufacturing Directorate, Wright Patterson Air Force Base, OH 45433-7817; ¹University of Dayton Research Institute, 300 College Park Drive, Dayton, OH 45469-0127
- 3:50 PM** **Development and Testing of Prototype Giant Magnetostrictive (GMR) Rotating Probe System**
---B. Wincheski, M. Namkung, and D. Perey, Structures and Materials, NASA Langley Research Center, Hampton, VA 23681; J. Simpson and J. Callahan, Lockheed Martin Engineering and Sciences Corporation, Hampton, VA 23681
- 4:10 PM** **Three-Channel Non-Force Magnetic Microscope**
---S. I. Bondarenko¹, A. A. Shablo¹, P. P. Pavlov¹, and N. Nakagawa², ¹Institute for Low Temperature Physics & Engineering, NASU, Kharkov, Ukraine; ²Center for NDE, Iowa State University, 1915 Scholl Road, Ames, IA 50011
- 4:30 PM** **Material Characterization and Life Prediction for Critical Components through Application of Photon Induced Positron Annihilation (PIPA)**
---D. W. Akers, Positron Systems Inc., 6151 N. Discovery Way, Boise, ID 83713-1556; A. B. Denison, Lawrence Livermore National Laboratory, Livermore, CA
- 4:50 PM** **Digital Meter of Ultrasound Phase Velocity**
---V. G. Bazhenov and S. N. Ligomina, Department of Nondestructive Testing, National Technical University of Ukraine, KPI, Kiev 03056, Ukraine

Ultrasound Burst Phase Thermography for Applications in the Automotive Industry

---T. Zweschper, G. Riegert, A. Dillenz, and G. Busse, Institute of Polymer Testing and Polymer Science (IKP) – Department of Non-Destructive Testing, University of Stuttgart, D-70569 Stuttgart, Germany

---The weight of modern cars suffers from new many built-in devices and enhanced crash safety. In order to keep fuel consumption low and to maintain the quality of driving dynamics, the structural weight needs to be reduced. However, the increasing use of light-weight structures in automotive applications results in a need for enhanced quality inspection (both in production and maintenance inspection) on materials that differ significantly from classical cars. The use of elastic waves in combination with thermal waves allows to separate structural information about the investigated material from defect specific thermal signatures. Due to its superior signal-to-noise-ratio, Ultra-sound Burst-Phase-Thermography (UBPT) as a new non-destructive testing method is an answer to this need since it is a defect-selective and fast imaging tool for damage detection. Besides detection of cracks in metallic structures and iron cast samples, modern applications for this method are adhesive joints as well as spot-welding and rivet joints which were characterized successfully. The paper will present results obtained on various kinds of problems related to modern vehicle production. It is obvious that this method can be automated easily since the measurement is performed within typically a few seconds while the interpretation of the defect-selective results allows for a clear discrimination between good and poor quality of components.

Determination of Dispersion Curves of Phase and Group Velocities Using Backward Radiated Leaky Lamb Waves

---Young H. Kim and Sung-Jin Song, School of Mechanical Engineering, Sungkyunkwan University, Suwon, 440-746, Korea; Sung-Duk Kwon, Department of Physics, Andong National University, Andong, 760-749 Korea

---The guided wave has been widely employed to characterize thin plates and layered media. The dispersion curves of phase and group velocities are essential for the quantitative application of guided waves. Numerous researches have been carried out to obtain dispersion curves in theoretical and experimental approaches. The technique using leaky Lamb wave (LLW) is one of excellent method to obtain dispersion curves. Most of previous works using LLW is focused to get phase velocity dispersion curves. In the present work, the method to obtain dispersion curves of not only phase but also group velocities is proposed. A fully automated system for the measurement of backward radiation of LLW was constructed. The specimen moves in two-dimensional plane as well as in angular rotation. The signals of backward radiation of LLW were obtained for an elastic plate with broad band transducer. At a given incident angle, phase velocity was determined from the incident angle and corresponding modes of Lamb waves are strongly generated in a plate. The generated Lamb waves propagate forward and backward with energy leakage into the water. Backward radiated LLW is detected by the same transducer and its frequency components contain information on the dispersion curves. Moving the specimen in a linear direction of LLW propagation, group velocity is determined by measuring the transit time shift in rf waveform. Typical results for steel and aluminum plates are presented.

Laser Ultrasonic Applications of Multiplexed Two-Wave Mixing Interferometry

---Y. Zhou, F. Zhang, and S. Krishnaswamy, Center for Quality Engineering and Failure Prevention, Northwestern University, 2137 N. Sheridan Road, Evanston, IL 60208-3020

---In recent work at Northwestern University, Multiplexed Two-Wave Mixing Interferometers (MTWM) have been developed. These systems are able to perform optical detection of ultrasonic motion over an array of points simultaneously. 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 form a multiplexed two-wave mixing 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 we present recent advances and applications of this technology. We will discuss the problems and potentials of using the MTWM system in combination with a long pulse laser to provide large array MTWM receivers. An application of the MTWM system for fast recovery of Lamb wave dispersion curves will also be presented. We obtain the dispersive time-domain Lamb wave signals at multiple source-to-receiver distances. Following the algorithm of Alleyne and Cawley, these time-position domain signals are transformed to the frequency-wavenumber domain using a 2D FFT technique. The MTWM systems enables rapid characterization of Lamb wave dispersion.

Nonlinear Laser Ultrasonic Measurements of Localized Fatigue Damage

---J. L. Blackshire, AFRL/MLLP, Wright Patterson AFB, OH 45433; S. Sathish, University of Dayton Research Institute, Dayton, OH 45469-0127; J. K. Na, Veridian Engineering, Dayton, OH 45440

---A nonlinear laser ultrasonic system was developed and used to characterize the fatigue status of a fractured Ti-6Al-4V sample with high spatial-resolution and sensitivity. The measurement system is built around a scanning heterodyne interferometer, which allows detailed displacement field images to be created and visualized for propagating surface and bulk acoustic fields on a material surface. An assessment of the local fatigue damage of the material was made using nonlinear ultrasonic interaction principles, where the local amplitudes of the fundamental and second harmonic displacement fields are monitored simultaneously. This provides a means for evaluating the local acoustical nonlinearity parameter, beta, which can be related to the accumulation of fatigue damage in a material. A large increase in beta was observed between the unfatigued area (near the grip section) and the heavily fatigued area (gauge section) for a fractured dogbone specimen. The propagation of both thru-transmission bulk-waves and surface acoustic waves (SAWs) were evaluated. Changes in beta were correlated to microstructural changes in terms of dislocation density, in an attempt to quantify the localized fatigue damage.

Development of an Acousto-Ultrasonic Scan System

---D. J. Roth¹, L. M. Harmon², R. E. Martin², and A. L. Gyekenyesi³, ¹NASA Glenn Research Center, MS 6-1, 21000 Brookpark Road, Cleveland, OH 44135, ²Cleveland State University, ³Ohio Aerospace Institute

---Acousto-ultrasonic (AU) interrogation of materials and structures has been a viable inspection method for nearly two decades. AU is a single-sided inspection technique using sending and receiving transducers in which characterization of the material between the transducers is the primary goal. AU has focused on assessing the distributed damage state as opposed to discrete flaw detection and therefore is complementary to more traditional NDE methods such as ultrasonic c-scan, x-ray radiography, and eddy current inspection. AU measurements can be performed directionally allowing correlations to be made between AU parameters and directionally-dependent material properties. Through its history, AU has been used to inspect polymer matrix composite, metal matrix composite, ceramic matrix composite, and even monolithic metallic materials. To date, AU has been implemented in basic point measurement, manual hand scan, and real-time monitoring point measurement mode. Drawbacks have been the lack of an automated capability to assure optimized reproducibility and allow scanning capacity. In this work, we will describe the development of an automated AU scan system that has been underway at NASA this past year. Preliminary results with the system will be presented. A brief history of the AU method will be discussed. Ultimately, NASA would like to transfer/license the technology to industry.

Acoustic Interferometer for Localized Rayleigh Wave Velocity Measurements

---R. W. Martin¹, S. Sathish¹, R. Reibel¹, T. J. Moran, and M. P. Blodgett, Metals, Ceramics and NDE Branch, Materials and Manufacturing Directorate, Wright-Patterson Air Force Base, Dayton, OH 45433-7817; ¹University of Dayton Research Institute, 300 College Park Drive, Dayton, OH 45469-0127

---Two instrumentation systems for measurement of Rayleigh surface acoustic wave (RSAW) velocity are described. The first system consists of a more conventional methodology using matched RF amplifiers and phase detector/mixer circuits. In the second system, a lock-in amplifier, operating at high frequency, replaces the matched RF amplifiers and phase detector/mixer circuit, therefore simplifying the instrumentation. Both systems have been used to measure relative Rayleigh wave velocity using a cylindrically focused acoustic transducer consisting of three elements. A high-precision relative velocity measurement of Rayleigh surface waves is performed by exciting the central element and one of the outer elements with a tone burst signal. The central element is utilized to detect the specular reflected signal and the other outer element is used to detect the Rayleigh surface wave. A phase comparison of the two received signals to a reference signal is utilized to measure relative phase changes in the RSAW. Results of phase measurements performed on several specimens using both systems are presented for comparison. The advantages and limitations of the methodology for characterization of residual stress on surface treated materials using RSAW measurements will be discussed.---This research was sponsored by and performed on-site at the NDE Branch, AFRL/Material and Manufacturing Directorate, Wright-Patterson Air Force Base, Ohio under contract #F33615-98-C-5217.

Development and Testing of Prototype Giant Magnetoresistive (GMR) Rotating Probe System

---B. Wincheski, M. Namkung, and D. Perey, Structures and Materials, NASA LaRC, Hampton, VA 23681; J. Simpson and J. Callahan, Lockheed Martin Engineering and Sciences Corporation, Hampton, VA 23681

---Continued development of the giant magnetoresistive based rotating probe system has resulted in the fabrication of a fieldable prototype instrument. The system, designed for the detection of deeply buried flaws under installed fasteners, utilizes a giant magnetoresistive sensor within the self-nulling probe design for improved low frequency capabilities. The prototype unit incorporates a new probe design for deep penetration and reduced edge effects along with new electronics and system software. The instrument is fully configurable through a laptop computer. The computer interfaces with the electronics package to record probe output as well as to control the drive and feedback signal amplitudes, frequency, and phases. Testing of the prototype system has been performed at SANDIA National Laboratories Aging Aircraft NDI Validation Center. The complete system configuration along with field testing results are presented.

Three-Channel Non-Force Magnetic Microscope

---S. I. Bondarenko¹, A. A. Shablo¹, P. P. Pavlov¹, and N. Nakagawa², ¹Institute for Low Temperature Physics & Engineering, NASU, Kharkov, Ukraine, ²Center for NDE, Iowa State University, 1915 Scholl Road, Ames, IA 50011

---This paper reports on the development of a scanning magnetic microscope (SMM) without appreciable applied forces or magnetic excitations on specimens. The magnetic microscope is intended to measure weak magnetic field distributions near the object surface at micron and sub-micron scales. Specifically, the SMM consists of three measurement units with respective output channels. The first channel uses a special fluxgate magnetometer as a field detector, and is designed for magnetic study of a specimen surface at room temperature ($T=300\text{K}$), with a magnetic sensitivity of 10^{-9}T , at a spatial resolution of $10\ \mu\text{m}$ in a scan area of $10\times 10\ \text{mm}$. The second channel uses a HTSC SQUID and a ferromagnetic flux concentrator, and is intended for detailed study of a room-temperature object at the sensitivity of $10^{-12}\ \text{T}$ with $0.1\text{-}1\ \mu\text{m}$ resolutions. The third component also uses the SQUID-concentrator combination, but is intended for detailed study of the object at liquid-nitrogen temperature ($T=77\text{K}$), covering the area of $100\times 100\ \mu\text{m}$.---The ILTPE authors wish to express their gratitude to the STCU Foundation for support (Project #2266). This work is also supported in part by the U.S. Civilian Research & Development Foundation (CRDF) Project Number UE2-2438-KH-02.

Material Characterization and Life Prediction for Critical Components through Application of Photon Induced Positron Annihilation (PIPA)

---D. W. Akers, Positron Systems, Inc., 6151 N. Discovery Way, Boise, ID 83713-1556; A. B. Denison, Lawrence Livermore National Laboratory, Livermore, CA

---A new patented technology, Photon Induced Positron Annihilation (PIPA) has been developed that provides the capability to nondestructively detect fatigue, corrosion induced fatigue, compressive stress, radiation and embrittlement damage in critical components and materials. Further, PIPA can accurately and quantitatively assess defect levels and predict the remaining life of various metallic, composite, and polymeric materials. Because PIPA detects lattice structure damage at the atomic level, PIPA is directly applicable to determining fatigue and manufacturing defect issues pertinent to composite and metallic alloy components used in industries today. PIPA has successfully detected microstructure fatigue mechanisms and crack growth phenomena in numerous materials, such as aluminum alloys, super nickel alloys, stainless steel and titanium. Crack growth typically propagates along lines of lattice structure damage. PIPA is ideally suited for detecting atomic level defects in the lattice structure such as manufacturing defects, crack nucleation and crack propagation phenomena. Additionally, PIPA has proven capable of detecting defects, such as precipitates in materials which may have been created during the fabrication process, providing direct application toward the detection of inclusions in titanium.

Digital Meter of Ultrasound Phase Velocity

---V. G. Bazhenov and S. N. Ligomina, Department of Nondestructive Testing, National Technical University of Ukraine "KPI", Kiev 03056, Ukraine

---The phase velocity is used in NDE to determine elastic constants of test object, which designate service properties of object: hardness, strength, internal stresses etc. But in case of dispersion mediums, most of widely used impulse methods give the error of measuring, because they measure velocity of complex ultrasonic signal propagation. The phase method of measurement in contrast to impulse one determines the phase velocity. Measuring by the phase methods arises problems in instrument realization of rf pulse phase meters of high precision and phase ambiguity elimination. These problems can be solved by digitizing signal and processing methods. Using of computer facilities and discrete orthogonal method to measure phase shift allows creating the digital meter of ultrasound phase velocity of high accuracy.

Monday, July 15, 2002

SESSION 6
“SMART” SYSTEMS FOR STRUCTURAL HEALTH MONITORING
J. Mittleman, Chairperson
FRASER 3

- 1:30 PM** **Future Directions for Nondestructive Evaluation and Maintenance**
---W. P. Winfree, NASA Langley Research Center, MS 231, Hampton, VA 23681-2199
- 1:50 PM** **Potential of Fiber Optic Sensors for Structural Health Monitoring**
---I. M. Perez, Materials Division, Office of Naval Research, Arlington, VA 22217-5660; A. Ogunyemi, Materials Division, Naval Air Systems Command, Patuxent River, MD 20678
- 2:10 PM** **A Hybrid Approach to Structural Health Monitoring Using Nondestructive Evaluation (NDE) and Active Damage Interrogation**
---R. W. Engelbart, D. D. Palmer, Jr., and D. M. Pitt, The Boeing Company, P. O. Box 516, MC S102-1322, St. Louis, MO 63166
- 2:30 PM** **Sensor Technology for Integrated Vehicle Health Management of Aerospace Vehicles**
---W. H. Prosser, T. L. Brown, S. E. Woodard, G. A. Fleming, and E. G. Cooper, NASA Langley Research Center, MS 231, 3 E. Taylor Street, Hampton, VA 23681
- 2:50 PM** **Enhanced Inspection of Multi-Layer Aircraft Structures**
---E.A. Lindgren¹, D.J. Judd¹, J.C. Aldrin², M.J. Concordia¹, and J.R. Mandeville¹, ¹SAIC – Ultra Image International, New London, CT 06320; ²Computational Tools, Inc., Gurnee, IL 60031
- 3:10 PM** **Coffee Break**
- 3:30 PM** **Permanently Installable, Active Guided-Wave Sensor for Structural Health Monitoring**
---H. Kwun, G. M. Light, S. Y. Kim, R. H. Peterson, and R. L. Spinks, Department of Sensor Systems & NDE Technology, Southwest Research Institute, San Antonio, TX 78238-5166
- 3:50 PM** **LaserNet Fines – A New Approach to Wear Debris Diagnostics**
---J. Reintjes, J. E. Tucker, and A. Schultz, Code 5610, Naval Research Laboratory, Washington, DC 20375; C. Lu, Towson University, Towson, MD; T. Sebok and C. Holloway, Lockheed Martin Naval Electronics and Surveillance Systems, Akron, OH; P. L. Howard, PL Howard Enterprises, New Market, NH; S. E. Thomas, Titan Systems, Arlington, VA
- 4:10 PM** **Fatigue and Stress Monitoring Using Scanning and Permanently Mounted MWM-Arrays**
---A. Washabaugh, V. Zilberstein, R. Lyons, K. Walrath, and N. Goldfine, JENTEK Sensors, Inc., 110-1 Clematis Avenue, Waltham, MA 02453-7013; E. Abramovici, Bombardier, Montreal, Quebec, H3C 3G9 Canada
- 4:30 PM** **Development of an Intelligent Electromagnetic Sensor to Detect Ferrous Corrosion Products Under Structural Coatings**
---J. M. Liu and R. L. Ruedisueli, Naval Surface Warfare Center, Carderock Division, Metals Department
- 4:50 PM** **Concepts for an Integrated Vehicle Health Monitoring System**
---D. C. Price, CSIRO Telecommunications and Industrial Physics, P. O. Box 218, Lindfield, NSW 2070 Australia

Future Directions for Nondestructive Evaluation and Maintenance

---W. P. Winfree, NASA Langley Research Center, MS 231, Hampton, VA 23681-2199

---For many critical structures from aerospace vehicles to bridges, the cost of maintenance is becoming prohibitive. To reduce the cost and turn around time for maintenance requires a different approach for inspection of the critical structures than conventional labor intensive technologies. Emerging technologies that show promise include "smart sensor", health monitoring and sensory materials. These technologies offer a way for the structure to "assess its own integrity". This paper examines some of needs and current directions of research aimed at transforming maintenance practices.

Potential of Fiber Optic Sensors for Structural Health Monitoring

---Ignacio M. Perez, Materials Division, Office of Naval Research, Arlington, VA 22217-5660; Alyssia Ogunyemi, Materials Division, Naval Air Systems Command, Patuxent River, MD 20678

---In order to guaranty the safe operation of many of our structures, the detection of damage and defects is of paramount importance. This has been a major driving force for the development and application of advanced nondestructive evaluation (NDE) techniques for the past many years. More recently and as a result of military transformations, streamlining of acquisition programs, demands for reduced manning, budget cuts and the limited purchase of new system we have been asked to extend the life of many of our existing assets. Consequently a significant increase in the inspection and maintenance cost is expected unless a new inspection and maintenance methodology is implemented. One possible approach to reduce the cost while maintaining safe operation of our platforms is by developing a health monitoring system that track material usage, together with the environmental conditions and yes sound failure mechanics algorithms to diagnose and prognosticate the occurrence of damage and/or to schedule maintenance. Our laboratory has been working with various types of fiber optic sensors to monitor strain, temperature and humidity. Our present interest is characterizing the response of Bragg grating sensors to high frequency ultrasonic signals such as from acoustic emissions. Results will be presented at the meeting.

A Hybrid Approach to Structural Health Monitoring Using Nondestructive Evaluation (NDE) and Active Damage Interrogation

---R. W. Engelbart, D. D. Palmer, Jr., and D. M. Pitt, The Boeing Company, P. O. Box 516, MC S102-1322, St. Louis, MO 63166

---With the useful lives of many aircraft being extended, in-service inspection, repair, and related support activities represent a considerable commitment of resources. Periodic maintenance operations involve comprehensive nondestructive inspections (NDI) and significant aircraft downtime for compilation of data, disposition of results, and any needed repairs. Confining the inspections to known or suspected problem areas still requires time to cover the area adequately, and to detect and assess flaws. Reducing this inspection time requires advance knowledge of the condition of the structure with respect to the existence and probable location of defects. Recent work has demonstrated the viability of active damage interrogation (ADI) for continuous monitoring of structural health. Piezoelectric transducers are used to actively excite and sense the vibration characteristics of the structure and use this information to make estimates regarding the health of the structure. By detecting changes in the structure's vibration signature, damage can be detected, localized, and assessed; however, additional information may be needed to accurately quantify flaws or damage. This paper will present a concept and preliminary supporting data for a hybridization of ADI and NDI technologies.

Sensor Technology for Integrated Vehicle Health Management of Aerospace Vehicles

---W. H. Prosser, T. L. Brown, S. E. Woodard, G. A. Fleming, and E. G. Cooper, NASA Langley Research Center, MS 231, 3 E. Taylor Street, Hampton, VA 23681

---The application of traditional NDE methods for on-ground inspection of air and spacecraft contributes greatly to their safety and reliability. However, periodic inspections significantly increase operating expense and vehicle processing time. Further, in some cases, the need to disassemble and reassemble structural components to allow inspections can lead to damage or degradation of the structure or auxiliary systems such as electrical wiring and hydraulic lines. To address these issues and meet NASA's demanding goals in reducing operating costs and improvements in safety and reliability for future generations of reusable launch vehicles, NASA is focussing on technology development for Integrated Vehicle Health Management (IVHM) systems. As part of these systems, on-board, real-time sensing systems will be required to provide detailed information on structural integrity. It is anticipated that such sensing systems will minimize the need for routine, periodic NDE inspections, or at least focus these inspections to specific vehicle areas where damage was indicated. For these applications, sensors must be able to withstand the extreme operating environments of aircraft and launch vehicles, and must be of minimal size, weight and power requirements. In this presentation, a number of sensor technologies under development will be discussed including fiber-optic sensors, vibration methods, and active and passive ultrasonic methods. As part of this review of the state of the art of IVHM sensor technology, current limitations and future research needs will be discussed.

Enhanced Inspection of Multi-Layer Aircraft Structures

---E.A. Lindgren¹, D.J. Judd¹, J.C. Aldrin², M.J. Concordia¹, and J.R. Mandeville¹, ¹SAIC – Ultra Image International, New London, CT 06320; ²Computational Tools, Inc., Gurnee, IL 60031

---To decrease the cost of inspecting multi-layered structures found in many military aircraft, traditional inspection methods are being replaced with automated techniques. This includes the deployment of ultrasonic C-scan imaging to replace hand-held inspection methods for the detection of fatigue cracks emanating from fastener holes. However, the use of ultrasound to inspect multi-layered structures can introduce signals from internal structures and other artifacts that are not relevant to the inspection. These items may yield indications in the C-scan image that can confuse an inspector who is analyzing the results. Therefore, a process to assist the inspector who is interpreting the C-scan images has been developed. This approach uses engineering data and several image processing and image manipulation tools to automate the analysis of the C-scan data. The output from this analysis is a report that provides a registration of the fastener holes that were inspected and which of these holes contain cracks above a designated size threshold. This automated process is being used to develop an inspection technique for the C-130 Hercules center wing. Results from the inspection of aircraft components will be shown and discussed. The authors acknowledge funding provided by the US Air Force and US Navy.

Permanently Installable, Active Guided-Wave Sensor for Structural Health Monitoring

---H. Kwun, G. M. Light, S. Y. Kim, R. H. Peterson, and R. L. Spinks, Department of Sensor Systems & NDE Technology, Southwest Research Institute, San Antonio, TX 78238-5166

---An active guided-wave sensor is described that can be used for periodic and long-term inspection and monitoring of structures for structural degradation such as crack magnetostrictive sensor technology developed and patented by Southwest Research Institute (SwRI), is low-profiled, inexpensive, and permanently attachable to structural surface. The sensor can inspect and monitor large areas of a structure and provide quantitative information on the condition of the structure. By multiplexing multiple sensors installed at strategic locations on a large structure (such as airplane, ship, bridge, offshore platform, large storage tank, building, etc.) from a single data acquisition station, the entire structure can be quickly inspected for damaged areas and trending that are needed for structural integrity assessment and determination of remedial action if necessary. Experimental data showing the sensor's applicability to structural health monitoring of large plate structures are given.

LaserNet Fines – A New Approach to Wear Debris Diagnostics

---J. Reintjes, J. E. Tucker, and A. Schultz, Code 5610, Naval Research Laboratory, Washington, DC 20375; C. Lu, Towson University, Towson, MD; T. Sebok and C. Holloway, Lockheed Martin Naval Electronics and Surveillance Systems, Akron, OH; P. L. Howard, PL Howard Enterprises, New Market, NH; S. E. Thomas, Titan Systems, Arlington, VA

---We describe the operation and application of LaserNet Fines - a new approach to wear debris analysis for mechanical diagnostics. LaserNet Fines is an optically based particle analyzer that determines type, severity and rate of progression of mechanical faults by measuring concentration, size distribution and shape characteristics of debris particles. It is broadly applicable to the detection of mechanical wear in oil-wetted machinery and particulate contamination in hydraulic systems. LaserNet Fines can be configured as an off line batch processor for analyzing fluid samples from a large number of pieces of equipment, or as an on line monitor for continuous autonomous monitoring. It is capable of identifying mechanical wear processes of fatigue, cutting and sliding, as well as sand contaminants, fibers, and free water while discriminating against air bubbles. It provides quantitative assessment of wear debris particles as well as a visual record of all particles larger than 20 micrometers. It provides information necessary for diagnosing current condition as well as enabling prognostics. We describe application of LaserNet Fines to the detection and identification of faults in diesel engines and hydraulic systems.

Fatigue and Stress Monitoring Using Scanning and Permanently Mounted MWM-Arrays

---A. Washabaugh, V. Zilberstein, R. Lyons, K. Walrath, and N. Goldfine, JENTEK Sensors, Inc., 110-1 Clematis Avenue, Waltham, MA 02453-7013; E. Abramovici, Bombardier, Montreal, Quebec, Canada H3C 3G9

---Recent developments in the design and application of shaped field eddy sensor arrays, such as the Meandering Winding Magnetometer Array (MWM-Array), provide valuable capabilities for materials characterization and defect detection in metallic materials for aerospace and other critical structures and components. The sensor arrays are designed so that the sensing element responses can be accurately modeled, which permits absolute property measurements with minimal calibration requirements. Attaching the arrays to structures permits on-line fatigue damage assessment and provides a cost-effective inspection solution for damage in difficult-to-access locations. Scanning of the arrays permits high-resolution wide-area imaging of the properties of conductive and/or magnetic materials. Model-based inversion methods convert each element response into property measurements and permit independent lift-off measurements with each element so that uniform lift-off over the sensor footprint is unnecessary. This paper presents recent application results including: (1) crack initiation detection and crack growth monitoring on both sides of a hole in a fatigue specimen with a pair of MWM-Arrays mounted inside hole, (2) automatically stopping fatigue tests by identifying early stage fatigue damage, (3) detecting pre-crack fatigue damage and cracks on shotpeened 4340 steel, and (4) characterizing applied and residual stresses using magnetic permeability measurements on steel specimens and components.

Development of an Intelligent Electromagnetic Sensor to Detect Ferrous Corrosion Products Under Structural Coatings

---J. M. Liu and R. L. Ruedisueli, Naval Surface Warfare Center Carderock Division, Metals Department

---Recent advances are evident in imaging NDE techniques using thermography, ultrasound, eddy current and other technologies to detect hidden corrosion. Imbedded sensors using special signal excitation and reception techniques, including those based on telemetry, also show promise for such an application. However, in most current systems the detection mechanism is based on the difference in the physical properties such as elastic moduli, thermal and electrical conductivities, or the presence of geometrical features such as cracks, voids, or surface roughness between the corroded and base material. There has not been much attention in exploiting the difference in specific chemical properties between the corroded and the base material. We will briefly review some examples of corrosion detection based on the chemistry of corrosion products under structural coatings that can be exploited for "smart" sensor development. This approach has the advantage that the effects of property variations unrelated to corrosion are reduced. One particular example is a concept based on the magnetic field induced microwave absorption in some of the corrosion products in steel. This absorption changes the strength of microwave reflected from the coated steel when an external magnetic field is applied. A sensor based on this mechanism should be particularly sensitive to the initiation of corrosion for which some of the current NDE techniques may be insensitive. We will present the physical basis and preliminary experimental results based on this concept.

Concepts for an Integrated Vehicle Health Monitoring System

---Don C. Price, CSIRO Telecommunications and Industrial Physics, P. O. Box 218, Lindfield, NSW 2070 Australia

---Recent interest in smart sensor networks, and developments in technologies such as MEMS, microelectronics, nanotechnology, communication networks and distributed computing, have encouraged interest in the development of integrated vehicle health monitoring (IVHM) systems. In the longer term, such systems will provide a basis for the development of self-repairing, and perhaps even ageless, structures. In the shorter term, IVHM could reduce or eliminate a number of present design constraints (e.g. relating to redundancy and inspectability), allowing more efficient designs, and should reduce maintenance and inspection requirements. A multi-disciplinary team, comprising people with expertise in sensors, measurement techniques and NDE, telecommunications and networking, smart data processing and intelligent artificial systems, has begun developing concepts for IVHM systems for aerospace vehicles as part of the NASA Ageless Vehicle Program. This work is at an early stage, and this paper will report only on the issues the team has discussed and approaches that are under consideration. Embedded real-time sensing systems for damage detection and evaluation have different capabilities, and present opportunities for solving problems in different ways than is the case for "traditional" NDE. Biological solutions to many of the relevant issues provide interesting guidance. The future practical demonstration of some of the concepts being considered will be discussed.

Tuesday, July 16, 2002

SESSION 7
ULTRASONIC ARRAYS
R. C. Addison, Chairperson
FRASER 3

- 8:30 AM** **Progress in Ultrasonic Phased Arrays for Billet Inspection**
---V. Lupien, Acoustic Ideas, Inc., 25 Eaton Street, Wakefield, MA 01880; W. Hassan, Honeywell Engines, Systems & Services, 111 S. 34th Street, Phoenix, AZ 85072-2181
- 8:50 AM** **The Effect of Electronic and Synthetic Ultrasonic Phased Array Focusing**
---A. Chahbaz, R/D Tech Aero, NDT Technology and Development, 2001 St. Regis Boulevard, Montreal, Quebec, H9B 2M9 Canada; R. Sicard, Institut du Recherche sur l'Hydrogene, Universite du Quebec a Trois-Rivieres, CP 500, Trois-Rivieres, Quebec, G9A 5H7 Canada
- 9:10 AM** **Ultrasonic NDT Simulation Tools for PA Techniques**
---P. Calmon, S. Mahaut, S. Chatillon, and R. Raillon-Picot, CEA/LIST, French Atomic Energy Commission, CEA-Saclay bat. 611, 91191 Gif-sur-Yvette Cedex, France
- 9:30 AM** **Development and Optimization of a Rotating Phased Array Inspection System**
---H. Rieder, M. Spies, and R. Licht, Fraunhofer-Institute for Nondestructive Testing (IZFP), University Bldg. 37, 66123 Saarbrucken, Germany; P. Kreier, Innotest AG, Rosenstrasse 13B, 8360 Eschlikon, Switzerland
- 9:50 AM** **An Experimental and Theoretical Investigation of the Crosstalk Mechanisms in 1-3 Piezoelectric Composite Arrays**
---G. Hayward, The Centre for Ultrasonic Engineering, University of Strathclyde, Glasgow, Scotland; P. Reynolds, Weidlinger Associates, Ltd., 4410 El Camino Real, Los Altos, CA; J. Hyslop, Alba Ultrasound Ltd., 110 Borron Street, Glasgow, Scotland
- 10:10 AM** **Coffee Break**
- 10:30 AM** **Phased Arrays Techniques and Split Spectrum Processing for Inspection of Thick Titanium Casting Components**
---D. E. Zellouf¹, J. Banchet², A. Chahbaz², and J. Goyette¹, ¹Institut de Recherche sur l'Hydrogene, Universite du Quebec a Trois-Rivieres, CP 500, Trois-Rivieres, Quebec, G9A 5H7 Canada; ²R/D Tech Aero, NDT Technology and Development, 2001 St. Regis Boulevard, Montreal, H9B 2M9 Canada
- 10:50 AM** **Groundwork for Rail Flaw Detection Using Ultrasonic Phased Array Inspection**
---D. Utrata, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011; R. Clark, Sperry Rail Service, 46 Shelter Rock Road, Danbury, CT 06810
- 11:10 AM** **Ultrasonic Linear Time Delayed Arrays for Crack Detection Under Fasteners**
---J. Banchet and A. Chahbaz, R/D Tech Aero, NDT Technology and Development, 2001 St. Regis Boulevard, Montreal, H9B 2M9 Canada
- 11:30 AM** **Corrosion Monitoring of Aircraft and Airframe Structures Using Ultrasonic Arrays and Guided Lamb Waves**
---R. Sicard^{1,2}, A. Chahbaz¹, and J. Goyette², ¹R/D Tech Aero, NDT Technology and Development, 2001 St. Regis Boulevard, Montreal, H9B 2M9 Canada; ²Institut de Recherche sur l'Hydrogene, Universite du Quebec a Trois-Rivieres, CP 500, Trois-Rivieres, Quebec G9A 5H7 Canada
- 11:50 AM** **An EMAT Array for the Rapid Inspection of Large Structures Using Guided Waves**
---P. D. Wilcox, Department of Mechanical Engineering, University of Bristol, Bristol, BS8 1TR, United Kingdom; M. J. S. Lowe and P. Cawley, Department of Mechanical Engineering, Imperial College of Science, Technology, and Medicine, London, SW7 2BX, United Kingdom
- 12:10 PM** **Lunch**

Progress in Ultrasonic Phased Arrays for Billet Inspection

---Vincent Lupien, Acoustic Ideas, Inc., 25 Eaton Street, Wakefield, MA 01880; Waled Hassan, Honeywell Engines, Systems & Services, 111 S. 34th Street, Phoenix, AZ 85072-2181

---Phased arrays offer promise in achieving an industry goal of detecting inclusions in billets at a #1 Flat Bottom Hole (FBH) sensitivity, partly through beam spot size reduction. Smaller spot sizes are possible with phased arrays by exploiting the division of the probe into separate elements to apply precise shape corrections that guarantee sub-wavelength accuracy even for the largest apertures. In the past two years progress in phased array ultrasound for billet inspection has included i) development of probe design tools; ii) design and manufacture of probes; and iii) methods for correcting the shapes of the probes. In this paper we report our most recent developments. First, the probe shape correction methodology presented at QNDE 2001 was implemented in the form of a commercially available Probe Calibration Toolbox in MATLAB. This toolbox was employed to find the true shape of a 5 MHz, 113 element annular sectorial array. Second, we employed the corrected shape to acquire inspection data. In order to account for the three-dimensional shape of the probe, independent control of each of the 113 probe elements was required. However, currently available hardware is typically limited to 32 simultaneously fired elements. Employing an off-line beamforming utility in the commercially-available Ultrasonic Data Processing (UTDP) Toolbox for MATLAB, we expanded the phased array hardware beyond this maximum and in so doing we were able to apply a full correction to the shape of the probe. A beam spot area reduction of 50% due to the shape correction was documented through scans of a 5/64" spherical tungsten carbide inclusion. Third, we ran numerical models to optimize the Dynamic Depth Focusing (DDF) algorithm allowing all depth zones in the billet to be inspected with a minimum number of array firings. Our optimization involved finding the optimal transmit focal law and the optimal set of receive focal laws to ensure constant beamwidth and amplitude as a function of depth.

The Effect of Electronic and Synthetic Ultrasonic Phased Array Focusing

---A. Chahbaz, R/D Tech Aero, NDT Technology and Development, 2001 St. Regis Boulevard, Montreal, Quebec, H9B 2M9 Canada; R. Sicard, Institut de Recherche sur l'Hydrogène, Université du Québec à Trois-Rivières, C.P. 500, Trois-Rivières, Québec, G9A 5H7 Canada

---Single-element scanning techniques are widely used in the NDT industry and have seen a number of successful applications. They require moving the sensor in time-consuming raster scan to create two-dimensional scan patterns. However, phased array technology is an emerging NDI technology which offers means to reach hidden parts in complex geometry and substantially reduce the scanning time by simplifying the scan pattern and scanning electronically in milliseconds instead of scanning mechanically in a few seconds. Under this work, we investigate and compare electronic and synthetic focusing of ultrasonic waves. Synthetic focusing makes it possible to increase the signal-to-noise ratio by averaging several shifted reflections from the same defect point. Lateral resolution is therefore improved, especially for long probe-to-defect distances. Moreover, the resolution remains constant along the beam axis, avoiding beam width perturbations and providing the user with a reconstructed image that makes defect interpretation easier.

Ultrasonic NDT Simulation Tools for PA Techniques

---P. Calmon, S. Mahaut, S. Chatillon, and R. Raillon-Picot, CEA/LIST, French Atomic Energy Commission, CEA-Saclay bat. 611, 91191 Gif-sur-Yvette cedex, France

---NDT techniques based on phased array technology are more and more applied in various industrial context. The advantages of basic phased arrays functions are now quite well known. However new promising techniques still remain required to improve detection, and especially characterization of flaws. These improvements are directly dependent on the application of relevant physical model connected to specific phased array algorithms. The development of such simulation and processing tools constitutes one of the major axis research of CEA NDT laboratory. In this communication, after having briefly recalled the propagation and beam-defect interaction models, on which are based the CEA tools, we present specific phased array algorithms and show some applications for complex specimen and inspection configurations. These applications deal with the design of transducers and the computation of adapted delay laws, the prediction of the ultrasonic beams generated by the transducer. We also present some simulations which allow to estimate the inspection coverage rate of the component. At last, the prediction of defects responses received by the array is used to apply specific reconstruction algorithms to accurately localize and to characterize flaws.

Development and Optimization of a Rotating Phased Array Inspection System

---Hans Rieder, Martin Spies, and Rudolf Licht, Fraunhofer-Institute for Nondestructive Testing (IZFP), University, Bldg. 37, 66123 Saarbruecken, Germany; Peter Kreier, Innotest AG, Rosenstrasse 13 B, 8360 Eschlikon, Switzerland

---Operating ultrasonic transducers as phased arrays, where each of the array elements can be pulsed with time delays, allows controlling the beam shape and the sound beam direction on a large scale. Appropriate array systems therefore offer excellent capabilities for a variety of practical field applications. This contribution describes the approach pursued in the development of a miniaturized phased array system. Aiming at the detection of corrosion damage at the inner and outer surface, an array transducer has first been optimized for immersion inspection of pipes with high radial and axial resolution. On the basis of appropriate models the generated beam fields have been simulated and optimized for several radii of curvature and thicknesses of the components to be inspected. In a second step, system components have been designed and developed on the basis of highly integrated electronic components. Here, benefit has been drawn from the limited and clear cut inspection parameters to be addressed, which are the frequency (up to 5 MHz), the sampling rate (20 ns) and the realtime capabilities. The inspection system, which is split into a front-end and a back-end unit, is based on a DSP multiprocessor concept for fast signal processing, data evaluation and communication with a PC. Additional performance is gained by intensively using FPGA technology for fast beam steering and data preprocessing. To meet the requirements of real time applications a bi-directional high speed optical link has been employed. The application-directed system development will be exemplified and illustrated by simulation as well as experimental verification results.

An Experimental and Theoretical Investigation of the Crosstalk Mechanisms in 1-3 Piezoelectric Composite Arrays

---G. Hayward, The Centre for Ultrasonic Engineering, University of Strathclyde, Glasgow, Scotland; P. Reynolds, Weidlinger Associates Ltd., 4410 El Camino Real, Los Altos, CA; J. Hyslop, Alba Ultrasound Ltd., 110 Borron St., Glasgow, Scotland

---Ultrasonic array imaging technology, that promotes rapid scanning of components without recourse to mechanical movement, is becoming increasingly attractive for many NDE applications. For all such systems, it is essential that the transducer array is efficient and unimodal around the specified center frequency and that the individual array element beam patterns are as wide as possible. To that end, 1-3 Piezoelectric composite transducers, comprising a matrix of active piezoelectric pillars embedded within a passive, usually polymeric, material, possess significant advantages, with the prospect of customized sensitivity, uniform, controllable beam patterns, in conjunction with relative ease of manufacture. This paper describes a fundamental investigation into cross coupling within such array configurations. Firstly, finite element modelling, using the ANSYS code, is used to examine the composite microstructure and the inter-pillar resonant modes are explained in terms of Lamb wave activity that arises due to the periodicity of the piezoceramic lattice. Next, the finite element code PZFLEX is used to evaluate dispersion data for different composite substrates. The main mechanisms for cross coupling within 1-3 monolithic arrays are then identified as propagating Lamb waves, with characteristics that are influenced by both active and passive phases. The theoretical results are verified by means of non-contact laser stimulation, combined with interferometric detection of surface displacement on prototype array samples.

Phased Arrays Techniques and Split Spectrum Processing for Inspection of Thick Titanium Casting Components

---D. E. Zellouf¹, J. Banchet², A. Chahbaz², and J. Goyette¹, ¹Institut de Recherche sur l'Hydrogène, Université du Québec à Trois-Rivières, C.P. 500, Trois-Rivières, Québec, G9A 5H7 Canada; ²R/D Tech Aero, NDT Technology and Development, 2001 St. Regis Boulevard, Montreal, H9B 2M9 Canada

---In aircraft structures, titanium parts and engine members are critical structural components. The quality and dependability of these castings is crucial. However, these structures with such casting material are difficult to inspect with conventional UT. The large grain structure of the titanium produce an important noise in the collected signals. Besides, a classical NDI testing method such as X-ray has specific drawbacks when applied to these complex structures. In this work, phased array inspection setups were developed to detect small defects such as simulated inclusions and porosity in thick titanium casting blocks, which are frequently used in the aerospace industry. Split Spectrum Processing (SSP) was then implemented on the acquired data by employing a set of parallel bandpass filters with different center frequencies. This process lead in substantial improvement of the signal to noise ratio and thus, of detectability.

Groundwork for Rail Flaw Detection Using Ultrasonic Phased Array Inspection

---Dave Utrata, Center for NDE, Iowa State University, Ames, IA 50011; Robin Clark, Sperry Rail Service, 46 Shelter Rock Road, Danbury, CT 06810

---An apparent increase in detectability of rail flaws was noted when the incident ultrasonic beam used for inspection was oriented in a non-traditional manner. Namely, orienting the plane of refracted 70° inspection beams 10°-15° off from the longitudinal axis of the rail resulted in larger flaw indications in C-scans. This work is predicated on such laboratory scans being linked to the axial scans of rail in track. The enhanced flaw signature was noted for single element immersion transducers of various designs, a linear phased array transducer, and a fluid-filled rail search unit (RSU). Such modified inspection protocol is researched to anticipate the implementation of a phased array transducer within a fluid-filled wheel. This involved noting the effects of rail surface profile as it varies from new rail profile, and selecting different beam angles conceivably optimized for inspection. A series of drilled holes angling down from the running surface are seen to enable verification of the extent of a test rail's head region "swept" by the inspection beams. These particular artificial reflectors overcome previously noted deficiencies that arose when large surface waves adversely interacted with the desired targets.---The first author wishes to acknowledge the funding support of Dr. Robin Clark of Sperry Rail Service to perform this work, and to Krautkramer, Inc., for the grant of the phased array system.

Ultrasonic Linear Time Delayed Arrays for Crack Detection Under Fasteners

---J. Banchet and A. Chahbaz, R/D Tech Aero, NDT Technology and Development, 2001 St. Regis Blvd., Montreal, Quebec., H9B 2M9 Canada

---Linear phased arrays approach is proposed in both comb and surface acoustic waves-like interdigital configurations to excite guided wave modes on relatively thin airframe skin and lap joint structures. Fatigue cracks and exfoliation under the shadow of fastener heads were interrogated. Tests to detect crack-like defects at the faying surface between the lower skin and the upper skin/doubler assembly were performed. Guided modes were selected and launched from outside the hidden area to interrogate the interested rivets. In pulse-echo setup, the received mode associated with RF signals included indications and reflections from defects. For each guided wave test, a single line of data is collected by moving the probe along the inspected specimen. Signals are then presented in color-coded two-dimensional C-scan format. For defect separation and characterization, images are then averaged and reconstructed using synthetic focusing technique.

Corrosion Monitoring of Aircraft and Airframe Structures Using Ultrasonic Arrays and Guided Lamb Waves

---R. Sicard^{1,2}, A. Chahbaz¹ and J. Goyette²,
¹R/D Tech Aero, NDT Technology and Development, 2001 St. Regis Blvd., Montreal, Quebec, H9B 2M9 Canada; ²Institut de Recherche sur l'Hydrogène, Université du Québec à Trois-Rivières, C.P. 500, Trois-Rivières, Québec, G9A 5H7 Canada

---Guided Lamb waves offer important inspection potential due to the range of available propagating wave modes; and compared to localized conventional point-by-point ultrasonic wave testing, they can be launched over long distances where larger and non accessible areas can be inspected using single pulse excitation. In this work, Lamb wave modes are excited using 2D linear array probes to detect corrosion/cracks on airframe structures. Lamb wave phase velocity variation technique was developed to evaluate material thinning caused by corrosion. Lower order symmetric S_0 mode was used at substantially dispersive region, yielding important phase velocity variation to characterize corrosion. To simplify phase variation calculations, we assumed either no mode conversion or a complete mode conversion occurring from mode interaction with defects. For defect separation, results were averaged and images were reconstructed using synthetic artificial focusing technique.

An EMAT Array for the Rapid Inspection of Large Structures Using Guided Waves

---P. D. Wilcox, Department of Mechanical Engineering, University of Bristol, Bristol, BS8 1TR, United Kingdom; M. J. S. Lowe and P. Cawley, Department of Mechanical Engineering, Imperial College of Science, Technology and Medicine, London, SW7 2BX, United Kingdom

---The rapid inspection of steel plate structures such as oil-storage tanks and pressure vessels is of great interest to the petrochemical industry. Guided ultrasonic waves provide an obvious solution since they enable a large area of the structure to be inspected from a single location. Ideally, the guided wave system should be able to interrogate the surrounding plate equally in all directions around the test location. For this reason, an array device is preferred because the necessary beam steering can be achieved electronically without the need for moving parts. Furthermore, it is also desirable to make use of a guided wave mode that will not be attenuated in liquid loaded plates. It is shown that pancake coil EMAT elements fulfill both the requirements of omni-directionality and sensitivity to the low attenuation S_0 Lamb wave mode. The implications and practicalities of using EMAT elements in an array are addressed. A prototype EMAT array device has been built and tested on a variety of steel plates in a thickness range from 5 - 20 mm. Results show that a signal to coherent noise ratio in excess of 30 dB can be obtained in most cases. The defect sensitivity of the array is discussed with reference to results obtained on a 6 mm thick steel plate containing artificial defects. Results obtained from severely corroded plate samples cut from real storage tank floors are also shown.

Tuesday, July 16, 2002

SESSION 8
NDE FOR BONDS, INTERFACES, AND COATINGS
B. Drinkwater, Chairperson
SMATE 150

- 8:30 AM** **Modeling of Transmitted Ultrasonic Signals Through Bonded Aluminum Skin and Mapping of Adhesive Bond Thickness**
---D. K. Hsu and D. Fei¹, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011; J. M. Amos, Cessna Aircraft – Textron, Wichita, KS 67215; ¹Caterpillar, Inc., Peoria, IL
- 8:50 AM** **A Comparison of the Detectability of Dry Contact Kissing Bonds in Adhesive Joints Using Longitudinal, Shear, and High Power Ultrasonic Techniques**
---C. J. Brotherhood, B. W. Drinkwater, F. J. Guild, Department of Mechanical Engineering, The University of Bristol, Queen's Building, University Walk, Clifton, Bristol BS8 1TR, United Kingdom
- 9:10 AM** **Nonlinear Angle Beam Ultrasonic Evaluation of Adhesive Bonds**
---S. I. Rokhlin, L. Wang, and A. Baltazar, The Ohio State University, 1248 Arthur E. Adams Drive, Columbus, OH 43221; V. Yakovlev and L. Adler, Adler Consultants, 1275 Kinnear Road, Columbus, OH 43212
- 9:30 AM** **The Interaction of Lamb Waves with Solid-Solid Interfaces**
---B. W. Drinkwater, Department of Mechanical Engineering, University of Bristol, University Walk, Bristol, BS8 1TR, United Kingdom; M. Castaings and B. Hosten, Laboratoire de Mecanique Physique, UMR CNRS 5469, 351 cours de la Liberation, Universite Bordeaux 1, 33400 Talence, France
- 9:50 AM** **Surface Acoustic Wave Propagation on Rough Anisotropic Materials**
---C. M. Flannery, Engineering, Colorado School of Mines, Golden, CO 80401 and National Institute of Standards and Technology, Boulder, CO 80303; H. von Kiedrowski, Paul Drude Institute for Solid State Electronics, Hausvogteiplatz 5-7, 10017 Berlin, Germany
- 10:10 AM** **Coffee Break**
- 10:30 AM** **Ultrasonic Detection of Weak Interface Signals Associated with Same Material Joining**
---B. A. Rinker, E. E. Jamieson, and J. A. Samayoa, Honeywell Federal Manufacturing and Technologies, Kansas City, MO; T. G. Abeln, Los Alamos National Laboratory, Los Alamos, NM; T. P. Lerch, Industrial and Engineering Technology, Central Michigan University, Mt. Pleasant, MI; S. P. Neal, Mechanical and Aerospace Engineering, University of Missouri-Columbia, Columbia, MO 65211
- 10:50 AM** **Simultaneous Non-Contact Measurements of Normal Incidence Ultrasonic Shear and Compression Wave Epoxy Adhesives Using EMATs**
---S. Dixon, D. Jaques, C. Edwards, and S. B. Palmer, Department of Physics, University of Warwick, Coventry, United Kingdom
- 11:10 AM** **The Use of Ultrasound to Measure Contact Stiffness and Pressure Distribution in Large Contacting Interfaces**
---C. Holmes and B. W. Drinkwater, University of Bristol, Department of Mechanical Engineering, Queen's Building, University Walk, Bristol BS8 1TR, United Kingdom
- 11:30 AM** **Characterization of Weathering Degradation in Epoxy Coatings Using NDE Imaging Techniques**
---V. A. Kramb and J. P. Hoffmann, Center for Materials Diagnostics, University of Dayton Research Institute, University of Dayton, Dayton, OH 45469-0120; J. A. Johnson, Air Force Research Laboratory, Wright Patterson Air Force Base, OH
- 12:10 PM** **Lunch**

Modeling of Transmitted Ultrasonic Signals Through Bonded Aluminum Skin and Mapping of Adhesive Bond Thickness

---D. K. Hsu and D. Fei¹, Center for Nondestructive Evaluation, Iowa State University, 1915 Scholl Road, Ames, IA 50011; J. M. Amos, Cessna Aircraft – Textron, Wichita, KS 67215; ¹Caterpillar, Inc., Peoria, IL

--- This work was motivated by some counter-intuitive industrial inspection results of adhesively bonded aluminum aircraft skins. For example, the ultrasonic signal transmitted through two adhesively bonded aluminum was sometimes greater than that through a single sheet of aluminum. To understand the behavior, we modeled the propagation of ultrasonic waves through the metal and adhesive layers as a general multi-layered system and calculated the transmission and reflection coefficients for the system. Using the model and the input signal used in the tests, we predicted the transmitted signals for various metal and bondline thicknesses. The amplitude and spectrum of the transmitted signal was found to depend sensitively on the adhesive bond thickness. The model can actually serve as a way to determine the bondline thickness by seeking an agreement between the modeled and experimental frequency spectra of the transmitted signal. In the through transmission ultrasonic (TTU) configuration, time-of-flight C-scans were also made on adhesively bonded aluminum skins and the data were processed to yield an image of the bondline thickness. The thickness results were in good agreement with mechanical measurements.---This work was supported by the NSF Industry/University Cooperative Research Center for Nondestructive Evaluation. * Present address: Caterpillar, Inc., Peoria, IL.

A Comparison of the Detectability of Dry Contact Kissing Bonds in Adhesive Joints Using Longitudinal, Shear and High Power Ultrasonic Techniques

---C. J. Brotherhood, B. W. Drinkwater, F. J. Guild, Department of Mechanical Engineering, The University of Bristol, Queens Building, University Walk, Clifton, Bristol, BS8 1TR, United Kingdom

---Dry contact kissing bonds are found in adhesive bonds when a compressive stress is applied to a previously fractured bondline. The fracture surfaces are forced into contact by the applied stress thereby increasing the degree of actual contact between them. The ultrasonic detectability of the kissing bond is largely determined by the degree of contact of the two surfaces. This is dependent on a number of variables, the most influential of which are the properties of the adhesive and adherends, the roughness of the two contacting surfaces and the applied stress itself. Therefore as the stress applied to an interface is increased, the detectability of the kissing bond decreases. In some cases, when the applied stress is large enough the kissing bond can become undetectable to standard ultrasonic inspection techniques. This paper describes a study into the detectability of dry contact kissing bonds in adhesive joints using three ultrasonic techniques. The adhesive bonds were inspected using focussed longitudinal wave inspection, shear wave inspection using Electro-Magnetic Acoustic Transducers (EMATs) and high power longitudinal wave inspection. The performance of these three different ultrasonic techniques are compared and the effect of compressively loading the interface assessed.

Nonlinear Angle Beam Ultrasonic Evaluation of Adhesive Bonds

---S. I. Rokhlin, L. Wang, and A. Baltazar, The Ohio State University, 1248 Arthur E. Adams Drive, Columbus, OH 43221; V. Yakovlev and L. Adler, Adler Consultants, 1275 Kinnear Road, Columbus, OH 43212

---We have developed an experimental method incorporating high frequency pulsed angle beam ultrasonic measurements under low frequency vibration of bonded structures utilizing the parametric/nonlinear mixing between high and low frequencies. We have demonstrated that the effect of environmental degradation of adhesive bonds can be detected by this method. It is shown that good quality (undamaged) bonds do not exhibit dependence of their ultrasonic signatures on the overlay of low frequency vibration loads; however, environmentally degraded or imperfect bonds exhibit a shift of the resonance frequency of the ultrasonic signal reflected from the bond. We have also found that a much higher level of mixing (two orders of magnitude) occurs for very brittle adhesive bonds whereas the linear method cannot discriminate among such bonds. We have developed a model for the case of two nonlinear interfaces separated by an adhesive layer and have described the variations in the reflection coefficient associated with nonlinear interfacial spring density changes for normal and oblique incidence of longitudinal or transverse waves. We have simulated a second harmonic generation as a function of the spring density and also developed a model and predicted parametric mixing of the high frequency reflected wave and the low frequency interface vibration excitation.---The work was sponsored by NASA Langley through the Small Business Administration.

The Interaction of Lamb Waves with Solid-Solid Interfaces

---B. W. Drinkwater, Department of Mechanical Engineering, University of Bristol, University Walk, Bristol, BS8 1TR, United Kingdom; M. Castaings and B. Hosten, Laboratoire de Mecanique Physique, UMR CNRS 5469, 351 cours de la Liberation, Universite Bordeaux 1, 33400 Talence, France

---This paper deals with the topic of the interaction of Lamb waves, more specifically the A0 and S0 modes, with a solid-solid interface. This solid-solid interface is the contact between two dry, rough surfaces and could represent a kissing bond in an adhesive joint or the contacting surfaces of a bolted joint. In this paper, a very thick elastomer with high internal damping is loaded against one surface of a glass plate to create a solid-solid interface. The principal effect is shown to be increased attenuation of the guided waves propagating along the glass plate. This attenuation is caused by leakage of energy from the plate into the elastomer, where it is dissipated due to high viscoelastic damping. It is shown that the increase in attenuation is strongly dependent on the compressive load applied across the solid-solid interface. This interface is represented as a spring layer in a continuum model of the multi-layered system. Both normal and shear stiffnesses of the interface are quantified from the attenuation of A0 and S0 Lamb waves measured at each step of the compressive loading.

Surface Acoustic Wave Propagation on Rough Anisotropic Materials

---Colm M. Flannery, Engineering, Colorado School of Mines, Golden CO 80401 and National Institute of Standards and Technology, Boulder CO 80303; Hartmut von Kiedrowski, Paul Drude Institute for Solid State Electronics, Hausvogteiplatz 5-7, 10017 Berlin, Germany

---The effect of surface roughness on adhesion and tribological properties of films and interfaces is of key importance. Therefore it is of the utmost importance to be able to measure this quantity and to predict the perturbing effects different roughness levels may cause.

Roughness is known to affect the propagation of surface acoustic waves on a material but there is little useful quantitative data on the topic. This experimental work investigates the dispersive effect of roughness on laser-generated surface acoustic wavepackets (30-200 MHz frequency range) for different degrees of nanometer roughness on silicon (001) and (111) surfaces. We show that the dispersion effect is significant, and that although available theory agrees qualitatively with the results, the theory is not adequate to predict the real SAW dispersion. These experimental results have considerable implications for applications to nondestructive testing, for design of SAW devices and for accuracy of Brillouin spectroscopy measurements. Previously unknown dispersive effects on anisotropic crystal surfaces are also demonstrated and an empirical modeling approach is discussed which gives results consistent with both measurements and theory.

Ultrasonic Detection of Weak Interface Signals Associated with Same Material Joining

---B. A. Rinker, E. E. Jamieson, and J. A. Samayoa, Honeywell Federal Manufacturing and Technologies, Kansas City, MO; T. G. Abeln, Los Alamos National Laboratory, Los Alamos, NM; T. P. Lerch, Industrial and Engineering Technology, Central Michigan University, Mount Pleasant, MI; S. P. Neal, Mechanical and Aerospace Engineering, University of Missouri-Columbia, Columbia, MO 65211

---In same material joining processes, if the process works well, the remaining interface will be acoustically weak and difficult to detect ultrasonically in the presence of grain noise. For the nearly perfect (but potentially inadequate) bond or weld the remaining interface may be defined only by small voids or by weak echo surfaces approximately aligned in the original interface plane. In this initial study, we investigate the utility of correlation based techniques for revealing the presence of bond/weld interface signals in the presence of grain noise. These approaches are attractive since they are independent of absolute scale and since the grain noise near the bond/weld time window may be useful in establishing baseline results for grain noise. Experimental results from three different same material joining processes are included in the study along with supporting results from an experimental-data driven simulation. This research was performed with support under contract from Honeywell Federal Manufacturing and Technologies, Kansas City, MO and with support from the National Science Foundation. A portion of this research was carried out while Brett Rinker was a Research Assistant and Terry Lerch was a Postdoctoral Fellow in Mechanical and Aerospace Engineering at the University of Missouri-Columbia.

Simultaneous Non-Contact Measurements of Normal Incidence Ultrasonic Shear and Compression Waves Epoxy Adhesives Using EMATs

---Steve Dixon, David Jaques, Christopher Edwards, and Stuart B. Palmer, Department of Physics, University of Warwick, Coventry, United Kingdom

---Thin epoxy resin adhesive samples were ultrasonically measured using normal incidence radially polarized shear wave ElectroMagnetic Acoustic Transducers (EMATs) that also generate a significant compression wave component. This allows us to make simultaneous measurement of the shear and compression wave propagation through the polymer, although the signal to noise ratio is significantly higher for the shear wave measurements. The adhesive thickness examined in the experiments was approximately 1mm, which was chosen to be the optimum thickness for experimental measurement using our apparatus. The epoxy resin systems (rapid cure and a standard cure) described in this paper were supplied in a 2-part cartridge form, mixed by injection through a special mixing nozzle. Although the number of samples investigated at this stage is small, there does appear to be a fundamental difference in the way in which the elastic moduli develop as cure rate is increased. This can possibly be explained in terms of the reaction kinetics and the development of the structure on a microscopic scale.

The Use of Ultrasound to Measure Contact Stiffness and Pressure Distribution in Large Contacting Interfaces

---Caroline Holmes and Bruce W. Drinkwater, University of Bristol, Department of Mechanical Engineering, Queens Building, University Walk, Bristol BS8 1TR, United Kingdom

---Graphite bricks, which are used to moderate the reaction in some nuclear power stations, are assembled in columns approximately ten high. Each brick has a square cross-section of 200mm and is 800mm in height. The bricks are inter-connected by graphite keys, which provide stability and allow the core to expand and contract during operation. We have developed a novel approach to measuring the contact stiffness and contact pressure in such large structures. The rocking stiffness of these columns is used to determine the natural frequency of the core for seismic response analysis. The top and bottom surface of each brick is in dry contact with the one above or below it and it is this solid-solid contacting interface, which governs the rocking behavior. This paper describes a study of the use of ultrasound to measure the contact pressure and stiffness between a rocking graphite brick and its foundation. Hydraulic loading apparatus has been developed to allow ultrasonic measurements to be made of the large solid-solid interface given specific loading conditions. Ultrasonic reflection coefficient measurements have been converted to contact stiffness and contact pressure using calibration curves. Results will be presented showing the effect of load and surface geometry on the contact pressure distribution.

Characterization of Weathering Degradation in Epoxy Coatings Using NDE Imaging Techniques

---V. A. Krumb and J. P. Hoffmann, Center for Materials Diagnostics, University of Dayton Research Institute, University of Dayton, Dayton, OH 45469-0120; J. A. Johnson, Air Force Research Laboratory, Wright Patterson Air Force Base, Dayton, OH

---Polymeric coatings used in aerospace coating systems are subject to degradation from ultraviolet light, thermal cycling and water exposure. This paper discusses the current progress in a new study to develop nondestructive evaluation (NDE) methods for monitoring degradation of polymeric coatings during service. In the current study, weathering tests were conducted on single layer epoxy coated aluminum panels. Artificial weathering of the coated samples was conducted using simulated sunlight exposure (Xenon arc lamps), combined with heat and humidity. The coatings were characterized as a function of weathering time using scanning acoustic microscopy (SAM), atomic force microscopy (AFM) and white light interferometry. The images obtained using these NDE methods will be correlated with damage metrics obtained from attenuated total reflection (ATR) - infrared spectroscopy and local elastic modulus measurements. Degradation in the coating as indicated by the IR spectra and NDE data will also be correlated with physical changes observed in the coating morphology. The result of this study will be to identify potential NDE parameters that can be correlated with the coating degradation as a function of weathering exposure time, for future development of new coating NDE inspection approaches.

Tuesday, July 16, 2002

SESSION 9
NDE OF CIVIL MATERIALS/STRUCTURES
J. Popovics, Chairperson
SMATE 140

- 8:30 AM** **Designing and Building to “Impossible” Vibration Tolerances**
---B. H. Hertlein, STS Consultants, LTD., 750 Corporate Woods Parkway, Vernon Hills, IL 60061
- 8:50 AM** **Electromagnetic Modeling of Water Movement in Mortar Cubes at Microwave Frequencies**
---S. Peer, R. Zoughi, and K. E. Kurtis*, Applied Microwave Nondestructive Testing Laboratory (*amntl*), Electrical and Computer Engineering Department, University of Missouri-Rolla, Rolla, MO 65409; *School of Civil and Environmental Engineering, Georgia Institute of Technology, Atlanta, GA 30332-0355
- 9:10 AM** **Microwave Reflection and Dielectric Properties of Mortar Exposed to Periodic Chloride Solution with 2% Salinity and Compression Force**
---T. Case, S. Peer, E. Gallaher, R. Zoughi, and K. E. Kurtis*, Applied Microwave Nondestructive Testing Laboratory (*amntl*), Electrical and Computer Engineering Department, University of Missouri-Rolla, Rolla, MO 65409; *School of Civil and Environmental Engineering, Georgia Institute of Technology, Atlanta, GA 30332-0355
- 9:30 AM** **Radar Detection of Rebars Including Use of Neural Networks and Horn Antennas**
---J. H. Bungey, S. G. Millard, T. C. K. Molyneaux, and J. Davies, Department of Civil Engineering, The University of Liverpool, Brownlow Street, Liverpool L69 3GQ, United Kingdom
- 9:50 AM** **NDE of FRP Wrapped Timber Bridge Components Using Infrared Thermography**
---U. B. Halabe, Department of Civil and Environmental Engineering, Constructed Facilities Center, West Virginia University, Morgantown, WV 26506-6103; W. E. Steele III, Modjeski and Masters, Inc., Mechanicsburg, PA 17055; H. V. S. GangaRao, Department of Civil and Environmental Engineering, Constructed Facilities Center, West Virginia University, Morgantown, WV 26506-6103; P. Klinkhachorn, Lane Department of Computer Science and Electrical Engineering, Constructed Facilities Center, West Virginia University, Morgantown, WV 26506-6104
- 10:10 AM** **Coffee Break**
- 10:30 AM** **NDE of FRP Bridge Beams and Decks**
---J. C. Duke, Jr., S. Case, and J. L. Lesko, Virginia Tech, Department of Engineering Science and Mechanics, MC 0219, Blacksburg, VA 24061
- 10:50 AM** **Inspection of Steel Tendons in Concrete Using Guided Waves**
---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
- 11:10 AM** **Ultrasonic Methodology to Characterize Curing of Cement-Based Materials**
---W. Punurai and L. J. Jacobs, School of Civil and Environmental Engineering, Georgia Institute of Technology, Atlanta, GA 30332-0355
- 11:30 AM** **Crack Depth Measurement in Concrete Using Surface Wave Transmission**
---J. S. Popovics, Department of Civil and Environmental Engineering, The University of Illinois at Champaign-Urbana, Urbana, IL 61801
- 12:10 PM** **Lunch**

Designing and Building to “Impossible” Vibration Tolerances

---B. H. Hertlein, STS Consultants, Ltd., 750 Corporate Woods Parkway, Vernon Hills, IL 60061

---As the precision and production capabilities of modern machines and factories increase, our expectations of them rise commensurately. Facility designers and engineers find themselves increasingly involved with measurement needs and design tolerances that were almost unthinkable a few short years ago. An area of expertise that demonstrates this very clearly is the field of vibration measurement and control. Magnetic Resonance Imaging, Semiconductor manufacturing, micro-machining, surgical microscopes – These are just a few examples of equipment or techniques that need an extremely stable vibration environment. The challenge to architects, engineers and contractors is to provide that level of stability without undue cost or sacrificing the aesthetics and practicality of a structure. In addition, many facilities have run out of expansion room, so the design is often hampered by the need to reuse all or part of an existing structure, or site vibration sensitive equipment close to an existing vibration source. High resolution measurements and nondestructive techniques have proved invaluable additions to the engineer’s toolbox in meeting these challenges. The author summarizes developments in this field over the last fifteen years or so, and lists some common errors of design and construction that can cost a lot of money in retrofit if missed, but can easily be avoided with a little foresight, an appropriate testing program and a carefully thought out checklist.

Electromagnetic Modeling of Water Movement in Mortar Cubes at Microwave Frequencies

---Shanup Peer, R. Zoughi, and Kimberly E. Kurtis*, Applied Microwave Nondestructive Testing Laboratory (*amntl*), Electrical and Computer Engineering Department, University of Missouri-Rolla, Rolla, MO 65409; *School of Civil and Environmental Engineering, Georgia Institute of Technology, Atlanta, GA 30332-0355

---Interactions between cement-based materials and water are important for both strength development (i.e., cement hydration) and performance. Thus, the development of a non-destructive technique to monitor changes in moisture content in cement-based materials should find broad applications. For instance, during initial hydration, such a tool would be useful for verifying water-to-cement ratio. After placement, this tool could also be used ascertain when a particular degree of hydration has been reached, allowing forms to be removed at an appropriate time, or to monitor moisture loss to the environment, as a means of assessing the likelihood of cracking. During service, ingress of moisture, which can be accompanied in some environments by potentially aggressive ions and gases (e.g., Cl^- , SO_4^{2-} , CO_2), could be monitored to provide information regarding the degree of saturation and depth of penetration. Such a tool, then, could form the basis for service life predictions and maintenance strategies where reactions involving moisture ingress (e.g., alkali-silica reaction, carbonation, corrosion, freeze-thaw cycling, sulfate attack) are expected. In concrete containment vessels, an embedded tool with the ability to monitor moisture content could be used to probe for leaks. Consequently, an electromagnetic model was developed describing the daily ingress of water into 8”x 8”x 8” mortar cubes. The only measured data that is incorporated into the model is the measured daily mass of the cubes (i.e., ground truth data). This paper briefly presents the experimental methodology and describes this “forward” modeling approach and the comparison between the measured and simulated phase and magnitude of reflection coefficients at 3 GHz and 10 GHz.

Microwave Reflection and Dielectric Properties of Mortar Exposed to Periodic Chloride Solution With 2% Salinity and Compression Force

---Tobias Case, Shanup Peer, Eric Gallaher, Reza Zoughi, and Kimberly Kurtis*, Applied Microwave Nondestructive Testing Laboratory (*amntl*), Electrical and Computer Engineering Department, University of Missouri-Rolla, Rolla, MO 65409; *School of Civil and Environmental Engineering, Georgia Institute of Technology, Atlanta, GA 30332-0355

---The presence of chloride is implicated as a prevalent cause of damage to the majority of the reinforced concrete structures and bridges. Corrosion of steel rebar adversely compromises the strength and integrity of such structures. Although techniques exist for chloride detection and its migration into the structure, they are destructive, time consuming and cannot be used for the interrogation of large surfaces. In recent years, several near-field microwave nondestructive testing techniques have been used to evaluate various properties of cement-based materials. It has also been shown that the presence of chloride in mortar specimens periodically exposed to chloride solution can be detected using these techniques. In the present experiment cubic (8"x 8"x8") mortar specimens were produced all with water-to-cement (*w/c*) ratio of 0.5 and sand-to-cement (*s/c*) ratio of 2.5 using type I/II Portland cement. Since the majority of field exposure to chloride is cyclical in nature, these specimens were cyclically exposed to a chloride bath with a salinity of 2%. To further simulate the real environment and also to promote penetration of chloride in mortar specimen, in the present investigations these specimens are also put under compression before exposure to chloride bath. Daily near-field microwave reflection and dielectric property measurements were conducted on these specimens, at S-band (3 GHz) and X-band (10 GHz), after they were taken out of the chloride bath. Similar measurements were also conducted on an identical specimen which was neither exposed to the chloride solution nor to any compression force. This paper presents the results of these measurements and well as a complete discussion of the findings and comparison with the results of similar experiments with higher and lower salinity chloride solutions.

Radar Detection of Rebars Including Use of Neural Networks and Horn Antennas

---J. H. Bungey, S. G. Millard, T. C. K. Molyneaux, and J. Davies, Department of Civil Engineering, The University of Liverpool, Brownlow Street, Liverpool L69 3GQ, United Kingdom

---The identification and positioning of steel reinforcing bars and metallic prestressing ducts within structural concrete is an important civil engineering application of Ground Penetrating Radar (GPR). The capabilities of GPR have been studied at the University of Liverpool for over thirteen years by means of laboratory experiments and numerical modeling. Laboratory tests have included the use of an oil-water emulsion to simulate the radar properties of concrete, extensive transmission-line determination of the dielectric properties of different concretes at a range of radar frequencies and the determination of characteristics of commonly used antennas applied to concrete surfaces. Artificial Neural Networks have also been examined in terms of their capability to classify reinforcing bar depth and size. Current ongoing work is seeking to develop and validate a wideband horn antenna system to characterize insitu dielectric properties of concrete, including layering effects due to moisture gradients and their influence on detailed interpretation of bar position.

NDE of FRP Wrapped Timber Bridge Components Using Infrared Thermography

---U. B. Halabe, Department of Civil and Environmental Engineering, Constructed Facilities Center, West Virginia University, Morgantown, WV 26506-6103; W. E. Steele III, Modjeski and Masters, Inc., Mechanicsburg, PA 17055; H. V. S. GangaRao, Department of Civil and Environmental Engineering, Constructed Facilities Center, West Virginia University, Morgantown, WV 26506-6103; P. Klinkhachorn, Lane Department of Computer Science and Electrical Engineering, Constructed Facilities Center, West Virginia University, Morgantown, WV 26506-6104

---This paper presents the results of an experimental study on the use of infrared thermography technique for detection of subsurface anomalies in fiber reinforced polymer (FRP) wrapped timber bridge components. Simulated subsurface delaminations were constructed in the laboratory in timber piles wrapped with FRP composite fabric. The delaminations varied in size, thickness and severity. These delaminations were placed between the 1/8" thick FRP wrap and the timber surface. The thermal images from the delaminated specimens were compared with the thermal images from undamaged specimens to study the effect of subsurface anomalies. In addition, several field tests were conducted using the infrared imaging system on three timber railroad bridges located in Moorefield, West Virginia that were reinforced with FRP composite fabric. The field test data was used to detect debonds at the composite-timber interface and study the effect of environmental parameters on the infrared images. This study showed that the infrared thermography technique can be effectively used to detect subsurface delaminations in timber components wrapped with FRP composite fabric. The study also shows the effect of different parameters (environmental conditions, heat source, etc.) on the clarity of the infrared images.

NDE of FRP Bridge Beams and Decks

---John C. Duke, Jr., Scott Case, and Jack L. Lesko, Virginia Tech, Department of Engineering Science and Mechanics, MC 0219, Blacksburg, VA 24061

---Over 100 FRP innovative bridge projects have been undertaken throughout the United States in the past 5 years. However, little if any effort has been devoted to developing the capability to nondestructively evaluate these components. Assumptions that experience with NDE of FRP for aircraft applications can be adapted to these applications are naive. Results of efforts to develop NDE for these types of materials and components will be presented. The use of infrared thermal imaging, ultrasonic examination, AE monitoring, Acousto-ultrasonic evaluation will be discussed. Research with distributed embedded strain sensors for overcoming the inadequacies of conventional NDE will be described.

Inspection of Steel Tendons in Concrete Using Guided Waves

---M D. Beard, M. J. S. Lowe, and P. Cawley, Department of Mechanical Engineering, Imperial College of Science, Technology and Medicine, London, SW7 2BX, England

---The research reported in this paper is aimed at establishing the potential of guided waves for the non-destructive testing of steel tendons in concrete. The inspection method uses a pulse-echo technique to identify reflections from breaks and defects, using a transducer mounted on the free end of the tendon. The use of ultrasound for tendons that are not embedded is relatively straightforward, but the presence of an embedding material, such as cement grout, causes guided waves to be attenuated strongly through leakage, and it is essential that this is properly taken into account. The existence of high frequency, low-leakage modes that minimize the leakage has been reported previously at QNDE, but the maximum inspection range has not yet been confirmed. This paper reports the results of experiments to measure the attenuation in short lengths of grouted tendon. It also assesses more broadly the practical utility of the technique, by considering the effects of important factors such as the tendon diameter, defect geometry, tendon curvature, and excitation signal. The outcome of this research shows that the inspection range for post-tensioning tendons is limited, but the outlook for the inspection of the larger diameter grouted bolts and re-bars that are used in the construction industry is promising.

Ultrasonic Methodology to Characterize Curing of Cement-Based Materials

---W. Punurai and L. J. Jacobs, School of Civil and Environmental Engineering, Georgia Institute of Technology, Atlanta, GA 30332-0355

---This research develops a technique that uses ultrasonic waves to monitor the state of cure of cement-based materials. The objective of this research is to develop a quantitative methodology capable of predicting the early-age properties of concrete components. The proposed experimental procedure uses embedded PZT receivers and an external ultrasonic source to assess ultrasonic waves that propagate in curing concrete. Changes in the properties of these ultrasonic waves are combined with temperature measurements from an embedded thermal-couple to predict material properties. The specific ultrasonic wave properties examined are wave speed and frequency dependent attenuation. Cross-correlation and time-frequency techniques are used to determine arrival times and to characterize frequency changes. These ultrasonic quantities are then related to material stiffness and density. Finally, these experimental results are interpreted in terms of an analytical model.

Crack Depth Measurement in Concrete Using Surface Wave Transmission

---J. S. Popovics, Department of Civil and Environmental Engineering, The University of Illinois at Champaign-Urbana, Urbana, IL 61801

---A technique to estimate the depth of surface-breaking cracks in concrete is presented. The surface wave transmission coefficient across the crack plane is determined and used to estimate the depth. A self-compensating testing scheme is applied to eliminate experimental difficulties such as heterogeneous wave path dependence, unknown characteristics of the receiver and the wave source, and variation of impact event or receiver coupling. Previous work shows that the signal transmission coefficient obtained with this set-up is an accurate estimate and is not affected by the experimental set-up or the heterogeneous nature of concrete. In this paper the self-compensating testing scheme is introduced and the approach to estimate crack depth from the measured surface wave transmission coefficient described.

Experimental results obtained from concrete specimens with pre-placed surface-breaking notches are then presented. The results of the experimental test series are evaluated and the effectiveness of the approach is discussed.

Tuesday, July 16, 2002

SESSION 10
THERMOSONICS AND THERMAL WAVE IMAGING AND APPLICATIONS
X. Han, Chairperson
FRASER 4

- 8:30 AM** **Flash-Gradient IR Evaluation of Metal Cracks**
---H. I. Ringermacher and D. R. Howard, General Electric Research and Development Center, P. O. Box 8, Schenectady, NY 12301
- 8:50 AM** **Thermographic Depth Profiling of Delaminations in Composites**
---W. P. Winfree, Nondestructive Evaluation Sciences Branch, NASA Langley Research Center, Hampton, VA 23681-2199; J. N. Zalameda, U. S. Army Research Laboratory, Vehicle Technology Directorate, NASA Langley Research Center, Hampton, VA 23681-2199
- 9:10 AM** **Inspection of Aircraft Components with Burst Phase Thermography**
---G. Riegert, T. Zweschper, A. Dillenz, and G. Busse, University of Stuttgart, Institute of Polymer Testing and Polymer Science (IKP), Department of Nondestructive Testing, Pfaffenwaldring 32, D-70569 Stuttgart, Germany
- 9:30 AM** **Laser Vibrometry Measurements of Thermosonic Activation**
---W. Davis¹ and M. B. Rankin², ¹Naval Air Warfare Center, Aircraft Division, Materials Department, Patuxent River, MD 20670; ²Naval Air Warfare Center, Aircraft Division, Avionics Department, Patuxent River, MD 20670
- 9:50 AM** **Recent Developments in Sonic IR Imaging**
---X. Han¹, L. D. Favro², and R. M. Thomas³, ¹Electrical and Computer Engineering; ²Institute for Manufacturing Research; ³College of Science; ^{1,2,3}Wayne State University, Detroit, MI 48202
- 10:10 AM** **Coffee Break**
- 10:30 AM** **Materials Characterization Using Reconstructed Thermographic Data**
---S. M. Shepard, J. R. Lhota, T. Ahmed, D. Wang, B. Rubadeux, and A. Esser-Kahn, Thermal Wave Imaging, Inc., 845 Livermois Street, Ferndale, MI 48220-2308
- 10:50 AM** **Optimizing the Thermosonics Signal**
---I. M. Perez, Materials Division, Office of Naval Research, Arlington, VA 22217-5660; W. R. Davis, Materials Division, Naval Air Systems Command, Patuxent River, MD
- 11:10 AM** **Sonic IR Imaging and Vibration Pattern Studies of Cracks in an Engine Disk**
--- X. Han¹, L. D. Favro², and R. M. Thomas³, ¹Electrical and Computer Engineering; ²Institute for Manufacturing Research; ³College of Science; ^{1,2,3}Wayne State University, Detroit, MI 48202
- 11:30 AM** **Acousto-Thermal Microstructure Characterization**
---N. Meyendorf, D. Eylon, J. Maurer, J. Frouin, W. Karpen, V. Kramb, H. Roesner, and S. Sathish, Center for Materials Diagnostics, 300 College Park, Dayton, OH 45469-0121
- 11:50 AM** **Monitoring of the Level of Residual Stress in Surface-Treated Specimens by a Noncontacting Thermoelectric Technique**
---B. Lakshminar, H. Carreon, and P. B. Nagy, Department of Aerospace Engineering and Engineering Mechanics, University of Cincinnati, Mail Location 0070, Cincinnati, OH 45221-0070
- 12:10 PM** **Lunch**

Flash-Gradient IR Evaluation of Metal Cracks

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

--- Flash lamps are used to create a lateral thermal gradient on metal surfaces to permit observation of vertical and other orientations of cracks in metal substrates, for example in engine compressor blades. The surface must generally be prepared with a black coating to improve observability. The IR temporal image data can be processed to obtain the depth and extent of the crack. Data on cracks is compared to theory.

Thermographic Depth Profiling of Delaminations in Composites

---W. P. Winfree, Nondestructive Evaluation Sciences Branch, NASA Langley Research Center, Hampton, VA 23681-2199; J. N. Zalameda, U. S. Army Research Laboratory, Vehicle Technology Directorate, NASA Langley Research Center, Hampton, VA 23681-2199

---The determination of the depth and size of delaminations is important for determining their impact on the structural integrity. The most common technique for depth determination from thermal responses relies on a calibration of the technique based on flat bottom hole in a NDE standard. This assumes a delamination will effectively block all the heat diffusion from the region above the delamination to the region below the delamination. For graphite fiber reinforce composites, where a thin delamination has a contact resistance which is comparable with the thermal resistance of the layer above it, this assumption is inaccurate. This paper discusses thermographic depth profiling based on a three layer analytical model for heat diffusion. The model is shown to accurately represent the thermal response obtained for flash heating of composite specimens with known delaminations. Using the model to fit the thermal responses enables an estimation of the depth of the delamination. The accuracy of the technique is determined from measurements on composite specimens with delaminations at known depths.

Inspection of Aircraft Components with Burst Phase Thermography

---G. Riegert, T. Zweschper, A. Dillenz, and G. Busse, University of Stuttgart, Institute of Polymer Testing and Polymer Science (IKP), Department of Non-Destructive Testing, Pfaffenwaldring 32, D-70569 Stuttgart, Germany

---Thermography with external excitation (e.g. Lockin Thermography, or flash thermography) provides images where defects are found by comparing the observed features with features expected either from theory or an intact reference sample. If the intact sample has a complicated thermal structure, defect detection requires attention and experience of the inspectors involved. Defect selective methods (known e.g. from dark field methods in optics) provide much better detectibility of defects (Dynamic thermography can be converted into such a technique by launching elastic waves into the component where they propagate until they are converted into heat. That is why defects with their locally enhanced losses heat up selectively - a technique investigated for the first time more than 20 years ago by Henneke and colleagues. If the elastic wave amplitude is modulated, the periodical heat generation turns the defect into a local thermal wave transmitter. Its emission is detected via the temperature modulation at the surface which is analysed by lockin thermography tuned to the frequency of amplitude modulation. Corresponding measurements are being performed using burst excitation which is used to obtain phase angle information simultaneously at many lockin frequencies. We will show how depth resolved phase angle images display various kinds of aerospace structures. The field of interest is aging aircraft as well as modern aircraft containing carbon fiber reinforced plastics (CFRP). The obtained phase angle images reveal areas of disbonds, impacts, and delaminations in CFRP. In all these cases the intact structure is suppressed since it heats up much less in the elastic wave field.

Laser Vibrometry Measurements of Thermoelastic Activation

---William Davis¹ and Michael B. Rankin², ¹Naval Air Warfare Center, Aircraft Division, Materials Department, Patuxent River MD, 20670; ²Naval Air Warfare Center, Aircraft Division, Avionics Department, Patuxent River MD, 20670

---Work in Thermoelasticity (Vibration Thermography) has demonstrated the ability to make cracks in metals, delamination in composites and disbonds visible to Infrared Thermography. A basic question of what energy levels are needed to "activate" the discontinuities remains as an impediment to a universal understanding of the technique. The authors would like to present some initial results using laser vibrometry measurements of the amplitude and frequency of the movement of the surface of simple samples. Some measurements will be made to measure the effect of varying some of the operating parameters. Results will be presented at the conference.

Recent Developments in Sonic IR Imaging

--- X. Han¹, Electrical and Computer Engineering¹; L. D. Favro², Institute for Manufacturing Research², Robert. M. Thomas³, College of Science³, ^{1,2,3}Wayne State University, Detroit, MI 48202

---We present the results of recent experiments on metal aircraft structures and composite test samples with natural and simulated defects. Metal examples will include cracks originating under fasteners and cracks in mechanical parts. Examples of defects in composites will include fatigue cracks, pillow inserts, pull-tab disbonds, skin-to-core disbonds, etc. This work was supported by in part by the DOT/FAA William J. Hughes Technical Center's Airworthiness Assurance Center of Excellence (AACE), under Contract Number DTFA0398D-00008, Award Number DTFA0300PIA037, in part by the U.S. Navy, NSWC, under P.O. Number N00167-00-M0498, in part by the Office of Naval Research under Award Number N00014-02-1-0259, and in part by the Institute for Manufacturing Research, Wayne State University.

Materials Characterization Using Reconstructed Thermographic Data

---S. M. Shepard, J. R. Lhota, T. Ahmed, D. Wang, B. Rubadeux, and A. Esser-Kahn, Thermal Wave Imaging, Inc., 845 Livermois St., Ferndale, MI 48220-2308

---Pulsed thermography has generally been used to identify, and in some cases, measure the depth of subsurface defects. Far less attention has been paid to the characterization of defect-free samples, where measurement of thermophysical properties is often useful. This has occurred because quantitative analysis of pulsed thermographic data typically requires the presence of a reference sample or region in the field of view, which is not practical for a majority of real inspection situations. Recently, we have developed a new approach to processing pulsed thermographic data, Thermographic Signal Reconstruction (TSR), which involves the creation of an equation for each pixel that is a low pass filtered representation of its time evolution. Elsewhere, we have reported the increased depth sensitivity and spatial resolution that the TSR approach provides. However, we have also found that this approach is effective in characterizing and measuring thermophysical properties of defect free samples. We have successfully applied this approach to diffusivity, conductivity and thickness measurements in metal, composite and ceramic samples.

Optimizing the Thermosonics Signal

---Ignacio M. Perez, Materials Division, Office of Naval Research, Arlington, VA, 22217-5660; William R. Davis, Materials Division, Naval Air Systems Command, Patuxent River, MD

---Extensive work has been done in the past characterizing the effects of high power ultrasonic energy on material properties. More recently high amplitude ultrasonic signals have been used in combination with infrared camera systems to detect the presence of flaws in materials. Defects such as cracks in metals, exfoliation and generalized corrosion in metals, delamination in composites and disbonds have been detected using this technique. Presently no systematic study has been developed that addresses the limitations and advantages of this technique. The authors would like to present some initial results on this technique that try to determine the effects that sample geometry, crack length and contact area have on the thermographic signal. For this purpose, the authors have developed a test fixture that allows the control of various of the experimental parameters for the possibility of optimizing the signal. Results will be presented at the conference.

Sonic IR Imaging and Vibration Pattern Studies of Cracks in an Engine Disk

---X. Han¹, Electrical and Computer Engineering¹; L. D. Favro², Institute for Manufacturing Research², Robert. M. Thomas³, College of Science³, ^{1,2,3}Wayne State University, Detroit, MI 48202

---We present the results of a study of vibration patterns, frequency spectra, and sonic IR image quality of cracks in the fir-tree slots in an F-110 fan disk. This study uses the results of laser vibrometer measurements of acoustic waveforms and their spectra, and IR measurements of temperature-time behavior of cracks to examine the behavior of Sonic IR imaging of cracks as a function of the circumferential distance between the ultrasonic source and the crack being imaged.---This work was supported in part by Universal Technology Corporation, under Contract Number F33615-97-D-5271, Task Order 0002-030, Subcontract Agreement 01-S437-002-30-C1, and in part by the Institute for Manufacturing Research, Wayne State University.

Acousto-Thermal Microstructure Characterization

---N. Meyendorf, D. Eylon, J. Maurer, J. Frouin, W. Karpen, V. Kramb, H. Roesner, and S. Sathish, Center for Materials Diagnostics, 300 College Park, Dayton, OH 45469-0121

---Cyclic mechanical loading generates heat due to internal microplastic deformations, internal friction, and non-adiabatic thermoelastic effects. These thermal effects are very sensitive to the mechanical properties and microstructure of the loaded material. The current study discusses the development of a new thermal parameter that can be used to characterize the material fatigue damage state from the heat generated per loading cycle. The thermal parameter was measured during short-term (5 seconds) cyclic loading as a function of fatigue life for a Ti alloy and stainless steel. High stress-low frequency, as well as low stress-high frequency (ultrasonic) loading conditions were used to excite the thermal effects. For the Ti alloy the thermal parameter showed a linear increase with accumulated fatigue cycles. For stainless steel the thermal parameter showed a completely different behavior. The acousto-thermal results will also be compared to the results of a parallel study that characterized the fatigue damage using the non-linear acoustic parameter beta and the dislocation density from TEM experiments.

Monitoring of the Level of Residual Stress in Surface-Treated Specimens by a Noncontacting Thermoelectric Technique

---Balachander Lakshminar, Hector Carreon, and Peter B. Nagy, Department of Aerospace Engineering and Engineering Mechanics, University of Cincinnati, Mail Location 0070, Cincinnati, OH 45221-0070

---Surface-treated methods are widely used to produce near-surface compressive residual stresses and a nondestructive method is needed to assure the proper fatigue life in such surface-treated components. This talk presents a noncontacting thermoelectric method based on magnetic detection of thermoelectric currents, that can be used to characterize the prevailing residual stress before and after thermal stress relaxation. Earlier experimental results in shot-peened copper specimens indicated that the thermoelectric method is more sensitive to residual stress effects than to the secondary material effects caused by cold work such as texture and hardening. Preliminary results in shot-peened and low-plasticity burnished IN100 nickel-base superalloy are presented to demonstrate that the proposed method might be applicable to a wide range of alloys and surface-treating methods. However, these experiments also revealed that the detectability of weak imperfections and subtle material variations by this method is ultimately limited by the intrinsic thermoelectric anisotropy and inhomogeneity of the material to be inspected.

Tuesday, July 16, 2002

SESSION 11 - POSTERS
ULTRASONICS AND ULTRASONIC APPLICATIONS, ELECTROMAGNETIC TECHNIQUES,
IMAGING AND INVERSION, NEW TECHNIQUES AND SYSTEMS, MATERIALS DEGRADATION,
NDE EDUCATION
Viking Union

1:30 PM

Ultrasonics and Ultrasonic Applications

Simulations of Laser-Generated Guided Waves for Two-Layer Bonded Plate with Weak Interface

---J. Du and J. Cheng, Institute of Acoustics, Nanjing University, Nanjing 210093, P.R. China

Semi-Analytical Finite Element Analysis for Ultrasonic Focusing in a Pipe

---T. Hayashi, Z. Sun, and J. L. Rose, Engineering Science and Mechanics Department, The Pennsylvania State University, University Park, PA 16802; K. Kawashima, Department of Mechanical Engineering, Nagoya Institute of Technology, Nagoya, Japan

Hybrid Modeling of Elastic Wave Scattering in a Welded Cylinder

---A. Mahmoud, A. Shah, and N. Popplewell, Faculty of Engineering, University of Manitoba, Winnipeg, R3T 2N2 Canada

Non-Axisymmetric Wave Focusing in Pipe Inspection

---Z. Sun, J. L. Rose, and W.-J. Song, Engineering Science and Mechanics Department, The Pennsylvania State University, University Park, PA 16803; T. Hayashi, Mechanical Engineering Department, Nagoya Institute of Technology, Nagoya 466-8555, Japan

Ultrasonic Evaluation of Adhesive Bonding Layers in Rocket Motor

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Fast Techniques for Calculating Dispersion Relations of Annular Structures

---J. Fong and M. J. S. Lowe, Department of Mechanical Engineering, Imperial College of Science, Technology, and Medicine, London SW7 2BX, United Kingdom; D. Gridin and R. Craster, Department of Mathematics, Imperial College of Science, Technology, and Medicine, London SW7 2BX, United Kingdom

Finite Element Simulation of Surface Waves Interaction with Surface Breaking Cracks

---H. Jeong and M.-C. Park, Division of Mechanical and System Design Engineering, Wonkwang University, Iksan, Jeonbuk 570-749, Korea

Wide Bandwidth Air-Coupled Ultrasonic Testing of Food Containers in Air

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Generation of the Focused Type Laser-Ultrasonic Wave

---K. Jhang, School of Mechanical Engineering, Hanyang University, Hangdang-dong 12, Seoul, Korea; K. Kim, H. Kim, and J. Na, Department of Precision Mechanical Engineering, Graduate School of Hanyang University, Seoul, Korea

Electromagnetic Techniques

Simulation of the Spatially-Nonstationary Electric Field Responses of a Layered Dielectric Under Unilateral Access Conditions

---Y. Bulbik^{1,2}, Y. Belikov¹, ¹Siberian State Aerospace University, Krasnoyarsk 660014, ²UNESCO Chair in New Materials and Technologies at Krasnoyarsk State, Technical University, Krasnoyarsk 660074, Russia

Tuesday, July 16, 2002

Model-Based ECT Signal Interpretation and Experimental Verification for the Quantitative Flaw Characterization in Steam Generator Tubes

---S.-J. Song, Y. H. Kim, and E.-L. Kim, School of Mechanical Engineering, Sungkyunkwan University, Suwon 440-746, Korea; T.-E. Chung, Korea Advanced Inspection Technology, Daejeon 305-353, Korea; Y. H. Choi, Nuclear Safety Research Department, Korea Institute of Nuclear Safety, 305-338, Korea

Electric Potential in Eddy Current Testing

---H. Hoshikawa, K. Koyama, and M. Maeda, Nihon University, Izumicho Narashino, Chiba 275-8575, Japan

Two-Step Algorithm in Calculation of Defect Influenced Eddy Current Field

---V. Lunin and Z. Zhdanov, Moscow Power Engineering Institute (TU), Krasnokazarmennaja 14, Moscow 111250, Russia

Imaging and Inversion

Reconstruction of 3D Flaws in Eddy Current Quantitative Nondestructive Evaluation

---D. Premel, A. Baussard, and J.-M. Decitre, LESIR/SATIE, ENS de Cachan, 61 Avenue du President Wilson, 94235 Cachan, France

Application of Linearized Inverse Scattering Methods to the Material with Flat Measurement Surface

---K. Nakahata, M. Onishi, and M. Kitahara, Department of Civil Engineering, Graduate School of Engineering, Tohoku University, Aoba-yama 06, Sendai 980-8579, Japan

Development of Enhanced Ultrasonic Imaging Methods for the Inspection of Water Distribution Pipelines

---H. J. Shin and Y. H. Jang, R&D, Inde Systems Co., Ltd., Suwon, Kyonggi-do, South Korea; H. D. Lee, P. J. Kwak, and S. K. Kim, Water Resources & Environmental Engineering Division, Korea Institute of Construction Technology, Koyang-si, Kyonggi-do, South Korea

Automatic Evaluation of Welded Joints Using Image Processing on Radiographs

---C. Schwartz, CEA Valduc, Is Sur Tille, 21120, France

New Approaches to Flaw Sizing Using Ultrasonic Testing Models

---H.-J. Kim, S.-J. Song, and Y. H. Kim, School of Mechanical Engineering, Sungkyunkwan University, Suwon, Korea

New Techniques and Systems

3D Modelling of a Magneto-Optic Imager by a Dyadic Green's Functions Approach

---J.-M. Decitre and D. Premel, LESIR/SATIE, ENS de Cachan, 61 av. President Wilson, 94235 Cachan Cedex, France

Digital Ultrasonic Systems and Signal Processing Techniques for Advanced Flaw Detection and Large Area Scanning

---R. J. Freemantle, NDT Solutions, Ltd., Dunston Innovation Center, Dunston Road, Chesterfield, S41 8NG, United Kingdom

Sequential Evaluation of QNDE Devices for Underground Storage Tanks

---Y. Michlin, Technion – Israel Institute of Technology, Quality Assurance and Reliability, Haifa, Israel 32000

Tuesday, July 16, 2002

Development of a Magnetic NDE Imaging System Using Magnetoresistive Sensors

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

Development of Modeling and Simulation for Magnetic Particle Inspection Using Finite Element Method

---J. Y. Lee, S. J. Lee, D. C. Jiles, M. Garton, R. Lopez, and L. Brasche, Iowa State University, Center for Aviation Systems Reliability, 1915 Scholl Road, Ames, IA 50011

Application of a Giant Magnetoresistive (GMR) Sensor for Characterization of Corrosion in a Laboratory Specimen

---R. T. Ko¹ and M. P. Blodgett, Metals, Ceramics, and NDE Division, Air Force Research Laboratory, Wright-Patterson Air Force Base, Dayton, OH 45433; ¹Structural Integrity Division, University of Dayton Research Institute, 300 College Park Drive, Dayton, OH 45469-0120

Nondestructive Evaluation of Outer Defects in the Welding Part of a Thick Plate of Austenitic Stainless Steel

---Z. Chen, N. Yusa, and K. Miya, International Institute of Universality, 1-3-5 Nezu, Bunkyo-ku, Tokyo 113-0031, Japan; A. Tanahashi and K. Sakai, The Kansai Electric Power Co., Inc., 3-3-22 Nakanoshima, Kita-ku, Osaka 530-8270, Japan

Seamless Tubing Process Control by On-Line Laser Ultrasonic Sensing

---R. V. Kolarik II, G. V. Jeskey^{***}, L. J. Duly, K. J. Samblanet, and S. E. Agger, The Timken Company, 1835 Dueber Avenue Southwest, Canton, OH 44706; M. Choquet^{**}, C. Néron, C. Padiou, D. Lévesque, and J.-P. Monchalain, Industrial Materials Institute, National Research Council of Canada, 75, de Mortagne Boulevard, Boucherville, Québec, J4B 6Y4, Canada; ^{**}Now with Tecnar Automation Ltd 1321 Hocquart St-Bruno, Québec J3V 6B5, Canada, ^{***}retired from The Timken Company

Materials Degradation

Localization of Dwell Fatigue Cracks in Ti-6242 Alloy Samples

---S. I. Rokhlin, J.-Y. Kim, B. Xie, and B. Zoofan, NDE Program, The Ohio State University, Edison Joining Technology Center, 1248 Arthur E. Adams Drive, Columbus, OH 43221

A Study on the Thermal Damage Monitoring of Degraded Materials by Ultrasonic Plate Wave

---I. K. Park and U. S. Park, R. I. of NDE Technology, Seoul National University of Technology, 172 Gongneung-dong, Nowon-gu, Seoul, 139-743, Korea; Y. H. Cho, School of Mechanical and Automotive Engineering, Inje University, 607 Obang-dong, Kimhae, Kyongnam 621-749, Korea; J. L. Rose, Department of Engineering Science and Mechanics, The Pennsylvania State University, Earth and Engineering Science Building, University Park, PA 16802

Dependence of Fatigue Damage and the Perpendicular Residual Leakage Magnetic Flux Density in Austenitic Stainless Steel

---M. Oka, Department of Computer and Control Engineering, Oita National College of Technology, 1666 Maki, Oita, 870-0152, Japan; T. Yakushiji, Department of Mechanical Engineering, Oita National College of Technology, 1666 Maki, Oita, 870-0152, Japan; Y. Tsuchida and M. Enokizono, Department of Electric and Electronics Engineering, Faculty of Engineering, Oita University, 700 Dannoharu, Oita, 870-1192, Japan

Monitoring Fatigue Damage Accumulation with Rayleigh Wave Harmonic Generation Measurements

---D. J. Barnard, L. J. H. Brasche, and A. D. Degtyar¹, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011; ¹Pratt & Whitney, 400 Main Street, E. Hartford, CT 06033

Tuesday, July 16, 2002

Estimation of Degradation of Strength Properties of a Material or Structures Intended for a Long Service Life Using a Combination of Mathematical Models and “Practicable” Measurements

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

NDE Education

NDT Education Resource Center on the Internet

---B. Larson and L. W. Schmerr, Iowa State Univ. Center for NDE, 1915 Scholl Rd., Ames, IA 50011

Recent Progress in Undergraduate Vertically Integrated Engineering Design Projects in Nondestructive Evaluation

---D. C. Jiles^{1,2,6}, M. Akinc^{2,6}, S. B. Biner^{2,6}, K. Constant², J. N. Gray³, M. Huba⁴, L. W. Schmerr⁵, and R. B. Thompson^{1,2,5}; ¹Center for NDE; ²Department of Materials Science & Engineering; ³Department of Mechanical Engineering; ⁴Department of Educational Leadership and Policy Studies; ⁵Department of Aerospace Engineering and Engineering Mechanics; ⁶Ames Laboratory; Iowa State University, Ames, IA 50011

3:10 PM

Coffee Break

Simulations of Laser-Generated Guided Waves for Two-Layer Bonded Plate with Weak Interface

---J. Du and J. Cheng, Institute of Acoustics, Nanjing University, Nanjing 210093, P. R. China

---The ultrasonic guided wave is powerful in characterization of the cohesive quality in bonded plates, while it largely depends on the understandings of the nature of the imperfect interface and propagating characteristics of ultrasonic guided waves. A model is presented for the laser-generated transient ultrasonic guided waveforms using method of normal mode expansion for two-layer bonded plate with a weak interface modeled by the spring model. The sensitivity of each mode and the total waveform on the physical parameters characterizing the cohesive quality of bonded plate are discussed in details in the numerical simulations.

Semi Analytical Finite Element Analysis for Ultrasonic Focusing in a Pipe

---T. Hayashi, Z. Sun, and J. L. Rose, Engineering Science and Mechanics Department, The Pennsylvania State University, University Park, PA 16802; K. Kawashima, Department of Mechanical Engineering, Nagoya Institute of Technology, Nagoya, Japan

---Guided wave focusing has been developed as a promising technique for defect detection in pipeworks, where non-axisymmetric flexural modes are tuned so that ultrasonic energy can be focused at a target point in a pipe. If a defect is located at the target point, large reflected waves can be observed. In this study, the focusing phenomenon is analyzed using a semi-analytical finite element method. For straight pipes, the one dimensional semi analytical finite element method is used, in which a region of a pipe is divided into the cylindrical subdivisions in the thickness direction. The waveforms in the circumferential and longitudinal directions are analytically described. For a curved pipe, the two dimensional semi analytical FEM, where a cross section of a pipe is divided in the thickness and circumferential directions, are adopted. Curved regions are described by a quasi-cylindrical coordinate system where the longitudinal axis is curved along the curved region, instead of along a straight longitudinal axis. Visualization of the calculation results reveals the focusing status both in a straight pipe and in a curved pipe. Experiments have also been carried out. Good agreement on the focusing phenomenon between numerical and experimental results has been achieved.

Hybrid Modeling of Elastic Wave Scattering in a Welded Cylinder

---A. Mahmoud, A. Shah, and N. Popplewell,
Faculty of Engineering, University of Manitoba,
Winnipeg, R3T 2N2 Canada

---The hybrid method is a technique that combines a finite element idealization of a bounded region containing a cracked weldment and a wave function expansion in the exterior region. A system of linear equations is generated that is solved for the unknown wave function amplitudes. These amplitudes are used to calculate the reflection and transmission coefficients of the scattered field for an incident longitudinal wave $L(0,1)$. Hybrid modeling of elastic wave scattering in welded cylinders has been reported previously but only for the axisymmetric case. In the present study, a 3D hybrid model is developed for the non-axisymmetric case. The model is validated by using previously obtained results for 3D scattering in a virgin cylinder and 2D scattering in a cracked welded cylinder. The results of 3D and 2D hybrid models agree exactly. The coarse finite element mesh needed for an acceptable computational effort, on the other hand, leads to an essentially constant 8.6 % offset below Bai et al.'s semi-analytical predictions. Novel results are presented for the case of scattering from a 0.71-mm-thick weld in a cylinder having a 5.08-mm thickness and 50.08-mm radius. The crack extends circumferentially either 360, 180 or 36 degrees.

Non-Axisymmetric Waves Focusing in Pipe Inspection

---Zongqi Sun, Joseph L. Rose, and Won-Joon Song, Engineering Science and Mechanics Department, The Pennsylvania State University, University Park, PA 16803; Takahiro Hayashi, Mechanical Engineering Department, Nagoya Institute of Technology, Nagoya, 466-8555, Japan

---Non-axisymmetric waves have been applied to pipe inspection recently. Due to the non-axisymmetric characteristics of the waves, the circumferential displacement profile is non-axisymmetric. With the aid of a circumferential transducer array we developed an algorithm to focus energy in the circumferential direction in the pipe by frequency and time delay tuning. Focusing will not only greatly enhance signal-to-noise ratio of defect echo but also make it possible to detect the circumferential location of defect. Experiments were also carried out to show the focusing effect. Since it can be realized in computer software, the focusing algorithm can be carried out very efficiently in the real NDE application.

Ultrasonic Evaluation of Adhesive Bonding Layers in Rocket Motor

---S.-J. Song, Y. H. Kim, and J. S. Park, School of Mechanical Engineering, Sungkyunkwan University, Suwon, 440-746, Korea

---In the present work, an effective ultrasonic testing method is under development to evaluate an adhesive layer in the rocket motor case assembly. The rocket motor case assembly consists of 1.3mm thick outer steel plate and 6mm thick layer of FRP. The 0.2mm thick epoxy is filled up between the steel plate and the FRP layer. One of the main tasks of the present endeavor is to locate debonded area between the steel and the epoxy. The relationship between adhesion ratio and reflected ultrasonic amplitude was calculated by considering reflection coefficient at the interface between steel and epoxy layers. It was found that the higher amplitude of ultrasound is reflected for the debonded area in numerical calculation, and shown good agreements with experimental results. Another important task is to distinguish area of lack-of-adhesive from kissing bonded area. Circumferential waves were employed to address this task. The amplitude of circumferential wave contains not only overall information on the entire propagation path but also localized information on the position of excitation. The higher amplitude of circumferential wave was detected when the transducer was placed on the area of lack-of-adhesive. The present study demonstrates the capability of conventional ultrasonic pulse-echo method to find the delamination, and the high potential of the circumferential waves to distinguish the region of lack-of-adhesive from the kissing bond.

Fast Techniques for Calculating Dispersion Relations of Annular Structures

---J. Fong and M. J. S. Lowe, Department of Mechanical Engineering, Imperial College of Science, Technology and Medicine, London, SW7 2BX, United Kingdom; D. Gridin and R. Craster, Department of Mathematics, Imperial College of Science, Technology and Medicine, London, SW7 2BX, United Kingdom

---There has been considerable interest recently in using guided waves to detect defects in various annular structures, such as helicopter rotor hubs, pipe walls and borehole linings. This is due to their potential for fast inspection, and their ability to cover the area around the circumference without necessarily needing access to the whole structure. The accurate and efficient determination of dispersion curves is fundamental to understanding and interpreting guided waves in curved structures. Much of the recent work extracts the dispersion relation as a complicated determinant which is solved numerically to extract the roots. However, due to the high-frequency nature of the problem, tracing the exact dispersion curves for a large number of modes both quickly and accurately becomes time consuming, and for many modes is impractical. We use various asymptotic techniques to extract useful and accurate dispersion relations that are more stable at high frequencies, are much simpler and quicker to evaluate, and they also elucidate the underlying ray structures of various modes. Comparisons of dispersion curves evaluated from the exact and asymptotic dispersion relations are presented. The error remains typically less than 0.1% except for the very low frequency region. Finally, some results found by two-dimensional harmonic Finite Element analysis are also presented for comparison.

Finite Element Simulation of Surface Waves Interaction with Surface Breaking Cracks

---H. Jeong and M.-C. Park, Division of Mechanical and System Design Engineering, Wonkwang University, Iksan, Jeonbuk 570-749, Korea

---Numerical simulation plays an important role in many aspects of quantitative nondestructive evaluation including flaw detection, location and sizing. In this investigation we use the finite element method to model Rayleigh surface wave generation, propagation and scattering from surface breaking cracks. The first model considers the conventional pulse-echo and pitch-catch methods and calculates scattered fields on the free surface both near the crack and far away from it. The farfield transmission and reflection coefficients are also calculated and compared with experimental results. The second finite element model deals with thermoelastic laser generation of ultrasound. A point or line-focused laser source is modeled by a single or distributed shear dipoles parallel to the surface. When the laser source scans over an area of test piece containing a surface-breaking crack, the amplitude variations in the laser generated ultrasound is observed and compared with experimental results. Finally a method to size surface-breaking cracks is discussed.

Wide Bandwidth Air-Coupled Ultrasonic Testing of Food Containers in Air

---T. H. Gan, D. A. Hutchins, and D. R. Billson, School of Engineering, University of Warwick, Gibbet Hill Road, Coventry CV4 7AL, United Kingdom

---Air-coupled NDE has been used to perform measurements on food containers. This relies on the broad bandwidth available from polymer-filmed capacitive transducers, combined with pulse compression techniques. The first experiments involve liquids within cylindrical polymer containers. It will be demonstrated that transmission through the drinks bottles can be used to measure liquid level, either from monitoring the through-transmitted signal directly, or by observation of a reflection from the liquid surface. This can be achieved without contact to the container. By scanning the transducers around the container, it is also possible to collect tomographic data. It will be demonstrated that this can be used to reconstruct air-coupled cross-sectional images of such containers, so that contaminants can be located. It is also shown that the temperature of a liquid can be estimated successfully, using time-of-flight measurements. The result is a powerful method for the NDE of such materials, which could be applied to production-line situations.

Generation of the Focused Type Laser-Ultrasonic Wave

---K. Jhang, School of Mechanical Engineering, Hanyang University, Hangdang-dong 12, Seoul, Korea; K. Kim, H. Kim, and J. Ha, Department of Precision Mechanical Engineering, Graduate School of Hanyang University

---An arc-shaped line array slit is used for the generation of focused laser-ultrasonic wave. The spatially expanded Nd:YAG pulse laser is illuminated through the arc-shaped line array slit on the surface of a sample to generate the ultrasonic wave of the same pattern as the slit. Then focal point of which distance from the slit position is dependent on the curvature of slit arc. The relationships between the characteristics of the generated ultrasonic wave including the focusing performance and several design parameters such like as slit width and slit interval are investigated. By using the focused wave we can upgrade the inspection ability for the small size defect with the improvement of spatial resolution. Also this method can be combined with the scanning mechanism to get image just like we can get by the scanning ultrasonic microscope(SAM).

Simulation of the Spatially-Nonstationary Electric Field Responses of a Layered Dielectric Under Unilateral Access Conditions

---Y. Bulbik^{1,2}, Y. Belikov¹, ¹Siberian State Aerospace University, Krasnoyarsk 660014; ²UNESCO Chair in New Materials and Technologies at Krasnoyarsk State, Technical University, Krasnoyarsk 660074, Russia

---It is well known that the electric field distributions in a dielectric medium can follow the electric charge spatial changes almost instantaneously. A coplanar electrode system having sensory electrodes, connected by some built-in planar resistors (buffer elements) with one pole of an electric pulse source, allows to reproduce the quasi-stationary electric charges on sensory part of the system when a pulse duration exceeds the transient time. Spatially-nonstationary mode of such sensor operation appears when a pulse duration is less than the transient time. In this case, the charges reproduced at different time durations correspond to data that could be obtained by a set of charge transfer (CT) sensors. Similar to the quasi-stationary mode of the CT sensor operation, these charges are also characterized by two quantities having positive and negative increments due to a local change of the layered dielectric parameters. Corresponding transient potentials of two sensory electrodes, fixed on as above-mentioned, give additional information about the layered dielectric under test. In this manner, the Fourier's transform of the transient potentials cross-correlation function provides a qualitative estimate. The both quantitative and qualitative estimates are used for the nondestructive evaluation of multilayered dielectric parameters. The paper concerns to a simulation of this technique.

Model-Based ECT Signal Interpretation and Experimental Verification for the Quantitative Flaw Characterization in Steam Generator Tubes

---S.-J. Song, Y. H. Kim, and E.-L. Kim, School of Mechanical Engineering, Sungkyunkwan University, Suwon, 440-746, Korea; T.-E. Chung, Korea Advanced Inspection Technology, Daejeon, 305-353, Korea; Y. H. Choi, Nuclear Safety Research Department, Korea Institute of Nuclear Safety, 305-338, Korea

---An automated, systematic inversion tools were developed by the novel combination of neural networks and finite element modeling for eddy current flaw characterization in steam generator tubes. Databases with abundant flaw signals from 2-D axisymmetric flaws with tip variation were constructed using finite element models. Sensitive features for flaw classification and sizing were extracted and selected. The inversions of ECT signals were performed by use of two neural networks for flaw classification and sizing. Performances of the developed inversion tools were evaluated with the synthetic ECT signals. Experimental verifications of the developed tools were carried out. The ECT flaw signals from the artificial flaws were acquired using ECT instrument. The phase and magnitude were corrected by comparing experimental and synthetic ECT signal for a through hole. The performances of the inversion of experimental ECT signal were evaluated.

Electric Potential in Eddy Current Testing

---H. Hoshikawa, K. Koyama, M. Maeda, Nihon University, Izumicho Narashino Chiba 275-8575, Japan

---It is well known in eddy current testing that the alternating current in the exciting coil induces eddy current by electromagnetic induction. However, little has been studied about why the eddy current is diverted away from discontinuities in the test material. The authors have studied how eddy current is induced by electromagnetic induction. The study has indicated that electric potential plays a major role in inducing eddy current especially around small discontinuities. 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 inductive electric field. As a result, attention has been concentrated to the eddy current induced by inductive electric field and the role of electric potential has hardly ever been taken into consideration in eddy current testing while 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 an important role in eddy current phenomena. When the exciting coils and test material are not arranged axi-symmetrically, some of the inductive electric field by the exciting current is converted into gradient of the electric potential. The gradient of the potential causes eddy current to flow in different directions from the inductive electric field vector in the area around a discontinuity in the test material. It is the gradient of the electric potential that diverts the eddy current away 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.

Two-Step Algorithm in Calculation of Defect Influenced Eddy Current Field

---V. Lunin and Z. Zhdanov, Moscow Power Engineering Institute (TU), Krasnokazarmennaja 14, Moscow 111250, Russia

---A creation of effective scheme for computing electromagnetic field perturbations due to particular defect in eddy current nondestructive tasks is necessary not only for decreasing computational cost (required solution time and computer memory). It is more important that such effective approaches open new ways for solution of practically interesting but difficult tasks which up to this days were unsolved by means of standard numerical techniques because of extremely expensive computational requirements. For example, such practical task is in predicting eddy current probe signal during an operation of steam generator tube inspection where the diameter of the tube may vary in expansion region of tube sheet, or where the probe signal may be distorted by influence of large massive ferromagnetic components. Presentation of vector potential \mathbf{A} as a sum of two vectors $\mathbf{A} = \mathbf{A}^0 + \mathbf{A}^{def}$ in many cases allows to considerably increase an acceptable accuracy of numerical computations, and at the same time, to decrease computational requirements. It is possible to take into account any kind of simplification for the nondefect field \mathbf{A}^0 calculation, in many cases – to consider cylindrical (or plane) symmetry that are destroyed when the defect is present. The other merit is that for the defect influenced field \mathbf{A}^{def} calculation usually a much smaller discretized region is necessary than for the total field because in the defect field model the source term occupies only a small region in the test sample, and the defect field is localized around this source.

Reconstruction of 3D Flaws in Eddy Current Quantitative Non Destructive Evaluation

---D. Premel, A. Baussard, and J.-M. Decitre, LESIR/SATIE, ENS de Cachan, 61 Avenue du President Wilson, 94235 Cachan, France

---The goal of this paper is to localize and to reconstruct the shape of 3D defects in conductive flat materials. The eddy current probe is constituted by an emitter coil and a receiver auxiliary coil. For several positions of the exiting coil, observed data are collected by scanning the receiver coil above the interest area. The corresponding forward problem is built up by means of the Green's Dyad functions. The resulting two coupled integral equations are discretized by the moment method via the Galerkin's variant. In order to solve the non linear and ill-posed inverse problem, a Bayesian estimation framework has been considered. This approach leads to introduce a priori knowledge on the object to be reconstructed in order to compensate the lack of information due to the pass-band behavior of the forward operator. The a priori knowledge is taken into account by using the Beta prior law and a weak membrane model. By taking the maximum a posteriori probability estimator, the inverse problem is translated like the optimization of the criteria optimized by successive local descent minimizations. Finally, to show the capabilities of the proposed algorithm, some 3D reconstructions from simulated data are presented.

Application of Linearized Inverse Scattering Methods to the Material with Flat Measurement Surface

---K. Nakahata, M. Onishi, and M. Kitahara, Dept. of Civil Engineering, Graduate School of Engineering, Tohoku University, Aoba-yama 06, Sendai 980-8579, Japan

---The linearized inverse scattering methods based on Born and Kirchhoff approximations have been utilized for the shape reconstruction of defects in an elastic solid. A principal operation of these inverse methods is the integration of backscattering amplitudes from defects in the K-space, which consists of the wave numbers and observation angles that enclose the defects. In this study, these inverse methods are applied to the material with a flat measurement surface. In this case, the transducer moves linearly on a side of the object surface and the backscattering waveforms are acquired at restricted access points. Here, a specimen with an interior cavity is prepared and the shape of the cavity is reconstructed from the ultrasonic measurements on one side of the specimen. A key point in this measurement is to extract the scattering amplitudes in elastic solid from measured waveforms. Here, the reference measurements with the same system setting are performed. Then the scattering amplitude can be obtained from the data processing.

Development of Enhanced Ultrasonic Imaging Methods for the Inspection of Water Distribution Pipelines

---H. J. Shin and Y. H. Jang, R&D, Inde System Co., Ltd., Suwon, Kyonggi-do, South Korea; H. D. Lee, P. J. Kwak, and S. K. Kim, Water Resources & Environmental Engineering Division, Korea Institute of Construction Technology, Koyang-si, Kyonggi-do, South Korea

---Recently, ultrasonic imaging technology is rapidly adapted in nondestructive testing and regards signal processing technique for imaging with great interest. On this study, digital signal processing technique for enhanced B-scan image construction is introduced. Dynamic receive focusing is applied for the post signal processing in the construction of the enhanced B-scan image. In using dynamic receiver focusing with single element transducer, ultrasonic beam directivity is considered during the receive beam forming. Therefore, the beam forming enhances signal to noise ratio as well as the resolution and sensitivity. This method is applied to obtain the ultrasonic cross-section images of water distribution pipelines. Simulation and experimental results are presented. For the intuitive identification of wall loss and flaw location, digital scan conversion employed.

Automatic Evaluation of Welded Joints Using Image Processing on Radiographs

---Christophe Schwartz, CEA Valduc, Is Sur Tille, 21120, France

---Radiography is frequently used to detect discontinuities (porosity, cracks, lack of penetration) in welded joints. Perfect knowledge of the geometry of these defects is an important step which is essential for judging the quality of the weld. Because of this, an action improving the interpretation of radiographs by image processing has been undertaken. The principle consists in making a radiograph of the welded joint and of a special penetrameter representing different thickness of the material. The radiograph is then finely digitized and an automatic processing of the radiograph of the penetrameter image allows the establishment of a correspondence between grey levels and material thickness. An algorithm based on image processing is used to localise defects in the welded joints and to isolate them from the original image. First, defects detected by this method are characterised in terms of dimension and equivalent thickness. Then, from the image of the healthy welded joint (that is to say without the detected defects), characteristic values of the weld are evaluated (thickness reduction, width).

New Approaches to Flaw Sizing Using Ultrasonic Testing Models

---Hak-Joon Kim, Sung-Jin Song, and Young H. Kim, School of Mechanical Engineering, Sungkyunkwan University, Suwon, Korea

---Flaw sizing is one of fundamental issues in ultrasonic nondestructive evaluation of various materials, components and structures. Especially, for cracks, accurate sizing is very crucial for reliable structural integrity evaluation. Therefore, robust and reliable flaw sizing methods are strongly needed. This paper will describe an efficient approach for crack sizing to address such a need. In this work, using multi-Gaussian beam, an efficient model to prediction of reflection signal from vertical crack corner is proposed. Based on the proposed model, a new reference curve which describes the variation in the amplitude of reflection signal according to the crack signal will be constructed for the initial estimation of crack size. In addition, with this initial sizing information, the diffraction signal from the upper tip of the crack can be identified very easily from complicated signals which contain large geometrical reflection signals. The accuracy of the proposed approach will be validated by the initial experiments.

3D Modelling of a Magneto-Optic Imager by a Dyadic Green's Functions Approach

---J.-M. Decitre and D. Premel, LESIR/SATIE, ENS de Cachan, 61 av. President Wilson, 94235 Cachan Cedex, France

---The goal of this work is to develop a 3D model for modelling a magneto-optic imager. This step is required in order to solve the full forward problem before implementing any quantitative non destructive evaluation method. The eddy-current excitation is constituted by several 8 cm large thin copper plates placed like a large coil which creates parallel lines of induced currents in a conductive target. An analytical method based on Dyadic Green's functions is proposed to solve the forward problem. The model is tested with a small crack in flat conductive media (length: 8 mm, width: 1 mm, depth: 1 mm). The normal component of the magnetic field is evaluated above the surface of the conductive copper plate, in place of the ferrimagnetic garnet. A comparison between data provided by the model and data calculated by a 3D finite element method is presented. In this paper, theoretical results will be first validated with experimental data obtained by the Magneto-Optic Imager from Physical Research Incorporation (model number 303). In a second step, the normal component is measured by a receiver coil. This study will be carried out for several frequencies.

Digital Ultrasonic Systems and Signal Processing Techniques for Advanced Flaw Detection and Large Area Scanning

---Richard J. Freemantle, NDT Solutions, Ltd., Dunston Innovation Center, Dunston Road, Chesterfield, S41 8NG, United Kingdom

---New ultrasonic systems developed by NDT Solutions are described that utilize digital transmit and receive electronics and advanced signal processing techniques. The focus of our research and development program has been to develop software configurable hardware systems that employ signal processing techniques for filtering, feature extraction and data interpretation. Circuits for digitally controlled arbitrary waveform excitation for specifying the spectral content of pulser sources and performing noise (PRBS) based measurements are described. Recent results showing the application of this technology for Lamb wave excitation and dynamic range improvement on low amplitude signals are presented. Practical examples from the automotive and aerospace industry are used to demonstrate the application of digital signal processing methods to overcome the challenges of interpreting complex ultrasonic signals from multi-layer joints. It is demonstrated that these techniques can perform robust and quantitative measurements that decrease inspection time, allowing the operator to concentrate on probe placement and data logging. Furthermore, processing methods can be used for data reduction of high bandwidth (> 35 Mbyte per second) ultrasonic data streams generated by large area scanning devices. Results are presented which show the practical application of signal processing to C-scans generated by a novel prototype portable scanning system.

Sequential Evaluation of QNDE Devices for Underground Storage Tanks

---Y. Michlin, Technion – Israel Institute of Technology, Quality Assurance and Reliability, Haifa, Israel 32000

---Data were obtained, showing that QNDE devices for tightness testing of underground storage tests require periodic precision checks under maximum reproduction of the field conditions. The peculiar feature of these checks is that the requirements regarding these devices are formulated in terms of the probabilities of distinction between tightness and non-tightness of the tank, and the tests themselves are extremely time-consuming. In the paper, the algorithm for such tests, and the necessary number of measurements, are substantiated. For a fixed sample size, the relevant acceptance interval and the necessary sizes were determined, the latter turning out to be very large. Accordingly, a modified test plan was developed based on the sequential approach, which makes for a reduced sample size. A criterion is also proposed for early termination of the test, thereby reducing the number of measurements based on the fixed-sample condition. The probability distributions of the number of measurements up to a positive/negative serviceability decision – were obtained for the respective cases of non-truncated and truncated tests. These distributions were determined in reference to: (1) the first- and second-kind errors in detecting the specified deviation from the hypothetical value, (2) the actual precision. These dependences permit advance assessment of the scope of the tests and optimization of their parameters in accordance with it.

Development of a Magnetic NDE Imaging System Using Magnetoresistive Sensors

---C. C. H. Lo, J. A. Paulsen and D. C. Jiles, Iowa State University, Center for Nondestructive Evaluation, 1915 Scholl Road, Ames, IA 50011

---A magnetic NDE imaging system has been developed for evaluation of surface mechanical and structural conditions of components using magnetic hysteresis and Barkhausen effect (BE) measurements. The approach is based on the fact that most engineering components exhibit anisotropy in structure (e.g. texture) or stress distribution which induces anisotropy in magnetic properties. By mapping the magnetic properties of a sample it will be possible to infer information on the structural and mechanical conditions of the sample. The sensor probe consists of electromagnets for applying field to a test specimen. To achieve high sensitivity and spatial resolution, integrated magnetic sensor probes have been developed using giant magnetoresistive (GMR) sensors for detecting stray magnetic field and BE signals. When imaging the sensor probe is canned over the test specimen and the sensor output is either amplified to give the stray field signal, or filtered using a band-pass filter to extract the Barkhausen effect signals. This allows the system to be interchangeable between the BE measurements and stray magnetic field imaging for detecting surface defects.---This work was supported by the NSF Industry/University Cooperative Research Program at the CNDE and by the Fall 2001 SPRIGs grant.

Development of Modeling and Simulation for Magnetic Particle Inspection Using Finite Element Method

---J. Y. Lee, S. J. Lee, D. C. Jiles, M. Garton, R. Lopez, and L. Brasche, Center for Aviation Systems Reliability, Iowa State University, Ames, IA 50011

---Magnetic particle inspection (MPI) is a widely used inspection method for aerospace applications with inspection development essentially limited to experimental and experience based approaches. Understanding of the MPI technique and factors that affect sensitivity and reliability would contribute not only reductions in inspection design cost and time but also improvement of analysis of experimental data. We employed the finite element method (FEM) for numerical calculation because this is known to be suitable for complicated geometry such as defects in samples. Magnetic particles are usually soft magnetic materials and sensitive to the magnetic field distribution around them. They are easily attracted toward high magnetic field gradient. Selection of magnetic field source, which produces a magnetic field gradient large enough to detect a weak defect in the sample, is an important factor in magnetic particle inspection. The magnetic field gradient from solenoid, air coil, Maxwell coil, and Helmholtz coil with different configurations are compared. The magnetic flux density, magnetic field gradient, and magnetic force at the sites of defects, which have different shapes and sizes, have been calculated. The results enable us to calculate the required current to generate sufficient magnetic force to cause the wet magnetic particles to adhere to the defects against their gravitational force.---This material is based upon work supported by the Federal Aviation Administration under Contract #DTFA03-98-D-00008, Deliver Order #IA051 and performed at Iowa State University's Center for NDE as part of the Center for Aviation Systems Reliability program.

Application of a Giant Magnetoresistive (GMR) Sensor for Characterization of Corrosion in a Laboratory Specimen

---Ray T. Ko¹ and Mark P. Blodgett, Metals, Ceramics, and NDE Division, Air Force Research Laboratory, Wright-Patterson Air Force Base, Dayton, OH 45433; ¹Structural Integrity Division, University of Dayton Research Institute, 300 College Park Drive, Dayton, OH 45469-0120

---In detecting corrosion deeper than the top layer in a multi-layered aluminum structure, both conventional ultrasonic and eddy current methods have limitations. In the case of ultrasonic testing, the presence of a gap between layers in a multi-layered structure becomes a strong reflector of sound waves and this gap makes the detection in the subsequent layer difficult. In eddy current testing, low frequency is often required to induce currents in thick and highly conductive materials like aluminum alloys. However, use of lower frequencies degrades the sensitivity and the resolution. This presentation describes the use of a solid state magnetic sensor called Giant Magnetoresistive (GMR) sensor to detect thickness variation in a multi-layered specimen. A series of frequency-response and modes-of-operation tests has been carried out to characterize a GMR sensor. The advantages and disadvantages of using the first and second harmonics of the GMR signal for corrosion detection will be discussed. The multi-layered specimen was also used to study the signal-to-noise ratio of the GMR. The proper use of the phase component of the signals for better signal discrimination will be presented.---This work was performed on-site in the Nondestructive Evaluation Branch of the Air Force Research Laboratory (AFRL/MLLP) at WPAFB, Ohio under Air Force contract #F33615-98-C-5217.

Nondestructive Evaluation of Outer Defects in the Welding Part of a Thick Plate of Austenitic Stainless Steel

---Zhenmao Chen, Noritaka Yusa, and Kenzo Miya, International Institute of Universality, 1-3-5 Nezu, Bunkyo-ku, Tokyo, 113-0031, Japan; Akira Tanahashi and Kazuo Sakai, The Kansai Electric Power Co. Inc., 3-3-22, Nakanoshima, Kita-ku, Osaka, 530-8270, Japan

---The Magnetic Flux Leakage Testing (MFLT) is being applied to the NDT of the gas pipelines and other structural components of ferromagnetic material. A drawback of the MFLT is that it is only efficient for a surface breaking defect or an embedded one just beneath the detecting surface. For detecting OD defects in the welding parts of a thick plate of austenitic stainless steel, the conventional MFLT is not efficient as, 1) signal due to the outer defect is small, 2) the irregular shape of the bead surface gives a large noise, and 3) the wave form of the OD signal is in a similar distribution with the signal due to the welding zone. In this paper a method based on the measurements of the residual magnetic field is proposed to overcome these difficulties, which includes ways to reduce bead/liftoff noise and to extract defect information from the measured signals. The most important idea of this method is the introduction of a high frequency demagnetization procedure. By controlling the frequency of the demagnetizer, the magnetization in the measuring side can be removed, which can reduce the bead/liftoff noise significantly. The way to distinguish defect information from the measured signals is the application of an inverse analysis. The performance of the inverse analysis is investigated by processing simulated and measured magnetic field signals. The numerical results show that an OD crack in a plate as thick as 20 mm is possible to be identified with the proposed approach.

Seamless Tubing Process Control by On-Line Laser Ultrasonic Sensing

---Robert V. Kolarik II, Gerald V. Jeskey***, Larry J. Duly, Kenneth J. Samblanet, and Steven E. Agger, The Timken Company, 1835 Dueber Avenue Southwest, Canton, OH 44706; Marc Choquet**, Christian Néron, Christian Padioleau, Daniel Lévesque, Jean-Pierre Monchalain, Industrial Materials Institute, National Research Council of Canada, 75, de Mortagne Boulevard, Boucherville, Québec, J4B 6Y4, Canada; **Now with Tecnar Automation Ltd 1321 Hocquart St-Bruno, Québec J3V 6B5, Canada, ***retired from The Timken Company

---Seamless mechanical steel tubing is used in demanding applications, such as hydraulic cylinders and power transmission components (gears and bearing races) where a weld seam is prohibited. The tube making process begins with heated cylindrical billets that are formed into hollows by cross rolling over a piercing plug. The hollows are elongated into shells by cross rolling over a mandrel bar and formed into the final tube size in a reducing mill. The piercing process can cause wall thickness variations which often follow a helical pattern. The need of a thickness measurement sensor follows not only from the requirement of controlling the wall thickness to specification, but also from the desire for improved process control to increase yield and reduce scrap and rework. Particularly in the case of hollow parts that are machined from tubes, the closer the tube is to optimal dimensions, the larger the savings, derived from reduced machining time and tool wear. For this purpose, a laser-ultrasonic system which uses Nd-YAG lasers for generation and detection has been installed on a production line of The Timken Company and is being used to control the tube making process. In the two-month period since deployment, more than 70,000 tubes have been measured on-line. During the presentation further details of the system will be disclosed, as well as results demonstrating its benefits.---Partially supported by the Department of Energy under Award No. DE-FC07-99ID 13651.

Localization of Dwell Fatigue Cracks in Ti-6242 Alloy Samples

---Stanislav I. Rokhlin, Jin-Yeon Kim, Bin Xie, and Bahman Zoofan, Nondestructive Evaluation Program, The Ohio State University, Edison Joining Technology Center, 1248 Arthur E. Adams Drive, Columbus, OH 43221

---The in-situ surface acoustic wave technique that has been developed for real-time monitoring of crack initiation and evolution is applied during cold dwell fatigue, cyclic fatigue and creep tests of Ti-6242 samples. From these tests the cracks developed in the samples were localized and crack initiation time and growth history assessed. After the tests an ultrasonic immersion scanning method, which we call vertical C-scan (VC-scan), have been applied for localization of initiated fatigue cracks in the sample cross section. In this method ultrasonic focus transducers with center frequencies of 25 and 20 MHz are positioned symmetrically on both sides of the sample. The angular positions of the transmitting and receiving transducers are determined for the ultrasonic beam to be refracted as a shear wave at 45° in the sample, so the ultrasonic wave incident at this angle on the crack which is normal to the sample surface. Scanning is performed in the cross section followed by the transducers vertical move along the sample axis for the cross section scans at different vertical locations. The technique developed can be scaled up for aircraft engine disk inspection. From scanned images together with microradiographic images and ultrasonic data from in-situ measurements, the locations, orientations and sizes of the cracks have been determined. The application of these three techniques together overcomes the technical limitations of each method used separately, and serves as a useful tool for monitoring, localization and sizing fatigue cracks.---This work was performed 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 sponsored by the Federal Aviation Administration (FAA) under contract #97-C-001.

A Study on the Thermal Damage Monitoring of Degraded Materials by Ultrasonic Plate Wave

---Ik Keun Park and Un Su Park, R. I. of NDE Technology, Seoul National University of Technology, 172, Gongneung-dong, Nowon-gu, Seoul, 139-743, Korea; Youn Ho Cho, School of Mechanical and Automotive Engineering, Inje University, 607 Obang-dong, Kimhae, Kyongnam, 621-749, Korea; Joseph L. Rose, Dept. of Engineering Science and Mechanics, The Pennsylvania State University, Earth and Engineering Science Building, University Park, PA 16802

---The feasibility of Lamb waves for monitoring thermally degraded materials is explored. It turns out that the use of Lamb waves can be a promising nondestructive technique for the purpose of microstructure evaluation and material characterization of such materials. This is because Lamb modes can interact with entire area of a plate-like specimen while a conventional point-by-point technique is confined to just local investigation. Consequently, Lamb modes data can show a better sensitivity and provide us with various features for the thermal damage evaluation, compared to ones of the local inspection, which results in the enhancement of experimental reliability. 2.25Cr-1Mo steel specimens for various degradation levels were prepared by the isothermal aging heat treatment at 650 and evaluated by the present technique to investigate the influence of the thermal damage to various guided wave features such as group velocity and attenuation changes.

Dependence of Fatigue Damage and the Perpendicular Residual Leakage Magnetic Flux Density in Austenitic Stainless Steel

---Mohachiro Oka, Department of Computer and Control Engineering, Oita National College of Technology, 1666 Maki, Oita, 870-0152, Japan; Terutoshi Yakushiji, Department of Mechanical Engineering, Oita National College of Technology, 1666 Maki, Oita, 870-0152, Japan; Yuuji Tsuchida and Masato Enokizono, Department of Electric and Electronics Engineering, Faculty of Engineering, Oita University, 700 Dannoharu, Oita, 870-1192, Japan

---It is very important to evaluate fatigue damage of stainless steel such as SUS304 used in structural components to prevent accidents. In order to evaluate the amount of fatigue damage in austenitic stainless steel plates, we are investigating the relationship between plane bending fatigue damage and the perpendicular residual leakage magnetic flux density induced by cyclic plane bending stress. The sample is excited in a constant perpendicular external magnetic field to measure the relationship between the amount of cyclic plane bending fatigue damage and the perpendicular residual leakage magnetic flux density 1 mm above a specimen accurately. It is measured by using a thin-film flux-gate (FG) magnetic sensor. It is considered that the residual leakage magnetic flux density is caused by partial martensitic structure in austenitic stainless steel induced by cyclic bending stress. From our experiments, we could know the relationship between the amount of cyclic plane bending fatigue damage and the perpendicular residual leakage magnetic flux density. In this paper, an advantage in the perpendicular residual leakage magnetic flux density method comparing with our previous method will be shown. Dependence of fatigue damage and the perpendicular residual leakage magnetic flux density above austenitic stainless steel plates will be discussed.

Monitoring Fatigue Damage Accumulation with Rayleigh Wave Harmonic Generation Measurements

---D. J. Barnard, L. J. H. Brasche, and A. D. Degtyar¹, Iowa State University, Center for Nondestructive Evaluation, 1915 Scholl Road, Ames, IA 50011; ¹Pratt and Whitney, 400 Main Street, East Hartford, CT 06033

---The use of nonlinear acoustics, and in particular harmonic generation, continues to gain interest as a means to characterize microstructural changes in engineering materials as a result of processing and in-service conditions. Typical measurements involve the propagation of a monochromatic longitudinal wave toneburst through the bulk of a sample in a through-transmission arrangement. This arrangement is not well suited for field applications, where two sided access is limited and parallel surfaces are rare. Harmonic generation measurements to monitor fatigue damage in aero engine alloys subject to fatigue will be presented. The use of Rayleigh waves has allowed one sided access and accommodates a small amount of surface curvature while restricting the probing wave to the surface where fatigue damage is typically initiated. Early results using uncalibrated receiving transducers on Ni-based alloys demonstrate a sensitivity to damage accumulation in low cycle fatigue, where damage is spread over the sample surface. Damage accumulation in high cycle fatigue is concentrated in small regions on the sample surface and so has not yet been revealed by changes in the generation of harmonics using the uncalibrated probes. Methods for enhancing sensitivity to high cycle fatigue damage are discussed.---This material is based upon work supported by NASA TEST Contract #NAS3-98005, Task Order 21 in cooperation with Pratt & Whitney and performed at Iowa State University's Center for NDE.

Estimation of Degradation of Strength Properties of a Material or Structures Intended for a Long Service Life Using a Combination of Mathematical Models and “Practicable” Measurements

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

---Using non-destructive methods for estimation of degradation of strength properties of a material of structures intended for a long-time operation at high temperatures, in aggressive environments or under radioactive radiation is very important for prediction of the residual safe life of such structures. This is especially important for the cases where the life of the structures is close to the design service limit. The search for such methods is a real challenge, as they are very helpful for solving the problems associated with prevention of accidents and extension of service life. The paper considers a number of approaches based on a combination of mathematical models of degradation of strength properties of structural steels under certain service conditions with practicable measurements of variations in the corresponding physical properties of a material, correlating with the degree of degradation of the strength properties.

NDT Education Resource Center on the Internet

---Brian Larson and Lester Schmerr, Center for NDE, Iowa State University, Ames, IA 50011

---A new Internet site that focuses on NDT Education has been developed by the Collaboration for NDT Education. The site can be visited at www.ndt-ed.org or www.nde-ed.org. The site is intended to serve as an educational resource for students and instructors of college NDT programs, and others with an interest in NDT technology. The site is also being used to promote NDT as a career field to students, teachers and counselors in middle and senior high schools, and to encourage students to study math and science in preparation for careers in high-technology fields, such as NDT. It is hoped that the site will also serve as a resource for information to the NDT community at-large. This paper will highlight some of the features of this new focal point for NDT education on the web.---Support for this work was provided by the National Science Foundation’s Advanced Technology Education (ATE) Program through grant #DUE 101709.

Recent Progress in Undergraduate Vertically Integrated Engineering Design Projects in Nondestructive Evaluation

---D. C. Jiles^{1,2,6}, M. Akinc^{2,6}, S. B. Biner^{2,6}, K. Constant², J. N. Gray³, M. Huba⁴, L. W. Schmerr⁵, and R. B. Thompson^{1,2,5}; ¹Center for Nondestructive Evaluation, ²Department of Materials Science & Engineering; ³Department of Mechanical Engineering; ⁴Department of Educational Leadership and Policy Studies; ⁵Department of Aerospace Engineering and Engineering Mechanics; ⁶Ames Laboratory; Iowa State University, Ames, IA 50011

---The Center for NDE, in collaboration with the Department of Materials Science and Engineering at Iowa State University, is currently incorporate engineering design experience into the undergraduate curriculum through the concept of "vertically integrated design". This experimental 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. In the 2001-2002 academic year we had 18 design projects during the Fall semester with 70 students, and 9 design projects during the Spring semester with 29 students. Projects are selected as long term investigations with lifetimes that extend over several semesters which goes beyond the normal one semester capstone design project. The longer time frame provides continuity to the investigations and allows a more ambitious scope of work to be addressed. We will report of recent experience with his experiment in education. The structure of the course offering in Fall 2001 was modified slightly from last year. Specifically the senior level component was completely devoted to the research project, while the junior and sophomore level course components continued as before with both classroom and project components. This change had been a result of the decision of the faculty on the project that more attention should be devoted to the practical aspects of design and also as a result of the requests from the students in Fall 2000 through surveys and feedback.---This research is supported by the National Science Foundation under grant number EEC-9980331.

Tuesday, July 16, 2002

SESSION 12
ULTRASONIC BACKSCATTER AND ATTENUATION
P. Cawley, Chairperson
FRASER 3

- 3:30 PM** **Simplified Modeling of Backscattered Noise and Attenuation Phenomena for Quantitative Performance Demonstration of UT Methods**
---S. Chatillon, C. Poidevin, N. Gengembre, and A. Lhemery, CEA/LIST, CEA-Saclay, Bat. 611, 91191 Gif-sur-Yvette Cedex, France
- 3:50 PM** **A Formal Approach to Include Multiple Scattering in the Estimation of Ultrasonic Backscattered Signals**
---S. Ahmed, Department of Computer Science, Saint Louis University, St. Louis, MO 63256; R. B. Thompson, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011; P. D. Panetta, Pacific Northwest National Laboratory, Richland, WA 99352
- 4:10 PM** **Computational Study of Grain Scattering Effects in Ultrasonic Measurements**
---A. Li, R. Roberts, F. Margetan, and R. B. Thompson, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011
- 4:30 PM** **Ultrasonic Attenuation as Influenced by Elongated Grains**
---S. Ahmed¹ and R. B. Thompson², ¹Pacific Northwest National Laboratory, Richland, WA 99352; ²Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011
- 4:50 PM** **Ultrasonic Detection of Damage in Heterogeneous Media**
---L. Yang and J. A. Turner, Department of Engineering Mechanics, University of Nebraska-Lincoln, Lincoln, NE 68588
- 5:10 PM** **Advances in Modeling Ultrasonic Noise Induced by Machining Roughness: Validation and Development of Computationally Efficient Approximations**
---R. B. Thompson, Y. Guo, and F. J. Margetan, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

Simplified Modeling of Backscattered Noise and Attenuation Phenomena for Quantitative Performance Demonstration of UT Methods

---Sylvain Chatillon, Clarisse Poidevin, Nicolas Gengembre, and Alain Lhémy, CEA/LIST, CEA-Saclay, bât. 611, 91191 Gif-sur-Yvette cedex, France

---Simulation tools are helpful for conceiving methods of ultrasonic testing, optimizing them and demonstrating their performances. To quantify the sensitivity of ultrasonic NDT methods in materials such as coarse-grained steels, both ultrasonic attenuation and backscattered noise phenomena have to be taken into account. Both effects are due to the same phenomenon that is the scattering of ultrasounds by the micro-structural heterogeneities. Simplified models are proposed to account for experimental observations of these effects. The backscattered noise is modeled assuming randomly distributed scatters. For a given probe position their responses are computed from the knowledge of their location in the ultrasonic beam. The beam is computed using the Champ-Sons software developed at the French Atomic Energy Commission, based on a pencil-matrix method for modeling elastic wave propagation. The attenuation is taken into account along the propagation of pencils by frequency power laws. Dedicated tools of model-based inversion have been developed to estimate from actual experimental results the various parameters to input into the backscattering noise model. In this paper, we present the models and underlying assumptions and approximations. Then, simulated and measured results are compared. Finally, examples of application are given, showing the quantitative importance of these phenomena in performance demonstration.

A Formal Approach to Include Multiple Scattering in the Estimation of Ultrasonic Backscattered Signals

---S. Ahmed and P. D. Panetta, Pacific Northwest National Laboratory, Richland, WA 99352; R. B. Thompson, Iowa State University, Center for NDE, Ames, IA 50011

---An ultrasonic wave propagating through a microscopically inhomogeneous medium, such as polycrystalline materials, is subject to scattering at the grain boundaries. The fraction of energy removed from the incident wave is responsible for important phenomenon like attenuation, dispersion, and background "noise" associated with a given ultrasonic inspection system. Since the backscattered signals tend to mask the signals from small and subtle defects, the estimation of probability of detection of such defects requires quantitative description of these signals. Although considerable attention has been given to the understanding of mean propagation characteristics of an ultrasonic beam, until recently there have been relatively little efforts devoted towards rigorous treatments of backscattered signals. Margetan, Thompson, et al. developed expressions for backscattered power using independent scatterer approximation. More recently, a general formalism based on Auld's electro-mechanical reciprocity relations has been developed by Rose to compute the backscattered power. As this formalism is basically intractable, he proceeded with the calculations using independent scatterer approximation. In this research, we attempt to include some degree of multiple scattering in the calculation of the backscattered signals by developing a formalism that relates mean wave propagation characteristics to this noise. Numerical results for the case of randomly oriented equiaxed cubic grains will be presented.

Computational Study of Grain Scattering Effects in Ultrasonic Measurements

---A. Li, R. Roberts, F. Margetan, and R. B. Thompson, Center for Nondestructive Evaluation, Iowa State University, 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 grain 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. We will report on recent work extending the algorithm to perform time-dependent computations using CNDE's 64 node PC cluster. Results will be presented which offer insight into the origins of experimentally observed forward and backward 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 Engine Titanium Consortium program, through the Airworthiness Assurance Center of Excellence".

Ultrasonic Attenuations as Influenced by Elongated Grains

---S. Ahmed¹ and R. B. Thompson², ¹Pacific Northwest National Laboratory, Richland, WA 99352; ²Iowa State University, Center for Nondestructive Evaluation, Ames, IA 50011

---Reliable nondestructive evaluation of structural/machine components fabricated from polycrystalline materials require the knowledge of attenuation and dispersion of an ultrasonic wave propagating through such microscopically inhomogeneous medium. Isotropic expected propagation characteristics of ultrasonic waves in randomly oriented equiaxed grains are relatively well understood. But when the grains are elongated and/or preferentially oriented, ultrasonic wave propagation constants exhibit anisotropic behavior. The authors have published a number of research articles on propagation of such waves in materials with macroscopic texture and elongated grains. The present paper sheds more light on the effect of grain shape on the attenuation and phase velocity of mean ultrasonic waves through polycrystals with elongated grains. Specifically, results will be presented showing the effects of different grain aspect ratios on the ultrasonic wave characteristics. It will be seen that for the same effective grain volume, grain elongation has smaller effect on attenuation.

Ultrasonic Detection of Damage in Heterogeneous Media

---Liyong Yang and Joseph A. Turner, Department of Engineering Mechanics, University of Nebraska-Lincoln, Lincoln, NE 68588

---The use of ultrasound for detecting material damage from microcracks within a heterogeneous medium is discussed. The ability to detect the damage is dependent on the amount of scattering due to the microcracks relative to the scattering from the heterogeneous background. The damage is modeled in terms of penny-shaped microcracks that are assumed to be randomly oriented and uniformly distributed. Scattering from the heterogeneous microstructure is considered in terms of two types of media: polycrystalline and two-phase. Expressions for attenuation and backscatter coefficient are derived using stochastic wave theory for both the assemblage of microcracks and for the microstructure. Incident longitudinal and shear waves are both considered. Wavespeed changes are shown to be weak indicators of damage. However, attenuation and backscatter are shown to change sufficiently for damage detection. The scattering from the microcracks is assumed independent of the microstructural scattering. Thus, the results are thought to provide a lower bound on damage detectability. The results are applicable to detection of microcracking for various applications including thermal fatigue damage in concrete and mechanical fatigue damage in metals.---Work supported by NSF.

Advances in Modeling Ultrasonic Noise Induced by Machining Roughness: Validation and Development of Computationally Efficient Approximations

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

---In papers given in previous years in this conference, a rigorous solution has been presented and experimentally verified for the 2-D problem of an ultrasonic wave backscattered from a periodically rough surface. While very successful, that theory has the limitation that it is very computationally intensive and that it only can be applied to the problem of planar interfaces. Practical applications, however, call for solutions that can be evaluated more rapidly and that can be generalized to the case in which the interface is curved. Such a theory is presented in this paper. The backscattering problem is formulated as a scattering process in which the strength of the scattering from individual grooves is viewed as an unknown. By summing over all scattering events and comparing to the rigorous solution, these unknown scattering strengths can be determined. In this paper, we present the theory, compare it to the rigorous solution, and use it to make numerical predictions for some practical cases.---This work was supported by the NSF Industry/University Cooperative Research program.

Tuesday, July 16, 2002

SESSION 13
X-RAYS AND APPLICATIONS
R. Green, Chairperson
SMATE 140

- 3:30 PM** **Special Features in Radiography Accessed by 3D Monte Carlo Model**
---G.-R. Tillack and C. Bellon, Federal Institute for Materials Research and Testing (BAM), Division VIII.3, Berlin, Germany
- 3:50 PM** **A Monte Carlo Analysis of the Lead Screen Impact on Film Radiography Image Formation**
---F. Inanc, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011
- 4:10 PM** **New Developments in Virtual X-Ray Imaging: Fast Simulation Using a Deterministic Approach**
---N. Freud and P. Duvauchelle, Laboratoire de Controle Non-Destructif par Rayonnements Ionisants, Institut National des Sciences Appliquees de Lyon, Villeurbanne, France
- 4:30 PM** **Automated Identification of Intergranular Corrosion in X-Ray CT Images**
---P. A. Howell and W. P. Winfree, NASA Langley Research Center, 3 East Taylor Road, Hampton, VA 23681
- 4:50 PM** **Issues with the High Energy Radiography Simulations**
---F. Inanc, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

Special Features in Radiography Accessed by 3D Monte Carlo Model

---Gerd-Ruediger Tillack and Carsten Bellon, Federal Institute for Materials Research and Testing (BAM), Division VIII.3, Berlin, Germany

---Standard radiography simulators are based on the attenuation law complemented by built-up-factors (BUF) to describe the interaction of radiation with material. The assumption of BUF implies that scattered radiation reduces only the contrast in radiographic images but do not image object structures itself. This simplification holds for a wide range of applications like weld inspection as known from practical experience. But only a detailed description of the different underlying interaction mechanisms is capable to explain effects like mottling or others that every radiographer has experienced in practice. The application of the N-particle Monte Carlo code MCNP is capable to handle primary and secondary interaction mechanisms contributing to the image formation process like photon interactions (absorption, incoherent and coherent scattering including electron-binding effects, pair production) and electron interactions (electron tracing including X-Ray fluorescence and Bremsstrahlung production). Additionally it opens up possibilities like the separation of influencing factors and the understanding of the functioning of intensifying screen used in film radiography. The paper intends to discuss the opportunities in applying the Monte Carlo method to investigate special features in radiography in terms of selected examples. It is important to note that the use of Monte Carlo methods is a laboratory type of technique for basic investigations because of the enormous computing power that is needed. For in-field applications such as for inspection planning the simplified models are of much greater importance and increasingly in use.

A Monte Carlo Analysis of the Lead Screen Impact on Film Radiography Image Formation

---F. Inanc, Center for Nondestructive Evaluation, Iowa State University, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

---Sandwiching the radiography film between lead screens is a very common practice in either industrial or medical radiography. The motive behind this practice is to increase the efficiency of the energy deposition into the film. In contrast with the medical radiography, the cases brought into the attention of the industrial radiographers show a large variation and screen-film-screen combination designed for one case can not be the optimum choice for another case. In this work, lead screen impact on the image formation has been analyzed through Monte Carlo computations for a large variety of combinations. General trends that need to be taken into consideration in film-screen designs have been determined.---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.

**New Developments in Virtual X-Ray Imaging:
Fast Simulation Using a Deterministic
Approach**

---N. Freud and P. Duvauchelle, Laboratoire de
Contrôle Non-Destructif par Rayonnements
Ionisants, Institut National des Sciences
Appliquées de Lyon, Villeurbanne, France

---The simulation code named VXI ("Virtual X-ray Imaging") has been considerably improved since the issue of its first version, two years ago. Emphasis was particularly laid on devising faster (dedicated and optimized) ray tracing algorithms. These algorithms are implemented in a portable C++ class library. At present, the computation time needed to simulate a radioscopy image, even with a polychromatic beam, complex sample geometry and high detector resolution, is typically in the range 0.01-10 s, with a simple personal computer (1 GHz microprocessor). This achievement offers new potential for designing and optimizing NDT setups, by using simulation as a virtual experimental workbench. The systematic study of the influence of various experimental parameters (geometric adjustment, photon spectrum, geometric unsharpness) is less and less limited by computation time. Three-dimensional tomography simulation is now easily accessible too. The issue of algorithm speed is even more critical for simulating the contribution of scattered photons in the final image. We have recently developed an algorithm to take into account first-order Rayleigh and Compton scattering, using the same deterministic ray tracing approach. The performance of our code in the case of transmission images as well as preliminary results of the simulation of scattering will be presented.

**Automated Identification of Intergranular
Corrosion in X-ray CT Images**

---P. A. Howell and W. P. Winfree, NASA
Langley Research Center, 3 East Taylor Road,
Hampton, VA 23681

---Characterization of a material or structure by computed tomography results in the acquisition of large quantities of data that need to be tediously examined to determine the location and size of damage. Since the computed tomography images are digital, there is significant potential for reducing the human effort involved in this process by digitally processing this data to enhance the signatures of flaws and perform automated identification of suspected flaws. Toward this goal, this paper presents techniques that enhance the contrast between corroded and uncorroded regions to simplify the analysis and improve quality of flaw identification. Algorithms developed in part for computer vision, such as anisotropic diffusion and edge detection techniques, are applied to the data. Anisotropic diffusion techniques are shown to significantly reduce image noise while maintaining the contrast between intergranular corrosion and uncorroded regions and preserving the important features of the flaw. Edge detection techniques are shown to enable a rapid location of regions requiring further analysis. In regions identified by the edge detection technique, neural network techniques are applied to automate defect detection of the intergranular corrosion.

Issues with the High Energy Radiography Simulations

---F. Inanc, Center for Nondestructive Evaluation, Iowa State University, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

---Although most of the industrial radiography rely on x-ray tubes, there are some cases where either gamma ray sources or linear accelerator sources form the interrogating radiation beam. When the radiation energy levels go above the conventional x-ray tube based radiography ranges, new physics start to accompany radiation absorption, scattering events. Most of these new physics are related to electron transport that is induced by the high-energy photon interactions. Electrons with sufficient energy levels are likely to produce photon radiation through various mechanisms. Radiography simulations for high-energy photons need to account for both photon and electron transport for proper simulation of high-energy photons. This work will outline various physical mechanisms that need to be taken into consideration and challenges that come with designing deterministic algorithms that can handle the mathematics related to these new physical mechanisms.---This manuscript has been authored by Iowa State University of Science and Technology under Contract No. W-7405-ENG-82 with the U. S. Department of Energy. The United States Government retains, and the publisher, by accepting this article for publication, acknowledges that the United States Government retains a non-exclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this manuscript, or allow others to do so, for United States Government purposes.

Tuesday, July 16, 2002

SESSION 14
FLUORESCENT PENETRANT INSPECTION
L. Brasche, Chairperson
SMATE 150

- 3:30 PM** **A Review of Recent Research Studies of Cleaning and Drying in Preparation for Fluorescent Penetrant Inspection**
---L. Brasche, B. Larson, and R. Lopez, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011
- 4:10 PM** **Fluorescent Penetrant Inspection Probability of Detection Demonstrations Performed for Space Propulsion**
---J. A. Lively, Pratt & Whitney, Space Propulsion/Materials & Processes Engineering, P. O. Box 109600, M/S 702-06, West Palm Beach, FL 33410
- 4:30 PM** **Implications of Human Factors Studies of FPI**
---A. L. Broz, FAA Chief Scientist and Technical Advisor for NDE, Burlington, MA 01803-5213

A Review of Recent Research Studies of Cleaning and Drying in Preparation for Fluorescent Penetrant Inspection

---L. Brasche, B. Larson, and R. Lopez, Iowa State University, Center for Nondestructive Evaluation, 1915 Scholl Road, Ames, IA 50011

--- Fluorescent penetrant inspection is the most widely used method for aerospace components such as critical rotating components of gas turbine engines. Successful use of FPI begins with a clean and dry part, followed by a carefully controlled and applied FPI process, and conscientious inspection by well trained personnel. A variety of cleaning methods are in use for cleaning of titanium and nickel parts with selection based on the soils or contamination to be removed. Cleaning methods may include chemical or mechanical methods with sixteen different types studied as part of this program. Low cycle fatigue (LCF) cracks were generated in approximately 40 nickel and 40 titanium samples for evaluation of the various cleaning methods. Baseline measurements were made for each of the samples using a photometer to measure sample brightness and a UVA videomicroscope to capture digital images of the FPI indications. Samples were exposed to various contaminants, cleaned and inspected. Brightness measurements and digital images were also taken to compare to the baseline data. Comparison of the effectiveness of various cleaning methods for the contaminants will be presented. In addition to the assessment of cleaning methods, a comparison oven drying to flash dry in preparation for FPI has been completed. Both the cleaning and drying studies were completed in cooperation with Delta Airlines with the cleaning, drying and FPI processes completed using typical engine overhaul process and equipment. The work was completed as part of the Engine Titanium Consortium and included investigators from Honeywell, General Electric, Pratt & Whitney, and Rolls Royce. Results will be presented from both of these studies in an extended presentation. A preview of the plans from a follow-on activity will also be provided.---This material is based upon work supported by the Federal Aviation Administration under Contract #DTFA03-98-D-00008, Delivery Order #IA029, performed at Iowa State University's Center for NDE, Honeywell, GE and Pratt & Whitney as part of the Engine Titanium Consortium program.

Fluorescent Penetrant Inspection Probability of Detection Demonstrations Performed for Space Propulsion

---J. A. Lively, Pratt & Whitney, Space Propulsion/Materials & Processes Engineering, P. O. Box 109600 M/S 702-06, West Palm Beach, FL 33410

---Fracture critical rocket hardware requires nondestructive testing for flight quality assurance. Fracture critical hardware is defined as hardware with failure modes that may endanger space systems, missions or crew. This hardware includes major housings, disks, impellers and gas path hardware. A number of these components are evaluated with fluorescent penetrant inspection for defects open to the surface. Industry data supports the conclusion that with ultra high sensitivity penetrant, defects > 0.090 inches in length can reliably be detected with a 90/95 probability of detection (POD). To ensure the same POD on fracture critical hardware with reject lengths < 0.090 inches, POD demonstrations are conducted. These demonstrations are conducted on in-house inspectors and on approved external vendor's inspectors. Included in this paper are the results from over 50 of these demonstrations including results from different levels, methods and manufactures of penetrant. The paper also describes the: a) POD specimens used, b) process used, c) different types of penetrant inspection lines tested, d) specimen cleaning, e) analysis of results, f) lessons and conclusions, g) problems encountered.

Implications of Human Factors Studies of FPI

---A. L. Broz, FAA Chief Scientist and Technical Advisor for NDE, Burlington, MA 01803-5213

--- Fluorescent penetrant inspection (FPI) is a widely used inspection technique for surface crack detection in both aircraft and engine components being used for both production qualification and inservice assessment. In a recent survey of airworthiness directives from 1995 – 1999, FPI was the third most frequent inspection called out behind visual and eddy current inspection methods. Because of the important contributions FPI makes to flight safety, the Federal Aviation Administration completed an assessment of the human factors which impact the effectiveness of fluorescent penetrant inspection. Recommendations for improved practices were provided at the conclusion of the study. A summary of results and the recommendations will be presented.

Tuesday, July 16, 2002

SESSION 15
METHODS FOR MATERIALS CHARACTERIZATION
S. Rokhlin, Chairperson
FRASER 4

- 3:30 PM** **Laser-Ultrasonic Characterization of the Annealing Process of Low-Carbon Steel**
---S. Kruger, L. Gille, N. Giguere, G. Lamouche, S. Bolognini, and A. Moreau, Industrial Materials Institute, National Research Council of Canada, 75 de Mortagne Boulevard, Boucherville, Quebec J4B 6Y4 Canada
- 3:50 PM** **Raleigh Angle Ultrasonic Scattering Studies of Chrome-Manganese-Nickel Stainless Steel**
---B. Bridge, Research Centre for Automated and Robotic Non-Destructive Testing, School of Engineering, South Bank University, 103 Borough Road, London SE1 0AA, United Kingdom
- 4:10 PM** **Ultrasonic Absorption in Ultra-Low Carbon Steel Using the Laser-Ultrasonic Reverberant Technique**
---S. Bolognini and A. Moreau, Industrial Materials Institute, National Research Council of Canada, 75 de Mortagne Boulevard, Boucherville, Quebec, Canada
- 4:30 PM** **Identification of Sintered Irons with Ultrasonic Nonlinearity**
---Y. Ohara, K. Kawashima, and M. Murase, Department of Mechanical Engineering, Nagoya Institute of Technology, Nagoya 466-8555, Japan; N. Hirose, Mechanical Engineering, Tokyo Metropolitan College of Aeronautical Engineering, Tokyo, Japan
- 4:50 PM** **Depth Profiling of Machined Surfaces Using Cross Correlation of Barkhausen Noise Butterfly Curves**
---H. Roesner and N. Meyendorf, Center for Materials Diagnostics, University of Dayton, 300 College Park, Dayton, OH 45469-0121

Laser-Ultrasonic Characterization of the Annealing Process of Low-Carbon Steel

---S. Kruger, L. Gille, N. Giguère, G. Lamouche, S. Bolognini, and A. Moreau, Industrial Materials Institute, National Research Council of Canada, 75 de Mortagne Blvd., Boucherville, Quebec, J4B 6Y4, Canada

---Laser-ultrasonic measurements are performed during the annealing of full hard low carbon steel at temperatures between 570°C and 630°C. During annealing, the ultrasound velocity behaves in a peculiar way, first decreasing and then increasing to a final value. The final velocity increases with the annealing temperature. The velocity variation is interpreted as resulting from two competing mechanisms: magneto-elastic effects and texture variations. The presence of magneto-elastic phenomena is supported by ultrasound absorption measurements performed with the reverberation technique as a function of temperature and applied magnetic field. Metallographic measurements of the recrystallized fraction and hardness measurements are also presented to help the interpretation of the measurement. This work shows that laser ultrasonics is a promising tool for the characterization of the annealing process of low-carbon steel.

Raleigh Angle Ultrasonic Scattering Studies of Chrome -Manganese-Nickel Stainless Steel

---B. Bridge, Research Centre for Automated and Robotic Non-Destructive Testing, School of Engineering, South Bank University, 103 Borough Road, London SE1 OAA

---A Chrome- Manganese Nickel stainless steel, widely used for armor plating was subjected to a wide variety of annealing temperatures and cooling rates. This produced grain sizes varying over two orders of magnitude without any phase change so that grain size was the main variable affecting ultrasonic scattering. The lack of phase changes in this steel make it an ideal material for investigating geometrical effects in ultrasonic scattering. In fact grain sizes were ultrasonically measured to a precision of a few % over a size range of a few hundred % by monitoring the amplitude of 5MHz compressional waves scattered at the Rayleigh Angle from the surfaces of water-immersed samples. A simple quantitative model relating the Rayleigh Angle scatter amplitude to local attenuation levels near the sample surface is presented

Ultrasonic Absorption in Ultra-Low Carbon Steel Using the Laser-Ultrasonic Reverberant Technique

---Stephane Bolognini and A. Moreau, Industrial Materials Institute, National Research Council Canada, Boucherville, Quebec, Canada

---Ultrasonic absorption in the 2 to 45 MHz frequency range in ultra-low carbon steel is measured using the laser-ultrasonic reverberant technique. This technique, being contactless, allows measurements of samples in an electromagnet (at room temperature) or in a high temperature furnace (20 – 1200 aC). At room temperature, two main contributions to the ultrasonic absorption are identified: a magnetoelastic contribution due to microeddy currents and a deformation contribution caused by dislocations. A typical microeddy current peak is observed and yields a reasonable estimate of the magnetic domain size. The non-magnetic contribution to the total absorption follows the classical vibrating string model with the addition of an independent strain-amplitude damping background below 10 MHz. At high temperatures but below the Curie temperature, the magnetoelastic contributions dominate the overall absorption. Two internal friction peaks are also detected. The first one, at 100C and 10 MHz, is related to the dislocation kink motion. The second one, measured at 330C and 10 MHz, is attributed to the Snoek relaxation of carbon and/or nitrogen. It is also observed that the Curie transition, as well as the ferrite-austenite transition, strongly affect the internal friction spectra.

Identification of Sintered Irons with Ultrasonic Nonlinearity

---Y. Ohara, K. Kawashima, and M. Murase, Department of Mechanical Engineering, Nagoya Institute of Technology, Nagoya, 466-8555, Japan; N. Hirose, Mechanical Engineering, Tokyo Metropolitan College of Aeronautical Engineering, Tokyo, Japan

---Two kinds of sinters made from reduced and atomized iron powders were identified by nonlinear acoustic measurement using PZT contact transducers of 5 and 10 MHz. Sintered irons contain micro gaps of which openings are comparable to the incident wave amplitude, therefore the gap clapping, i.e., closure by compressive wave and gap opening by tensile wave, results in nonlinear response of transmitted longitudinal wave. To evaluate this nonlinear response quantitatively, the ratio of the second harmonic wave amplitude to the fundamental one is measured using a super heterodyne detection technique. For two kinds of sinters of the same porosity, the identification of the powder which is impossible by wave velocity measurement is possible by the ratio. This difference is explained by that the sinter of reduced iron powders contains more micro gaps suitable for harmonic generation than the sinter of atomized one in spite of the same porosity. Thus, the nonlinear acoustic measurement can identify the kinds of sintered iron which is impossible by the wave velocity measurement.

**Depth Profiling of Machined Surfaces Using
Cross Correlation of Barkhausen Noise
Butterfly Curves**

---H. Roesner and N. Meyendorf, Center for
Materials Diagnostics, University of Dayton, 300
College Park, Dayton, OH 45469-0121

---Barkhausen noise technique was used to
characterize machined surfaces of small
diameter tensile specimens. The Barkhausen
noise butterfly curves measured for specimens
with different surface finishing (grinding, lathe
working) at several different analyzing
frequencies were compared to those obtained
on electro-polished specimens. Microstructure
modifications at the surface by machining are
the reason for a complex structure of the
butterfly curves, especially those achieved at
high analyzing frequencies. A new analyzing
technique was developed. It is based on cross
correlation of a Barkhausen noise butterfly curve
with a curve of a reference material. Depth
profiling results achieved by this method showed
excellent agreement to x-ray diffraction
measurements. Additionally, a new
magnetization technique by an electrical current
enabled a very sensitive imaging of the entire
specimen surface by Barkhausen microscopy.

Wednesday, July 17, 2002

SESSION 16
UT MODELING
N. Saffari, Chairperson
FRASER 3

- 8:30 AM** **Modeling of the Ultrasonic Response of Inclusions in Steels**
---M. Darmon and P. Calmon, CEA/LIST, French Atomic Energy Commission, CEA Saclay Bat. 611, 91191 Gif-sur-Yvette, Cedex, France; B. Bele, MC, IRSID, Voie Romaine BP 30320, 57283 Maizieres-les-Metz, Cedex, France
- 8:50 AM** **A Multilevel Multipole Method for Modelling Elastic-Wave Multiple Scattering in Fiber-Reinforced Composites**
---A. Lange¹, A. Harker², and N. Saffari¹, ¹Department of Mechanical Engineering, University College London, London, United Kingdom; ²Department of Physics and Astronomy, University College London, London, United Kingdom
- 9:10 AM** **A Coupling Method of BEM and Generalized Ray Theory for Elastic Wave Scattering in a Thick Plate**
---K. Kimoto and S. Hirose, Department of Mechanical and Environmental Informatics, Tokyo Institute of Technology, West 8 Building, Room W301, 2-12-1, O-okayama, Meguro-ku, Tokyo 152-8552, Japan
- 9:30 AM** **Scattering by a Rough Crack Edge**
---V. A. Borovikov, Benemerita Universidad Autonoma de Puebla, Facultad de Ciencias Fisico Matematicas (BUAP), Mexico; L. Fradkin, Center for Waves and Fields, School of Engineering, South Bank University, London, United Kingdom
- 9:50 AM** **A Theoretical Model for the Ultrasonic Detection of Surface-Breaking Cracks with the Scanning Laser-Source Technique**
---I. Arias and J. D. Achenbach, Center for Quality Engineering and Failure Prevention, Northwestern University, Evanston, IL 60208-3020
- 10:10 AM** **Coffee Break**
- 10:30 AM** **Scattering of Elastic Waves by a Rectangular Crack in a Thick-Walled Anisotropic Solid**
---A. Bostrom, T. Grahn, and A. J. Niklasson, Department of Applied Mechanics, Chalmers University of Technology, SE-412 96 Goteborg, Sweden
- 10:50 AM** **Diffraction Coefficients for Tilted Surface-Breaking Cracks**
---V. Kamotski and V. M. Babich, St. Petersburg Branch, S. Mathematics Institute, St. Petersburg, Russia; V. A. Borovikov, Benemerita Universidad de Puebla, Facultad de Ciencias Fisico Matematicas, Mexico; B. A. Samokish, Mathematics Department, St. Petersburg University, St. Petersburg, Russia; L. J. Fradkin, School of Engineering, South Bank University, London, United Kingdom
- 11:10 AM** **An Extension of the Spring Model to Nonlinear Interfaces**
---C. Pecorari, Marcus Wallenberg Laboratory, Department of Vehicle Engineering, Royal Institute of Technology, 100 44 Stockholm, Sweden
- 11:30 AM** **Scattering of Ultrasonic Guided Waves in Partly Embedded Cylindrical Structures**
---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
- 11:50 AM** **Waves in Anisotropic Elastic Media**
---E. L. Roetman, MathMechanics, 3016 67th Avenue S.E., Mercer Island, WA 98040-2427
- 12:10 PM** **Lunch**

Modeling of the Ultrasonic Response of Inclusions in Steels

---Michel Darmon and Pierre Calmon, CEA/LIST, French Atomic Energy Commission, CEA Saclay Bât 611, 91191 Gif-sur-Yvette cedex, France; Bertrand Bèle, MC, IRSID, Voie Romaine BP 30320, 57283 Maizières-les-Metz Cedex, France

---Detection and characterization of inclusions are an important issue in steel industry. The inclusion harmfulness depends on several factors : composition, shape, size, position in the product. The ultrasonic response of these flaws is difficult to interpret and modeling can be very helpful to improve methods of inspection and analysis. We present a modeling study performed in this aim and based on the application of low frequency approximations. The Born and the extended quasistatic approximations have been evaluated and then modified to improve their accuracy in our domain of application. The added hypothesis takes into account both density and wave velocity differences between the host medium and the inclusion. The modified Born approximation, allowing to deal with various inclusion shapes, shows a satisfactory reliability for solid spherical inclusions by comparison with Ying and Truell's exact analytical solution. The approximate and the exact models have been implemented in the CIVA software platform. This integration allows the connection of the inclusion-wave interaction model to the transducer field computation available in CIVA, and therefore the simulation of a real inspection. In parallel, measurements have been carried out upon both natural and artificial cylindrical alumina inclusions. They show a good agreement with the models.

A Multilevel Multipole Method for Modelling Elastic-Wave Multiple Scattering in Fiber-Reinforced Composites

---A. Lange¹, A. Harker², and N. Saffari¹,
¹Department of Mechanical Engineering, University College London, London, United Kingdom; ²Department of Physics and Astronomy, University College London, London, United Kingdom

---In the effort to model large-scale scattering problems, analytical methods based on multipole expansions have been extensively developed and used as a substitute or a complement to numerical methods. Multilevel multipole methods have been originally developed to solve problems of particle interactions quicker. As an example, using the multilevel technique reduces the complexity of a multipole method from $O(N^2)$ to $O(N)$ for solving a 2D multiple scattering problem with N scatterers. However, such a reduction is possible only if the truncation orders in the multipole expansions are small compared to N . But too small truncation orders may also result in poor accuracy for the solution. Thus, a good estimate of the truncation error is necessary in order to verify if a given problem may be solved efficiently via multipole methods. A rigorous truncation error analysis is presented for the first time for Graf's series i.e. the addition theorem for cylindrical Bessel functions. It is the key analytical tool for multipole methods in linear acoustic and/or elastic-wave scattering problems. As an application, the elastic-wave multiple scattering problem associated with a bounded Titanium Metal-Matrix Composite region that may contain several defects is considered. The scatterers are unidirectional Silicon Carbide circular cylinders plus stress-free defects embedded around or inside the composite region. Large-scale 2D problems involving thousands of scatterers are solved using a multilevel multipole method for both SH and P/SV waves. The ability of the method to provide detailed information on the dependence of the scattered field on the composite structure is discussed.

A Coupling Method of BEM and Generalized Ray Theory for Elastic Wave Scattering in a Thick Plate

---K. Kimoto and S. Hirose, Department of Mechanical and Environmental Informatics, Tokyo Institute of Technology, West 8 Bldg. Room W301, 2-12-1, O-okayama, Meguro-ku, Tokyo 152-8552, Japan

---A coupling method of Generalized Ray Theory (GRT) and the Boundary Element Method (BEM) is developed for simulations of ultrasonic testing of a thick plate. The two methods are coupled to reduce computational cost for scattering analysis by the BEM, which is otherwise intractable in many practical problems. For analyses of wave guides, a normal mode expansion technique is more popular than the GRT. However, the latter is used because interpreting wave field in a plate in terms of rays is essential for flaw detection and characterization by bulk or surface waves. In the present method, the free field due to a normal surface load is calculated by the GRT while the scattered field on the surface of arbitrarily shaped scatterer by the BEM. Given the fields on the scatterer, they are continued to a receiver point by the GRT. Since the scattered field is small perturbation to the free field, considerably small number of boundary elements is needed in our method to achieve desired accuracy. Hence an efficient method can be developed. As a numerical example, scattering problem by a small cavity in a plate is solved and the results are shown as transient motions and radiation pattern at receiver points on the plate surface. Since decomposition of the total field to those of corresponding rays is very easy with our method, the numerical results are shown for respective rays.

Scattering by a Rough Crack Edge

---V. A. Borovikov, Benemerita Universidad Autonoma de Puebla, Facultad de Ciencias Fisico Matematicas (BUAP), Mexico; Larissa Fradkin, Center for Waves and Fields, School of Engineering, South Bank University, London, United Kingdom

---We describe statistical properties of an ultrasonic field scattered from a rough crack edge assuming that the statistics of the rough crack edge are known. We assume that the crack surface is a polyhedron and the crack edge is a polygonal line with the following properties: Length of each segment is no smaller than a few wavelengths. Each segment is so small that the incident field may be approximated by a plane wave and that the transducer may be assumed to lie in the far-field of each segment. The rough edge is close to a smooth non-perturbed crack edge whose radii of curvature are far larger than the lengths of edge segments. As the result, we obtain approximate analytical expressions for the mean and variance of the diffracted field. We use the Monte Carlo method for simulating different realizations of the crack edge to verify the result.

A Theoretical Model for the Ultrasonic Detection of Surface-Breaking Cracks with the Scanning Laser-Source Technique

---Irene Arias and Jan D. Achenbach, Center for Quality Engineering and Failure Prevention, Northwestern University, Evanston, IL 60208-3020

---A theoretical model for a novel non-destructive technique for the detection of small surface-breaking cracks using laser-generated ultrasound ? the Scanning Laser Source technique ? is presented. This technique does not monitor the interaction of a well-established ultrasonic surface wave with a flaw, but rather monitors the changes in the generated ultrasonic signal as the laser source passes over a defect. The cracked test specimen is modeled as an isotropic, homogeneous, linearly elastic half-space with a two-dimensional surface-breaking crack, which is perpendicular both to the direction of scanning and the free surface of the half-space. The ultrasonic response of the cracked half-space to a pulsed laser line source operating in the thermoelastic regime is decomposed, by virtue of linear superposition, into the incident and the scattered fields, which can be obtained consecutively. The incident field is generated by the line laser heat source in the uncracked half-space. The corresponding thermoelastic problem is solved semi-analytically. Since the laser source is swept across the test specimen, and therefore passes over the flaw, an accurate description of the field both far and near the source is required. While the far field can be well approximated from equivalent elastic sources, the thermal effects from the generation process are needed for the near field and therefore have to be taken into account in the formulation. The scattered field in the cracked half-space is obtained by a direct frequency domain boundary element method. Results for both the incident and the scattered fields will be presented.

Scattering of Elastic Waves by a Rectangular Crack in a Thick-Walled Anisotropic Solid

---Anders Bostrom, Tomas Grahn, and A. Jonas Niklasson, Department of Applied Mechanics, Chalmers University of Technology, SE-412 96 Goteborg, Sweden

---The scattering of elastic waves by a rectangular crack in a half-space of arbitrary anisotropy is considered. The application in mind is ultrasonic testing of a thick-walled anisotropic component where the crack is close to a planar back surface. The orientation of the crack and the back surface may be arbitrary relative the anisotropy. The scattering problem is formulated as a hyper-singular integral equation for the crack-opening-displacement (COD) by means of the half-space Green's tensor. The integral equation is solved by expanding the COD in a double series of Chebyshev functions with the correct behavior along the crack's edges. Projection onto the same set of functions results in a linear system of equations for the COD's expansion coefficients. The transmitting transducer is modeled by the traction beneath it on the scanning surface and the incident field may then be calculated. An electromechanical reciprocity relation is used to model the receiving transducer. Numerical examples are included which show the influence of the anisotropy and especially the presence of the close back surface.

Diffraction Coefficients for Tilted Surface-Breaking Cracks

---V. Kamotski and V. M. Babich, St. Petersburg Branch, S. Mathematics Institute, St. Petersburg, Russia; V. A. Borovikov, Benemerita Universidad de Puebla, Facultad de Ciencias Fisico Matematicas, Mexico; B. A. Samokish, Mathematics Department, St. Petersburg University, St. Petersburg, Russia; L. J. Fradkin, School of Engineering, South Bank University, London, United Kingdom

---The Geometrical Theory of Diffraction (GTD) is a powerful means of modelling the ultrasonic inspection of smooth cracks in ferritic steel when misoriented away from the direction of specular reflection to the incident ultrasonic beam. Theoretically computed "diffraction coefficients" are used to quantify the amplitudes of the echoes diffracted from the tips or edges of such misoriented cracks. 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. We have adopted the Sommerfeld-Malyuzhinets-Budaev approach to this problem and have developed a complete user-friendly code which appears to be successful when calculating the diffraction coefficients for the wedges with wedge angles between 40 and 170 degrees and a plane incident wave, whether compressional or shear. The code has undergone several stringent verification tests. We have also validated it for the case of the Rayleigh wave incidence by comparing our reflection and transmission coefficients against experimental and numerical data.---The project was sponsored by the Industry Management Committee of the UK Nuclear Licensees under the IMC Contract PG/GNSR/5129.

An Extension of the Spring Model to Nonlinear Interfaces

---Claudio Pecorari, Marcus Wallenberg Laboratory, Department of Vehicle Engineering, Royal Institute of Technology, 100 44 Stockholm, Sweden

---This paper presents preliminary results of an investigation on the limit within which nonlinear scattering of ultrasonic waves can be used to detect and characterize partially closed cracks and imperfect interfaces. In particular, this work examines an extension of the well-known spring model for boundary conditions, which are often used in modeling interface scattering problems. The terms introduced to describe the nonlinear behavior of the interface are derived from the micromechanics of two rough surfaces in contact. A simple perturbation approach is used to solve the boundary value problem by assuming the nonlinear terms to be much smaller than the linear contributions. To the leading order of the field expansion in power series of the perturbation parameter, two of the three nonlinear mechanisms considered are shown to generate second harmonics only. The third mechanism, which is hysteretic in nature, generates a cascade of odd harmonics with amplitude decreasing with their order. Numerical examples are presented both for normal and oblique incidence, and their relevance to detection and characterization of partially closed cracks discussed.

Scattering of Ultrasonic Guided Waves in Partly Embedded Cylindrical Structures

---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

--- At the QNDE 2000 meeting, a cure monitoring technique for epoxy resins based on ultrasonic guided waves in wires was presented. The technique measures the guided wave reflection that occurs at the point where the waveguide enters the epoxy resin. It was initially developed for cure monitoring, but can also be used as a sensor for the measurement of material properties in general. For these purposes, modelling tools are needed to evaluate the relationship between the material properties of the embedding medium and the reflection coefficient for a given guided wave system. Information about the magnitude of this entry reflection is also useful in many other practical applications of guided waves, especially in the development stages of a guided wave technique. Examples are the use of waveguides as liquid level sensors and the inspection of partly buried pipes. Finite Element (FE) analysis presents a powerful tool, but the computational analysis can be tedious. In an alternative approach, the reflection coefficient can be calculated using a modal analysis. This is much more efficient than FE, particularly in cases where a small element size and time step is required due to low velocities in the embedding material. The theoretical foundation of this method and its numerical implementation are presented. Examples are given for the lowest order longitudinal mode in bars which are partly embedded in epoxy resin and validated against FE modelling, the agreement being very good. In this context, the role of non-propagating and inhomogeneous waveguide modes in the scattering process is discussed.

Waves in Anisotropic Elastic Media

---E. L. Roetman, MathMechanics, 3016 67th Avenue, S. E., Mercer Island, WA 98040-2427

---The propagation of plane waves of infinitesimal amplitude in an isotropic material is determined by solving the linear second order Navier equations for the displacements. The potential methods that are traditionally used decompose the displacement field into a scalar potential term and a vector potential term, which thereby decompose the vector dynamical system into uncoupled systems for the individual fields. The disadvantages include the fact that there is no obvious path to non-linear problems, there is difficulty applying some boundary conditions, and it is very difficult to analyze an an-isotropic problem by using the method of potentials as the an-isotropic system does not uncouple in any reasonable way. Reformulation of the problem to that of a system of first-order partial differential equations suggests that the above objections can be mitigated. The development of the first order system is reviewed and several preliminary results are presented for isotropic materials that suggest that the approach will extend in a reasonable way to analysis of more general materials. Here the dynamical equations are attacked directly with a unified mathematical approach without the employment of potentials. The propagating fields are expressed as a sum of characteristic propagation modes determined as eigenvectors of an expanded acoustic matrix. This gives a representation of the propagation modes that include the stress terms as well as the displacements for each mode. The reflection and refraction coefficients are determined using the representations and their coupling at the boundary. Boundary projection operators are determined for several distinct conditions. The classic Frennel coefficients are recovered as particular examples within a more general theory. Isotropic and an-isotropic examples are given to illustrate the methods.

Wednesday, July 17, 2002

SESSION 17
INVERSION AND IMAGING
P. Nagy, Chairperson
SMATE 140

- 8:30 AM** **Estimation of Flaws' Geometrical Parameters with a Heat Method**
---A. G. Protasov and V. M. Sineglazov, Department of Nondestructive Testing, National Technical University of Ukraine, Kyiv, Ukraine
- 8:50 AM** **A Tomographic Approach to Thermal Imaging**
---R. A. Kline, San Diego Center for Materials Research, San Diego State University, San Diego, CA; W. P. Winfree, NASA Langley Research Center, Hampton, VA
- 9:10 AM** **Three Dimensional Born and Kirchhoff Inversions for Shape Reconstruction of Defects**
---M. Yamada, K. Murakami, K. Nakahata, and M. Kitahara, Department of Civil Engineering, Graduate School of Engineering, Tohoku University, Sendai, Japan
- 9:30 AM** **Defect Determination Using Waveform Data Obtained with Laser Measurements**
---H. Yoshikawa, Department of Global Environment Engineering, Kyoto University, Kyoto, Japan; N. Nishimura, Department of Civil Engineering, Kyoto University, Kyoto, Japan; S. Kobayashi, Department of Construction Engineering, Fukui University of Technology, Fukui, Japan
- 9:50 AM** **Ultrasonic Tomographic Imaging of Air Flow in Pipes Using an Electrostatic Transducer Array**
---I. J. O'Sullivan and W. M. D. Wright, Department of Electric and Electronic Engineering, University College Cork, National University of Ireland – Cork, Cork, Ireland
- 10:10 AM** **Coffee Break**
- 10:30 AM** **Visualization of Surface-Breaking Tight Cracks by Laser-Ultrasonic SAFT**
---M. Ochiai and A. Fukumoto, Power and Industrial Systems R&D Centre, Toshiba Corporation, Yokohama, Japan; D. Levesque, R. Talbot, A. Blouin, and J.-P. Monchalain, Industrial Materials Institute, National Research Council of Canada, Boucherville, Quebec, Canada
- 10:50 AM** **Application of Optimization Methods to Crack Profile Inversion Using Eddy Current Data**
---J. Bowler, Z. Wei, and A. Dogandzic, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011
- 11:10 AM** **Optimization of Test Parameters for Magneto-Optic Imaging Using Taguchi Method**
---Z. Zeng, L. Xuan, W. Shih¹, G. Fitzpatrick¹, L. Udpa, and S. Udpa, Material Assessment Research Group, Department of Electrical and Computer Engineering, Iowa State University, Ames, IA 50011; ¹PRI Research and Development Corporation, 25500 Hawthorne Boulevard, #2300, Torrance, CA 90505
- 11:30 AM** **The Influence of Slot Defect Length to Magnetic Flux Leakage**
---H. Songling, L. Luming, Y. Haiqing, and W. Laifu, Tsinghua University, Department of Mechanical Engineering, Beijing 100084, P.R. China
- 11:50 AM** **Groove Sizing Using a Robust Neural Network Approach**
---L. Le Brusquet, M.-E. Davoust, and G. Fleury, Service des Mesures, Ecole Superieure d'Electricite, Plateau de Moulon, 3 Rue Joliot Curie, 91192 Gif-sur-Yvette, France
- 12:10 PM** **Lunch**

Estimation of Flaws' Geometrical Parameters with a Heat Method

---Anatoliy G. Protasov and Viktor M. Sineglazov, Department of Nondestructive Testing, National Technical University of Ukraine, Kyiv, Ukraine

---In this paper the solution is developed to a problem of estimation of flaws' parameters using surface temperature measurement (the thermal NDT method). The basic criterion flaw presence is temperature difference on a sample's surface above a flaw. The object of the control is a flat sample with a cavity, which has different thermal characteristics from the basic material. The process of heating is described by the two-dimension non-stationary equation of a heat conduction inside a sample and cavity of the flaw. There is a condition of thermal interface on the border of the sample and cavity. On the front surface of the sample acts as a source of heat. The other surfaces are in free heat exchange with an environment under Newton's law. The sample is in thermodynamic balance with the environment at the initial phase of the experiment. The problem has been realized in two stages. At the first stage, it has been estimated relationship between temperature difference of a heated sample's surface and geometrical parameters of the flaw. For this purpose we have solved a direct heat conduction problem for various combination of the geometrical sizes of the flaw. At the second stage, we have solved an inverse heat conduction problem using the H - infinity method of identification. The results have shown good convergence to real parameters.

A Tomographic Approach to Thermal Imaging

---R. A. Kline, San Diego Center for Materials Research, San Diego State University, San Diego, CA; W. P. Winfree, NASA Langley Research Center, Hampton, VA

---Thermal imaging is an attractive NDE technique as it is rapid, inexpensive and most importantly has a wide coverage area with a single experimental measurement. The principal goal of this research effort is improved flaw definition and material property characterization capability through advanced image processing. Here, tomographic analysis of thermal data is used to achieve this goal. In this research program, a diffusion based approach to thermal tomographic imaging is described. The approach is based on the use of a forward heat transfer code and a modified algebraic reconstruction technique (ART) for the reconstruction process. Results from a variety of different experimental configurations using synthetic data will be presented to illustrate the potential of this approach.

Three Dimensional Born and Kirchhoff Inversions for Shape Reconstruction of Defects

---Masaki Yamada, Kenji Murakami, Kazuyuki Nakahata, and Michihiro Kitahara, Department of Civil Engineering, Graduate School of Engineering, Tohoku University, Sendai, Japan

---The 3D linearized inverse scattering methods are used to reconstruct the 3D defect. The linearized inverse scattering methods are based on the Born and Kirchhoff approximations for unknown displacements in the integral representations of the scattered waves. From these approximations, the scattering amplitudes reduce to the Fourier transforms of the characteristic functions in the K-space that consists of the wavenumber and observation direction. The characteristic functions that represent the defect geometry can be reconstructed from the inverse Fourier transformation by measuring the scattered amplitudes in the K-space. In this study, the specimen that has a 3D defect model is prepared and the scattered amplitudes are measured experimentally. The measured scattering amplitudes are fed into the form of the inverse Fourier transform and the characteristic functions are obtained. The versatilities of the methods are discussed from characteristic viewpoints of Born and Kirchhoff inversions.

Defect Determination Using Waveform Data Obtained with Laser Measurements

---H. Yoshikawa, Department of Global Environment Engineering, Kyoto University, Kyoto, Japan; N. Nishimura, Department of Civil Engineering, Kyoto University, Kyoto, Japan; S. Kobayashi, Department of Construction Engineering, Fukui University of Technology, Fukui, Japan

---We consider an inverse problem of determining the shape of an unknown defect in a structure by illuminating the defect by an incident wave having a known wave form and measuring the scattered wave from the defect measured as a function of time. Inverse problems of this type have been investigated theoretically by several researchers, but inversions using real data obtained from ultrasonic transducers have seldom been investigated. This is because both the generation and measurement of ultrasounds are usually made by ultrasonic transducers, in reality, but the output of ultrasonic transducers has not been related to physical quantities in a quantitative manner. In view of this, we may use a laser interferometer to measure the ultrasound. However, the incident waves still remain to be determined. We therefore consider an inverse problem of determining the elastic wave produced by an ultrasonic transducer from laser velocimetry data. The quality of the inversion is tested via a comparison between simulation results obtained with a 3 dimensional time domain elastodynamic BIEM (boundary integral equation method) and experimental data. The agreements of these results are seen to be quite satisfactory. Also, we show that our method can determine the size of a simple defect with high accuracy.

Ultrasonic Tomographic Imaging of Air Flow in Pipes Using an Electrostatic Transducer Array

---I. J. O'Sullivan and W. M. D. Wright, Department of Electrical and Electronic Engineering, University College Cork, National University of Ireland – Cork, Cork, Ireland

---Ultrasonic tomographic imaging of gas properties has received little attention, due to the lack until recently of suitable ultrasonic transducers that operate effectively in gases. In this work, a circular array of prototype divergent electrostatic ultrasonic transducers was constructed, and incorporated into a 100mm diameter test pipe through which air flow rates of up to 18m/s could be achieved. Various bluff bodies were placed in the pipe upstream of the transducer array, and cross sectional images of the resulting disturbances at different flow rates were reconstructed from ultrasonic time-of-flight data using a filtered back-projection algorithm, based on a fan-beam geometry. The air flow through the array was modelled using the computational fluid dynamics software package FLOTRAN. The images reconstructed from the ultrasonic tomographic data were found to be in good agreement with the FLOTRAN models.

Visualization of Surface-Breaking Tight Cracks by Laser-Ultrasonic SAFT

---M. Ochiai and A. Fukumoto, Power and Industrial Systems R&D Centre, Toshiba Corporation, Yokohama, Kanagawa, Japan; D. Lévesque, R. Talbot, A. Blouin, J.-P. Monchalain, Industrial Materials Institute, National Research Council of Canada, Boucherville, Quebec, Canada

---A new method to obtain a detailed image of surface-breaking tight cracks on a metallic material by using laser-ultrasonics is proposed. The surface opposite to the cracking surface of a plate-like sample is scanned by nearly superimposed spots of the generation and detection lasers. Signal demodulation is performed with a confocal Fabry-Perot interferometer. Recorded signals are processed by the Fourier-domain Synthetic Aperture Focusing Technique (F-SAFT). Unlike previous reported works in which the longitudinal wave signal was used, we are using here the shear wave signal. Laser-generated shear waves, which have a particular directivity pattern, with maximum emission at an angle, interacts very effectively with the crack roots. We are reporting results obtained on a stainless steel plate containing stress corrosion cracks having depths of typically 0.5 mm and widths of less than 0.05 mm. The scan step size is about 0.2 mm. An image of the stress corrosion cracks is successfully reconstructed and shows very fine details after F-SAFT processing with laser-generated shear waves. The results are compared to images obtained by liquid penetrants testing.

Application of Optimization Methods to Crack Profile Inversion Using Eddy Current Data

---J. Bowler, Z. Wei, and A. Dogandzic, Center for NDE, Iowa State University, 1915 Scholl Road, Ames, IA 50011

---An key aim of eddy-current nondestructive evaluation is to quantify damage in conductors using probe measurements. In pursuit of this goal, a procedure has been developed for finding the shape and size of a planar crack in a conductor from single-frequency eddy-current probe impedance measurements. The crack is represented theoretically as an impenetrable barrier to electric current and the quasi-static electromagnetic field is calculated in order to predict the probe impedance variation with position for comparison with the measurements. The crack shape is sought through a standard iterative inversion scheme in which a nonlinear least squares cost function quantifying the overall difference between predictions and measurements is minimized using descent optimization methods. Conjugate-gradient, Gauss-Newton, and quasi-Newton methods will be investigated and compared. Cramér-Rao lower bounds on the crack shape parameters will be derived and used to (i) compute confidence intervals for the estimated parameters and (ii) quantify the accuracy and improve the design of eddy-current nondestructive evaluation systems.---The work is supported by NASA.

Optimization of Test Parameters for Magneto-Optic Imaging Using Taguchi Method

---Z. Zeng, L. Xuan, W. Shih¹, G. Fitzpatrick¹, L. Udpa, and S. Udpa; Material Assessment Research Group, Department of Electrical and Computer Engineering, Iowa State University, Ames, IA 50011; ¹PRI Research and Development Corporation, 25500 Hawthorne Boulevard, #2300, Torrance, CA 90505

---Magneto-optic Imaging (MOI) is a relatively new non-destructive evaluation (NDE) technique for detecting surface and subsurface cracks and corrosion in aircraft skin structures. Defects are displayed as an analog video image that is interpreted by the inspector. Subtle images such as for small surface and subsurface defects may be difficult for the inspector to detect. Under these circumstances, digital image processing methods may assist the inspector to interpret the MOI images. Such techniques are being developed under FAA sponsorship to improve the ability to detect small defects in aging aircraft. Progress in this development is reported in the paper. The accept / reject decision for a test specimen is determined by observing the binary image obtained by thresholding the magnetic flux density distribution. The coefficient of skewness of the binary magneto-optic (MO) image can be used for calculating the probability that the image contains a crack. Larger the skewness value, larger the likelihood of the presence of a crack. Several test parameters affect the skewness of binary MO image and hence the likelihood of the image containing a crack. The optimal set of test parameters (frequency, threshold, etc.) that generates the maximum skewness of binary image can be found using an optimization algorithm based on the Taguchi method. The number of trials necessary for the optimization is significantly reduced with Taguchi's methodology of experimental design.-
--This material is based upon work supported by the Federal Aviation Administration under Contract #DTFA03-98-D-00008, Delivery Order # IA013 and performed at Iowa State University's Center for NDE as part of the Center for Aviation Systems Reliability program.

The Influence of Slot Defect Length to Magnetic Flux Leakage

---Huang Songling, Li Luming, Yang Haiqing, and Wang Laifu, Tsinghua University, Department of Mechanical Engineering, Beijing 100084, P. R. China

---A key issue, which influences the applications of magnetic flux leakage testing, is defect quantification. The relationship between characteristics of defect leakage field and defect length was investigated. Testing results show that defect length is an important parameter needed to consider in quantifying defects.

Groove Sizing Using a Robust Neural Network Approach

---L. Le Brusquet, M.-E. Davoust, and G. Fleury, Service des Mesures, Ecole Supérieure d'Electricité, Plateau de Moulon, 3 Rue Joliot Curie, 91 192 Gif-sur-Yvette, France

---Remote field eddy current (RFEC) technique is used to inspect ferromagnetic conductive pipes from the inside. A typical sensor is used for groove dimensioning. In our case, as the sensor is pushed inside the pipe, the modulus and phase of the detector voltage are acquired along with the coil positions. They are called observed data. The problem is to calculate an estimation of groove dimensions from these observed data. A first approach was previously developed using a two step parametric inversion. The first one was to find an algebraic model from results of finite elements calculations. The second one was to find a measurement equation to bind optimized parameters to the dimensions of the groove. The estimation of the groove dimensions were quite accurate except when the parametric model does not agree sufficiently with the observed data. In this context of complex physical systems, an automated parametric method may be helpful because no precise prior knowledge is required. The paper presents some results obtained with a one-hidden layer feed-forward neural network and compares them to the previous results. A large part of the paper deals with the lack of robustness which may occur. This problem depends on the ratio between the number of neural network parameters to be estimated (the weights) and the number of observations used to estimate those parameters. In our case, the number of simulated defaults used to train the neural network is particularly low. That is why we reduced the dimension of the observed data (in order to limit the number of weights) and we generate synthetic noisy observations. A trade-off between bias and variance has been achieved by adjusting both the reduction level and the noise level.

Wednesday, July 17, 2002

SESSION 18
NEW TECHNIQUES AND SYSTEMS II
G. Busse, Chairperson
SMATE 150

- 8:30 AM** **Modulation Enhanced Detectability of Cracks Using Surface Acoustic Waves**
---J.-Y. Kim, V. Yakovlev, and S. I. Rokhlin, Nondestructive Evaluation Program, The Ohio State University, Edison Joining Technology Center, 1248 Arthur E. Adams Drive, Columbus, OH 43221
- 8:50 AM** **NDE of Flaws Using Nonlinear Vibro-Acoustic Imaging**
---N. Krohn, K. Pfeleiderer, and G. Busse, Institute for Polymer Testing and Polymer Science (IKP), Nondestructive Testing (ZFP), University of Stuttgart, Pfaffenwaldring 32, D-70569, Stuttgart, Germany; I. Yu. Solodov, Department of Physics, Moscow State University, Moscow 119899, Russia
- 9:10 AM** **Low-Coherence Optical Probe for Non-Contact Detection of Photothermal and Photoacoustic Phenomena**
---S. A. Telenkov, D. P. Dave, and T. E. Milner, Biomedical Engineering Department, University of Texas at Austin, Austin, TX 78712
- 9:30 AM** **Microwave Radar Detection of Gas Pipeline Leaks**
---N. Gopalsami, S. Bakhtiari, and A. C. Raptis, Energy Technology Division, Argonne National Laboratory, Argonne, IL 60439-4825; D. B. Kanareykin and V. D. Asanov, AOZT Finn-Trade, St. Petersburg, Russia
- 9:50 AM** **Detecting Incipient Fatigue Damage with Scanning SQUID Microscopy**
---J. W. Morris, Jr. and T. K. Lee, Department of Materials Science and Engineering, University of California, Berkeley, Berkeley, CA 94720; S. K. Lee and J. Clarke, Department of Physics, University of California, Berkeley, Berkeley, CA 94720
- 10:10 AM** **Coffee Break**
- 10:30 AM** **Nondestructive Characterization of Porous Materials with One-Sided Access NMR**
---B. Wolter, N. Surkowa, F. Kohl, and A. Marko, Dept. Material Characterization, Fraunhofer-Institut Zerstoerungsfreie Pruefverfahren (IZFP), Saarbrucken, Germany
- 10:50 AM** **Optical Low-Coherence Reflectometry for Nondestructive Process Measurements**
---S. Lockerbie Randall, A. M. Brodsky, and L. W. Burgess, Center for Process Analytical Chemistry, University of Washington, Seattle, WA 98195-1700
- 11:10 AM** **Design of a Fiber Bragg Based Measurement System for Strain and Temperature Monitoring**
---J. A. Smith and S. Glaesemann, Corning Incorporated, SP-TD-02-1, Corning, NY 14831
- 11:30 AM** **A Portable Magnetic Flux Leakage Testing System for Pipelines Defect Inspection**
---L. Luming, Y. Haiqing, H. Songling, and W. Laifu, Department of Mechanical Engineering, Tsinghua University, Beijing 100084, P.R. China
- 11:50 AM** **Quantitative Evaluation of a Crack Inside of Pressure Pipe by Strain Analysis with ESPI**
---K.-S. Kim and Y.-H. Cha, Department of Mechanical Engineering, Chosun University, 375 Seosuk-dong Dong-gu, Kwangju 501-759; South Korea; M.-Y. Choi, Korea Research Institute of Standard and Science, POX 102 Yuseong, Daejeon 305-600, South Korea; K.-S. Kang, Chosun University, 375 Seosuk-dong Dong-gu Kwangju 501-759, South Korea; D.-P. Hong, Department of Mechanical Engineering, Chonbuk National University, 664-14 1 Duckjin-Dong, Duckjin-Gu, Jeonju, Chonbuk 561-756, South Korea
- 12:10 PM** **Lunch**

Modulation Enhanced Detectability of Cracks Using Surface Acoustic Waves

---Jin-Yeon Kim, Vadim Yakovlev, and Stanislav I. Rokhlin, Nondestructive Evaluation Program, The Ohio State University Edison Joining Technology Center, 1248 Arthur E. Adams Drive, Columbus, OH 43221

---This paper addresses experimental and theoretical aspects of stress modulation effects on a surface acoustic wave interacting with a partially closed fatigue crack emanating from a surface cavity. Such a crack may be considered as an imperfect interface in a solid under different clamping conditions modified by small external periodic loading. The loading results in change of interfacial conditions and/or crack length leading to wave mixing (modulation). In our case the ultrasonic pulse has a center frequency of 5MHz; the modulation frequency is 10Hz, thus the external dynamic action can be considered quasi-static. The measurements were performed during fatigue tests for different crack lengths, variable static crack closure stresses, and different stress modulation levels. The reflected ultrasonic pulses were digitized and amplitudes of the first and higher modulation harmonics extracted. The fatigue crack initiation and propagation and its opening-closure behavior are related to the harmonic amplitudes. It turns out that the application of low amplitude modulation loads enhances the detectability of partially closed fatigue cracks helping to discriminate the evolving crack from a volumetric flaw. However, this effect is sensitive to the crack state and is not suitable for crack sizing.

NDE of Flaws Using Nonlinear Vibro-Acoustic Imaging

---N. Krohn, K. Pfeleiderer, and G. Busse, Institute for Polymer Testing and Polymer Science (IKP) -Nondestructive Testing- (ZFP), University of Stuttgart, Pfaffenwaldring 32, D-70569 Stuttgart, Germany; I. Yu. Solodov, Department of Physics, Moscow State University, Moscow 119899, Russia

---Nonlinear interaction of boundaries is observed using various ultrasound techniques, but in most cases under idealized laboratory conditions. However, the gaps and roughness of boundaries in real-life defects are so large that the ultrasound amplitudes are too small to achieve nonlinear interaction. Much higher amplitudes can be generated at lower frequencies thereby allowing to overcome this problem. This vibro-acoustic excitation is performed by a piezoelectric stack actuator clamped to the sample. A high power diffuse like sound-field is generated in the inspected, so that excitation at a single constant point is sufficient for raster imaging of larger areas. Resonant states of the sample need to be avoided because local vibration nodes would appear as "dark areas" with zero detection sensitivity. For measuring the local vibration spectra a scanning laser vibrometer was used. Both higher harmonics and nonlinear frequency mixing products act as sensitive probes for imaging of local nonlinearity, which is well correlated with damaged areas. Our contribution presents results showing how this kind of remote imaging can be used for NDE of various industrial-component containing specific kinds of damage.

Low-Coherence Optical Probe for Non-Contact Detection of Photothermal and Photoacoustic Phenomena

---Sergey A. Telenkov, Digant P. Dave, and Thomas E. Milner, Biomedical Engineering Department, University of Texas at Austin, Austin, TX 78712

---We report development of a dual channel low-coherence optical probe to monitor thermal deformations and acoustic transients in materials exposed to laser excitation. Our approach utilizes principles of low-coherence interferometry with phase-sensitive detection of the scattered light from a test sample. High spatial resolution and sensitivity of the optical probe may be used to identify subsurface light-absorbing structures in turbid media and determine optical properties non-invasively. The low-coherence optical sensor may prove to be useful for non-contact studies of tissue-like materials and various biomedical applications.

Microwave Radar Detection of Gas Pipeline Leaks

---N. Gopalsami, S. Bakhtiari, and A. C. Raptis, Energy Technology Division, Argonne National Laboratory, Argonne, IL 60439-4825; D. B. Kanareykin and V. D. Asanov, AOZT Finn-Trade, St. Petersburg, Russia

---With the growing demand for natural gas and the aging of the natural gas infrastructure in the U.S., remote sensing systems are needed to inspect over 2 million miles of natural gas transmission and distribution systems for potential leaks and to ensure safety and reliability of service to the public. Current leak detection techniques are based on sniffing, which are labor-intensive and impractical for inspecting the vast network of pipes around the country. This paper presents a remote sensing technique based on X-band radar imaging for detection and location of natural gas leaks. The underlying detection principle exploits the radar-backscattering signal changes from the index of refraction inhomogeneities introduced by the flow of methane in air. We will present a physics-based model of methane leak turbulence in air and estimate the radar cross sections of leak plumes for different leak sizes. We will also discuss the experimental efforts that are underway to validate the theoretical prediction and to assess practically achievable detection sensitivities of the radar technique for methane leaks.

Detecting Incipient Fatigue Damage With Scanning SQUID Microscopy

---J. W. Morris, Jr. and T. K. Lee, Department of Materials Science and Engineering, University of California, Berkeley, Berkeley, CA 94720; S. K. Lee and J. Clarke, Department of Physics, University of California, Berkeley, 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 detection of incipient fatigue failure in 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. Studies on several metallurgically different structural steels show the development of local peaks in remanent magnetization prior to the development of visible fatigue cracking, that is, in "Region II" of fatigue damage. Because of the combined magnetic and spatial resolution of the SQUID microscope, these local changes can be detected well before there is any dramatic change in the overall magnetization of the specimen.

Nondestructive Characterization of Porous Materials With One-Sided Access NMR

---Bernd Wolter, Nina Surkowa, Frederic Kohl, and Andriy Marko, Dept. Material Characterization, Fraunhofer-Institut Zerstoerungsfreie Pruefverfahren (IZFP), Saarbruecken, Germany

---Hydrogen nuclear magnetic resonance (^1H NMR) is a direct method to determine the hydrogen content and with it the water content (moisture) in solids. Simultaneous it is highly sensitive probe of local, molecular-scale dynamical information in the 1 to 10^8 Hz frequency range, allowing to characterize structure molecular dynamics in hydrogenous liquids as well as in hydrogenous solids. Recent research results have demonstrated the extensive capability of NMR for characterizing structural properties in porous media. For a long time, NMR instrumentation was found only in laboratories of institutional and industrial research facilities. Meanwhile, for outside laboratory application and for nondestructive inspection of large objects special NMR devices are available, based on the one-sided access (OSA) NMR approach. Using this hardware type, many technologically valuable NMR applications could be transferred in nondestructive testing methods. This presentation will review the possibilities of OSA NMR for the characterization of porous solids, including the determination of moisture profiles in different materials, the investigation of specific surface and restricted diffusion in stones and the characterization of concrete hardening. Applications in terms of building inspection, geophysical investigations and examination of organic materials will be discussed.

Optical Low-Coherence Reflectometry for Nondestructive Process Measurements

---Summer Lockerbie Randall, Anatol M. Brodsky, and Lloyd W. Burgess, Center for Process Analytical Chemistry, University of Washington, Seattle, WA 98195-1700

---Optical Low-Coherence Reflectometry (OLCR) is a white-light interference technique originally developed for applications in the optoelectronics test and measurement arena. The reflectometer is a fiber optic-based instrument in which 180° reflected (backscattered) light is collected as incident light passes from one optical medium to another. The technique is based upon a Michelson interferometer, with the sample substituted for the stationary mirror and utilizes a broadband (low coherence) light source. By taking advantage of advances in scattering theory and applying appropriate signal processing, OLCR has potential as a sensor in a number of processing applications. In reflective or weakly scattering systems, OLCR can be used to monitor the thickness of single and multiple layer polymer films, as well as transparent coatings upon complex, scattering substrates. In dense, highly scattering systems, applications include the on-line measurement of the state of missing, mean particle size determination in attrition milling, monitoring of paint curing rates, non-invasive thickness determination of highly scattering coatings on both conducting and non-conducting substrates, and fermentation monitoring. Recent work using a commercial available Hewlett-Packard 8504 instrument will be presented.

Design of a Fiber Bragg Based Measurement System for Strain and Temperature Monitoring

---J. A. Smith and S. Glaesemann, Corning Incorporated, SP-TD-02-1, Corning, NY 14831

---To provide more efficiency in the design of systems involving, engineering structures adaptive structures and manufacturing processes, the ultimate limits of the engineering materials used in the systems are being approached. The reduced margins of safety for the material used in the design of the systems will require the use of sensing systems to measure strain and temperature. This will allow the designs to maintain safety and reliability. The design of a fiber optic sensing system will be presented. The goal is to develop a measurement system that will be deployed in a manufacturing or field environment. The sensing elements will be formed from Bragg gratings and from Fabry-Perot interferometers constructed from fiber Bragg gratings. A theoretical simulation studying the shifts in center wavelengths from the fiber Bragg and the Bragg Fabry-Perot at various strains and temperatures will prove the feasibility of separating strain changes from temperature changes. These results will also be used to specify the instrumentation. The sensor system will be designed for a strain resolution of 10 microstrains, a bandwidth of 50 kHz and a temperature range from -50°C to 200°C. The cost and development time of the sensing system will be minimized by using off the shelf technology.

A Portable Magnetic Flux Leakage Testing System for Pipelines Defect Inspection

--- Li Luming, Yang Haiqing, Huang Songling, and Wang Laifu, Department of Mechanical Engineering, Tsinghua University, Beijing 100084, P. R. China

---This paper describes a portable, lower power magnetic flux leakage (MFL) testing system that combines MFL method, signal processing technique and singlechip (SCM) technique. Experimental data shows that the system can inspect the inside and outside defects of pipeline quickly and reliably in one process of scanning. The system can be widely used in defects testing of industrial pipelines.

Quantitative Evaluation of a Crack Inside of Pressure Pipe by Strain Analysis with ESPI

---K.-S. Kim and Y.-H. Cha, Department of Mechanical Engineering, Chosun University, 375 Seosuk-dong Dong-gu, Kwangju 501-759, South Korea; M.-Y. Choi, Korea Research Institute of Standard and Science, POX 102 Yuseong, Daejeon 305-600, South Korea; K.-S. Kang, Chosun University, 375 Deosuk-dong Dong-gu Kwangju 501-759, South Korea; D.-P. Hong, Department of Mechanical Engineering, Chonbuk National University, 664-14 1ga Duckjin-Dong, Duckjin-Gu, Jeonju, Chonbuk 561-756, South Korea

---Electronic Speckle Pattern Interferometry(ESPI) for non-contact, non-destructive inspection and safety evaluation is described. Shearography is used widely for non-destructive inspection because of high sensitivity and simple interferometer. The method provides only 2 dimensional geometries of crack and cannot measure crack depth. But, crack depth has influence on safety evaluation. Also, it is difficult to determine the defect size quantitatively because there are so many factors- shearing distance, load, depth of crack, material property and etc. In this paper inside cracks in pressure pipe are inspected with ESPI and 3D-deformation of object surface around inside crack can be measured and analyzed to strain or stress through the simple processing. The strain distribution related to strain concentration implies information of crack size and shape. So, this paper presents the possibility of quantitative analysis of inside crack more easily using ESPI. Artificial inside crack in pressure pipe is tested and the crack size by ESPI is compared with that of Shearography. Also, the calculated strain/stress is compared with allowable stress, which is based on safety evaluation.

Wednesday, July 17, 2002

SESSION 19
MATERIAL PROPERTIES AND MICROSTRUCTURE
M. Blodgett, Chairperson
FRASER 4

- 8:30 AM** **Principal Surface Wave Velocities in the Point Focus Acoustic Materials' Signature $V(z)$ of an Anisotropic Solid**
---A. G. Every, School of Physics, University of the Witwatersrand, PO WITS 2050, South Africa; M. Deschamps, LMP, Université de Bordeaux 1, 351 Cours de la Libération, 33405 Talence-Cedex, France
- 8:50 AM** **A Cross Correlation Method for Velocity Measurement Using EMAT**
---Z. S. Lim¹ and R. B. Thompson², ¹RIST, Pohang, Korea; ²Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011
- 9:10 AM** **Parabolic Mirror and Air-coupled Transducer for Multimodal Plate Wave Detection**
---B. Hosten and M. Castaigns, Laboratoire de Mécanique Physique, Université Bordeaux 1, UMR C.N.R.S. 5469 351, Cours de la Libération 33405 – TALENCE Cedex, France
- 9:30 AM** **In-Situ, Laser-Ultrasonic Monitoring of the Annealing of an Al-Mg Alloy**
---S. E. Kruger and A. Moreau, Industrial Materials Institute, National Research Council of Canada, Boucherville, QC, Canada; M. Militzer and T. Biggs, The Centre for Metallurgical Process Engineering, The University of British Columbia, Vancouver, BC, Canada
- 9:50 AM** **Errors in the Measurement of Ultrasonic Phase Velocity in the Context of Materials Evaluation**
---A. N. Kalashnikov and R. E. Challis, School of Electrical and Electronic Engineering University of Nottingham, University Park, Nottingham, NG7 2RD, United Kingdom
- 10:10 AM** **Coffee Break**
- 10:30 AM** **A Guided-Wave Technique for the Characterization of Highly Attenuative Viscoelastic Materials**
---F. Simonetti and P. Cawley, Department of Mechanical Engineering, Imperial College of Science, Technology and Medicine, London, SW7 2BX, United Kingdom
- 10:50 AM** **Electrostatic Detection of Density Variations in Green-State Powder Metallurgy Compacts**
---G. H. Leuenberger and R. Ludwig, Electrical Engineering Department, Worcester Polytechnic Institute, Worcester, MA 01602
- 11:10 AM** **Simultaneous Measurement of Grain Size and Shape from Ultrasonic Backscattering Measurements Made from a Single Surface**
---Y. Guo, R. B. Thompson, and F. J. Margetan, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011
- 11:30 AM** **A Theory for the Ultrasonic Attenuation and Backscattering in Duplex Alloys**
---P. D. Panetta Pacific Northwest National Laboratory, 902 Battelle Boulevard, P. O. Box 999, Mail Stop K5-26, Richland, WA 99352; S. Ahmed and R. B. Thompson, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011
- 11:50 AM** **Modeling Ultrasonic Grain Noise Variation Within Ti-6Al-4V Forgings**
---L. Yu, R. B. Thompson, and F. J. Margetan, Iowa State University, Center for NDE, Ames, IA 50011; A. Degtyar, United Technologies, Pratt&Whitney, East Hartford, CT 06108
- 12:10 PM** **Lunch**

Principal Surface Wave Velocities in the Point Focus Acoustic Materials' Signature $V(z)$ of an Anisotropic Solid

---A. G. Every, School of Physics, University of the Witwatersrand, PO WITS 2050, South Africa; M. Deschamps, LMP, Université de Bordeaux 1, 351 Cours de la Libération, 33405 Talence-Cedex, France

---The point focus acoustic materials' signature $V(z)$ of an anisotropic solid is given by an integral over a product of an aperture function, the azimuthally averaged angular dependent reflectivity, and a phase factor. A common perception is that the folding of the entire directional dependence of the reflectivity into a single $V(z)$ signal washes out most detailed information on the surface dynamics. Most acoustic microscopy (AM) investigations of anisotropic solids in the past have therefore been conducted with line focus lenses (LFAM), whereby individual $V(z)$ curves are obtained for each value of the azimuthal angle, yielding the angular dependence of the Rayleigh (RW) and other surface wave velocities. The purpose of this paper is to show that point focus $V(z)$ signals obtained on anisotropic solids are dominated by a small number of principal surface wave rays, which correspond to directions in which the surface wave slowness is stationary. As an example, the computed $V(z)$ curve for the (001) surface of Cu is analyzed, and is found to be the superposition of 4 dominant periods. Two of these are associated with the RW, one corresponding to the [100] direction where the RW slowness is a maximum, and the other to an oblique direction where the RW slowness is a minimum. The other two periods correspond to a maximum and a minimum in the PSAW slowness. The practical advantages of using point focus AM for anisotropic solids is that a single measured $V(z)$ curve provides almost as much useful information as does an entire family of curves obtained by LFAM, and secondly, the technical difficulties of maintaining the focal line accurately parallel to the specimen surface are circumvented.

A Cross Correlation Method for Velocity Measurement Using EMAT

---Z. S. Lim¹ and R. B. Thompson², ¹RIST, Pohang, Korea; ²Center for NDE, Iowa State University, 1915 Scholl Road, Ames, IA 50011

---Various methods have been proposed for the measurements of the ultrasonic wave velocity. In this paper we have proposed a new method for the ultrasonic velocity measurements using EMAT based on the cross correlation analysis. Since the EMAT electronics use a high voltage circuit, a preprocessing for the noise reduction has been done using median filtering and Savitzky-Golay smoothing. Then the cross correlation method is applied to the pair of the adjacent tone bursts. Results showed that the time resolution was about 1 nsec, which was sufficient for the materials analysis.

Parabolic Mirror and Air-coupled Transducer for Multimodal Plate Wave Detection

---B. Hosten and M. Castaings, Laboratoire de Mécanique Physique, Université Bordeaux 1, UMR C.N.R.S. 5469 351, Cours de la Libération 33405 – TALENCE Cedex, France

---A conventional contact piezoelectric transducer is used to generate many Lamb waves simultaneously in a plate. Throughout the propagation, these waves leak into the ambient air producing bulk waves with many directions of propagation. The association of a parabolic mirror and an air-coupled transducer (PMAT) permits to receive these waves in air with a broad angular range and to measure the velocity of Lamb waves in a very large wave number/frequency domain with only one shot and without changing the orientation of the receiver. The angular range covered by the PMAT is 25°. Since the sound velocity in air is much lower than the Lamb wave velocities, this range covers the totality of that usually required to detect the bulk waves in air produced by the leakage. In addition, the emitter is fed through an arbitrary signal generator with a broadband burst (chirp) which covers the whole bandwidth of the transducer (50..400 kHz). Then, the waveforms captured in space and time, are classically converted in the wave number/ frequency domain with a 2D Fourier transform. The resulting data, a set of experimental velocities for many modes and in a large frequency domain, is then used to identify the moduli of elasticity for plates made of glass fibers and polymer matrix.

In-Situ, Laser-Ultrasonic Monitoring of the Annealing of an Al-Mg Alloy

---S. E. Kruger and A. Moreau, Industrial Materials Institute, National Research Council of Canada, Boucherville, QC, Canada; M. Militzer and T. Biggs, The Centre for Metallurgical Process Engineering, The University of British Columbia, Vancouver, BC, Canada

---Laser-ultrasonics is a non-destructive and non-contact technique that can characterize many microstructural and elastic parameters of materials and is suitable for on-line applications. In this paper, cold-rolled samples of an Al-Mg alloy (AA5754) are annealed in a Gleeble thermomechanical simulator at various temperatures (275°C, 300°C, 325°C and 350°C). The recrystallization kinetics is monitored in-situ and in real time by laser-ultrasound. It is found that longitudinal velocity variations correlate well with the recrystallized fraction, as evaluated by metallography and mechanical testing on samples submitted to similar thermal cycles.

Errors in the Measurement of Ultrasonic Phase Velocity in the Context of Materials Evaluation

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

---Ultrasonic spectroscopy in various wave modes is used for the non-destructive evaluation of both liquid and solid materials either in a stationary state or while undergoing chemical reaction. Required physical and engineering properties of the material are derived from measurements of ultrasonic attenuation and phase velocity, generally as functions of frequency. Bias and variance errors in these variables bring about corresponding errors in the estimates of the required material properties and so must be constrained to values between limits specified by the application. In earlier work we have shown that errors in attenuation measurement depend on the intensity of the noise sources in the instrumentation use for measurement, multiplied by a factor which is a strongly non-linear function of the actual value of the attenuation being measured. In the current work we apply a similar statistical technique to investigate how errors in the estimates of wave phase velocity are affected by system noise. The system noise is represented by a combination of additive (Johnson and shot) noise with a frame jitter representing uncertainty in timing circuits typical of digital oscilloscopes and other data acquisition devices. We show that the variance in the phase velocity estimate is a function of both the jitter statistics and the variance of the additive noise. It also depends on the value of the attenuation being measured, expressed in Nepers, as well as frequency and the propagation distance over which it is measured. There is a trade-off between the accuracy of attenuation measurements and the accuracy of phase velocity estimates. The analysis is verified by experiment and the paper concludes with ideas for optimizing measurement conditions.

A Guided-Wave Technique for the Characterization of Highly Attenuative Viscoelastic Materials

---F. Simonetti and P. Cawley, Department of Mechanical Engineering, Imperial College of Science, Technology and Medicine, London, SW7 2BX, England

---The measurement of the acoustic properties of highly attenuative materials such as bitumen is very difficult. One possibility is to use measurements of the extent to which filling a cylindrical waveguide with the material affects the dispersion relationship of the cylinder. Guided modes have been excited using piezoelectric transducers placed at one end of the cylinder, while the measurement of phase velocity and attenuation spectra have been carried out by means of laser scanning. Under the hypothesis of linear viscoelasticity and on the basis of a monochromatic approach, the bulk shear velocity and the bulk shear attenuation spectra have been derived from the measured torsional dispersion curves. Longitudinal properties have been obtained following the same procedure but, while torsional waves are related only to the shear bulk properties, extensional modes depend on both shear and longitudinal properties. As a consequence, in order to determine the longitudinal properties, the shear properties need to be determined first. Validation of the technique is presented and results for bitumen are given.

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

---Georg H. Leuenberger and Reinhold Ludwig, Electrical Engineering Department, Worcester Polytechnic Institute, Worcester, MA 01602

---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 offer the highest pay-off for quality control through nondestructive evaluation (NDE) techniques. A detection of compacting-related problems in the green-state samples permits early process intervention, and thus prevents the creation of potentially significant numbers of faulty parts. Work at WPI currently has concentrated on extending the previously developed method for crack detections to measure density variations within the parts. In this paper a physical model and a mathematical formulation are reported, which are capable of relating green-state density to electric conductivity for various lubricant concentrations. Electrostatic measurements of cylindrical compacts have so far confirmed the theoretical model assumptions. Specifically, the green-state conductivity increases as the sample density increases up to approximately 6.9-7.0g/ccm. Any further density increase results in a decrease in conductivity. Preliminary measurements with a range of cylindrical samples support the theoretical model.

Simultaneous Measurement of Grain Size and Shape from Ultrasonic Backscattering Measurements Made from a Single Surface

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

---Ultrasonic techniques for the characterization of grain size have been investigated for over two decades, including important practical applications. Generally, however, these make the assumptions that the grains are equi-axed. In this paper, we consider the more general case in which the grains are elongated. Expressions are presented relating the ultrasonic backscattering coefficient to the geometrical parameters of the grains for both normal longitudinal incidence and oblique shear incidence. These are verified in terms of previous experimental data for the normal-incidence, longitudinal wave case and new data for the oblique-incidence, shear wave case. An inversion procedure is then presented to infer the geometrical parameters of the grains from this data. Measurement results are presented which demonstrate the effectiveness of this new approach on a set of aluminum samples that were rolled as either rods or plates. The major practical advantage of this approach is that all data can be taken from the single side of a sample with no requirements for a parallel back surface.---This work was supported by the NSF Industry/University Cooperative Research program.

A Theory for the Ultrasonic Attenuation and Backscattering in Duplex Alloys

---P. D. Panetta: Pacific Northwest National Laboratory, 902 Battelle Boulevard, P. O. Box 999, Mail Stop K5-26, Richland, WA 99352; S. Ahmed and R. B. Thompson, Center for NDE, Iowa State University, 1915 Scholl Road, Ames, IA 50011

---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 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.---Pacific Northwest National Laboratory is operated for the U.S. Department of Energy by Battelle under Contract DE-AC06-76RLO18310.

Modeling Ultrasonic Grain Noise Variation Within Ti-6Al-4V Forgings

---Linxiao Yu, R. B. Thompson, and F. J. Margetan, Iowa State University, Center for NDE, Ames, IA 50011; Andrei Degtyar, United Technologies Pratt & Whitney, East Hartford, CT 06108

---A large variation of backscattered ultrasonic grain noise has been observed within Ti-6Al-4V forgings. Such variation is believed to be correlated with the microstructural variations that occur during the forging processing. A modeling effort is described whose objective is to provide a basis for correlating the ultrasonic grain noise with available microstructure information. One model input is the local deformation caused by the forging process, as calculated using DEFORM software (a product of Scientific Technologies Corporation, Columbus Ohio). From this local deformation the elongations and orientations of microstructural scattering element are determined. Other model inputs are the mean volume of a scattering element and a parameter that quantifies the effective elastic property anisotropy within a scatter. The grain noise levels predicted by the model at various locations are compared with experiments for one particular forging.---This material is based upon work supported by the Federal Aviation Administration under Contract #DTFA03-98-D-00008, Deliver Order #IA029 and performed at the Iowa State University's Center for NDE and United Technologies Pratt & Whitney as part of the Engine Titanium Consortium program, through the Airworthiness Assurance Center of Excellence.

Wednesday, July 17, 2002

SESSION 20
ACOUSTIC EMISSION
M. López Pumarega, Chairperson
SMATE 140

- 1:30 PM** **Detection and Identification of Corrosion Cracking in Reinforced Concrete by Acoustic Emission**
---M. Ohtsu, Graduate School of Science & Technology, Kumamoto University, 2-39-1 Kurokami, Kumamoto 860-8555, Japan
- 1:50 PM** **Multifrequency AE for Monitoring the Time Evolution of Microprocesses within Solids**
---G. Paparo and G. P. Gregori, Istituto di Acustica O. M. Corbino (CNR), via Fosso del Cavaliere 100, 00133 Roma, Italy
- 2:10 PM** **Mechanical and Electrical Noise in the PVLAS Experiment**
---M. Bregant¹, G. Cantatore¹, S. Carusotto², G. K. Domenico³, F. Della Valle¹, U. Gastaldi⁴, E. Milotti⁵, G. Petrucci⁶, E. Polacco², G. Ruoso⁴, E. Zavattini³, and G. Zavattini¹, ¹Universita' di Trieste and INFN-Sezione di Trieste; ²Universita' di Pisa and INFN-Sezione di Pisa; ³Universita' di Ferrara and INFN-Sezione di Ferrar; ⁴INFN-Laboratori Nazionali di Legnaro; ⁵Universita' di Udine and INFN-Sezione di Trieste, Via delle Scienze, 208, 1-33100 Udine; ⁶CERN, Italy
- 2:30 PM** **Relation Between Amplitude and Duration of Acoustic Emission Signals**
---M. I. L. Pumarega, M. Armeite, and J. Ruzzante¹, ENDE, Centro Atomico Constituyentes, Comision Nacional de Energia Atomica, San Martin, Provincia de Buenos Aires, Argentina; ¹Universidad Tecnologica Nacional, Facultad Regional Buenos Aires, Buenos Aires, Argentina; R. Piotrkowski, Univ. Nacional de General San Martin, San Martin, Prov. de Buenos Aires, Argentina
- 2:50 PM** **Acoustic Emission Technique for Characterizing Deformation and Fatigue Crack Growth**
---B. Raj, C. K. Mukhopadhyay, V. Moorthy, and T. Jayakumar, Metallurgy and Materials Group, Indira Gandhi Centre for Atomic Research, Kalpakkam, Tamil Nadu, India
- 3:10 PM** **Coffee Break**
- 3:30 PM** **Acoustic Emission Monitoring of Large Civil Structures**
---D. W. Prine, Infrastructure Technology Institute, Northwestern University, 1801 Maple Avenue, Evanston, IL 60201
- 3:50 PM** **High Resolution Acoustic Emission Monitoring of Cracking Failure in Contact Mechanical Applications**
---J. von Stebut, LSGS, UMR CNRS-INPL-UHP-EdF 7570, Écoles des Mines, F-54042 Nancy Cedex, France; F. Lapostolle and N. B. de Longchamp, LTI-Centre de Recherche Public Henri Tudor, Technoport Schlassgoart, L-4002 Esch/Alzette, Luxembourg; C. Comte, CSIRO, P. O. Box 218, Lindfield NSW 2070, Australia; H. Vallen, Vallen-Systeme GmbH, Schaeftlarner Weg 26, D-82057 Icking, Germany
- 4:10 PM** **AE Performance for Damage Monitoring of Impacted FRP Composite Laminates**
---C. Caneva, Dept. of Chemical and Materials Eng., Via Eudossiana, 18, 00184 Rome, Italy
- 4:30 PM** **NDE Evaluation of Fiber-Glass Insulation Material**
---F. Shu, V. F. Godinez-Azcuaga, and R. D. Finlayson, Physical Acoustics Corp., 195 Clarksville Rd., Princeton Junction, NJ 08550; J. Sacks, Certain Teed Insulation Group, Blue Bell, PA
- 4:50 PM** **Embedded Ultrasonic Transducer Design and Wireless Communications for Intelligent Monitoring of Structures**
---G. Hayward, G. Benny, A. Gachagan, R. Farlow, B. Hailu, and A. McNab, Centre for Ultrasonic Engineering, University of Strathclyde, 204 George Street, Glasgow, G1 1XW; D. Girma, Communications Division, University of Strathclyde, 204 George Street, Glasgow, G1 1XW; J. Hendry, Centre for Advanced Structural Materials, Mechanical Engineering, University of Strathclyde, Glasgow G1 1XW, United Kingdom

Detection and Identification of Corrosion Cracking in Reinforced Concrete by Acoustic Emission

---M. Ohtsu, Graduate School of Science & Technology, Kumamoto University, 2-39-1 Kurokami, Kumamoto 860-8555, Japan

---Cracking of concrete due to corrosion of rebars in reinforced concrete is one of critical problems in concrete engineering. Accordingly, a variety of research has been conducted on nondestructive inspection (NDI), nucleation mechanisms, prevention methods, and repair techniques for corrosion problems. For NDI, such electro-chemical techniques as half-cell potential and polarization resistance are developed. Here, an application of acoustic emission (AE) is studied. In an accelerated corrosion tests, AE occurrence is monitored continuously. Investigating permeation of chloride ions, a relationship with chloride concentration and AE activity is clarified. Thus, an onset of corrosion and an initiation of cracking are qualified from AE observation. Further, applying SiGMA procedure, nucleation mechanisms of a surface crack, a spalling crack, and an internal crack due to expansion of corrosive product are studied. It is found that the surface crack is nucleated dominantly by tensile cracks. For the spalling crack, both the tensile and the shear cracks are generated, as the former is domination the latter near a stress-free surface. In contrast, the main mechanisms of the internal crack is of shear-crack motion.

Multifrequency AE for Monitoring the Time Evolution of Microprocesses within Solids

---G. Paparo and G. P. Gregori, Istituto di Acustica O. M. Corbino (CNR), via Fosso del Cavaliere 100, 00133 Roma, Italy

---Acoustic Emissions occur whenever atomic bonds yield, varying in time according to bond yielding organization. AE events of comparatively higher frequency precede events of lower frequency. Every AE transducer is tuned only over one narrow frequency-band. Every macro-event is not a Dirac delta-function, rather approximately lognormal, with maximum followed by a tail. This ought to occur in every case history, although on time-scales function of the physical system. Laboratory applications, either on metal samples or on instrumentation components, are concerned with short time-scales. In contrast, observationally more convenient configurations are encountered within natural systems, that will be here presented, depending either on daily warming and cooling, or on time varying pressure of endogenous hot fluids, such as within geothermal or volcanic areas. In the case of a laboratory sample, e.g. when stressing a homogeneous bar of some alloy, the prime processes are comparatively different. Upon repeated stresses, the chemical bonds yield according to sequences more ordered vs. time, tending towards planar from initial 3D pattern. Such effect was recognized by fractal methods. The argument here emphasized is the relative comparison between trends vs. time at different frequencies. Multi-frequency AE monitoring ought therefore to reveal unprecedented yielding microstructures and temporal evolution.

Mechanical and Electrical Noise in the PVLAS Experiment

---M. Bregant¹, G. Cantatore¹, S. Carusotto², G. Di Domenico³, F. Della Valle¹, U. Gastaldi⁴, E. Milotti⁵, G. Petrucci⁶, E. Polacco², G. Ruoso⁴, E. Zavattini³, and G. Zavattini¹, ¹Universita' di Trieste and INFN-Sezione di Trieste; ²Universita' di Pisa and INFN-Sezione di Pisa; ³Universita' di Ferrara and INFN-Sezione di Ferrar; ⁴INFN-Laboratori Nazionali di Legnaro; ⁵Universita' di Udine and INFN-Sezione di Triests, Via delle Scienze, 208, 1-33100 Udine; ⁶CERN, Italy

---Almost seventy years ago, Heisenberg, Euler and Weisskopf predicted that photons may be scattered by a static electric or magnetic field. This is a straightforward prediction of Quantum Electrodynamics, and it is believed that such scattering processes (and the associated photon splitting processes) play an important role in astrophysical environments (such as on the surfaces of pulsars and magnetars, or in the weak but very extended galactic magnetic fields), but until now it has never been directly verified in the laboratory. VLAS is an experiment which aims at the direct detection of photon-field scattering: it employs optical methods and a large rotating superconducting magnet. Infrared photons are injected into a Fabry-Perot interferometer in the magnetic field region and as they bounce back and forth between the interferometer mirrors, they may occasionally interact with the magnetic field. The interaction is polarization-dependent and therefore the vacuum between the interferometer mirrors behaves as a uniaxial birefringent medium. The light exiting the interferometer is analyzed by a polarizing prism and a tiny signal is picked up by a low noise photodiode. The large, compact structure of the PVLAS experiment is affected by both mechanical and electrical noises. This presentation introduces briefly the data analysis methods employed in the experiment and summarizes the mechanical and electrical noise situation. Though we achieved an excellent detection sensitivity we have not yet reached the breakthrough level which would let us perform an actual measurement of the QED prediction.

Relation Between Amplitude and Duration of Acoustic Emission Signals

---Maria Isabel Lopez Pumarega, Maria Armeite, and Jose Ruzzante¹, ENDE, Centro Atómico Constituyentes, Comisión Nacional de Energía Atómica, San Martín, Provincia de Buenos Aires, Argentina; ¹Universidad Tecnológica Nacional, Facultad Regional Buenos Aires, Buenos Aires, Argentina; Rosa Piotrkowski, Universidad Nacional de General San Martín, San Martín, Provincia de Buenos Aires, Argentina

---The Acoustic Emission burst signals are asymmetric and are characterized by their Amplitude (A), Duration (D) and Risetime (R). In previous papers we studied different aspects of the properties of these parameters. In the present paper we continue studying the relation between A and D in the AE signals coming from different tests. We begin analyzing the correlation matrix for A, D and R, finding an important correlation between the former two parameters. Following the model previously initiated, bursts were modeled as superposition of a certain number of events: the original one superposed with those obtained by successive reflections at adequate boundaries. To determine these boundaries, the characteristic differences of times involved in each physical process had to be considered. If A is the relative amplitude and D the duration of the complex signal, our model conducts to families of convex lines with parameters related with the reflected events, one family for each number of reflections. When the considered number of reflections is higher the family of curves is moved to the right, where the D parameter is higher. For the present paper the decay constant was again carefully determined from experiments, and more reflection were included. So, in many cases, each experimental point in the ln(A) vs. D graph, representing a complex event, could be interpreted as due to a determined number of reflections. In more complicated cases, including oxidized samples, the rupture of oxide layers corresponded to the region of the map with higher D values, corresponding by the way to a higher number of reflections. In this way the fit between the experimental cloud of points and the calculated curves, conforming a map, was improved.

Acoustic Emission Technique for Characterizing Deformation and Fatigue Crack Growth

---B. Raj, C. K. Mukhopadhyay, V. Moorthy, and T. Jayakumar, Metallurgy and Materials Group, Indira Gandhi Centre for Atomic Research, Kalpakkam, Tamil Nadu, India

---Acoustic emission (AE) during tensile deformation and fatigue crack growth (FCG) of austenitic stainless steels (SS) has been studied. An important contribution of this study is the use of optimum experimental approach to record and analyze AE signals in stainless steels reported to generate very weak signals. In 316 SS, AE has been used to detect micro-plastic yielding occurring during macroscopic plastic deformation. This enables judicious selection of AE sensor with high response to a frequency corresponding to that of AE signal generated from yielding phenomenon. A theoretical model has been developed to predict frequency range of AE generated from dislocation sources and has been validated experimentally. Study on notched tensile specimens of 304 SS has shown that relation of AE with stress intensity factor and plastic zone size depends on region (stress state) of deformation and cleanliness of steel. Cumulative counts bear direct proportionality with plastic zone size at notch tip. In 316 SS, two sub-stages (a and b) in stage II Paris regime of FCG could be distinguished by a change in the rate of AE activity. A relationship between cumulative counts and stress intensity range has been proposed and validated experimentally for sub-stage IIa.

Acoustic Emission Monitoring of Large Civil Structures

---D. W. Prine, Infrastructure Technology Institute, Northwestern University, 1801 Maple Avenue, Evanston, IL 60201

---Acoustic emission monitoring (AE) can provide useful information on the condition of large civil structures such as bridges and buildings. The Infrastructure Technology Institute (ITI) of Northwestern University has used AE to evaluate fatigue cracks in steel highway bridges and to localize noise sources such as stick slip in bearings. ITI has also used this technology to evaluate fatigue crack mitigation retrofits. This paper will discuss recent applications in these areas. Sensors and monitoring techniques as well as signal processing approaches will be discussed.

High Resolution Acoustic Emission Monitoring of Cracking Failure in Contact Mechanical Applications

---J. von Stebut, LSGS, UMR CNRS-INPL-UHP-EdF 7570, Écoles des Mines, F-54042 Nancy Cedex, France; F. Lapostolle and N. Bonnel de Longchamp, LTI-Centre de Recherche Public Henri Tudor, Technoport Schlassgoart, L-4002 Esch/Alzette, Luxembourg; C. Comte, CSIRO, P. O. Box 218, Lindfield NSW 2070, Australia; H. Vallen, Vallen-Systeme GmbH, Schaeftlerner Weg 26, D-82057 Icking, Germany

---The low cost, acoustic emission (AE) module ASCO-P® *) has been adopted for on-line detection of small cracks during indentation and scratching of brittle materials. This module consists of a standard resonant piezo transducer with specific electronics transforming an AE "wavepackage" into a square voltage pulse with tunable length and an intensity corresponding to the peak of the original AE pulse. Thus event monitoring is possible allowing for off-line post synchronisation of high resolution metallographical video documents. Validation of AE pulses as damage indicators must always be done by post test video inspection. Otherwise stick-slip artifacts may easily lead to erroneous results when based on AE analysis alone. In particular, AE as a failure indicator in multipass friction experiments turns out to be highly problematic. Backed up by such a validation procedure AE has been applied successfully as an on-line damage indicator to the following reference materials: bulk sintered AlFeCu quasicrystals as well as TiN, DLC, and carbon doped Cr coatings. Because of the low vibrational noise level the highest resolution has been achieved for indentation. Ring cracks outside of the plastic indent have been clearly identified. During scratching brittle cracking failure is seen to be triggered at the trailing edge of the indenter. This implies that the identification of the critical failure loads must be corrected by the half-width of the actual scratch position.

AE Performance for Damage Monitoring of Impacted FRP Composite Laminates

---Claudio Caneva, Department of Chemical and Materials Engineering, Via Eudossiana, 18, 00184 Rome, Italy

---The purpose of this paper is to emphasize the capabilities of AE on detection and characterization of the damage due to impact of FRP composite laminates. This kind of material, in particular FRP, has an anisotropic and non homogeneous property that confer it a hardly predictable mechanism of damage such as initiation, growth and propagation of failure, delamination, breaking of matrix and fibers, debonding, pull out and more else, as a consequence of impact. The impact in composite materials, even if it is performed with low velocity can cause considerable and also invisible damage, so, knowing the behavior of this material after impact is useful especially to the aeronautical industry that uses a great deal of composite material in its component and manufacture. AE represent a suitable NDT method to detect in real time the progressive damage that occurs, giving information about the nature and location of the damage. By means of AE we have characterized the damage of composite laminates and evaluated the cumulative damage of FRP undergo a fatigue load and more else. In the spirit of the impact field we have also analyzed many aspect of the damage like the magnitude of the damage, the residual life of the composite. By the whole research we have carried on in these years we reported here the investigation of the potential of AE to provide the detection and the characterization of the damage in composite material.

NDE Evaluation of Fiber-Glass Insulation Material

---Fong Shu, Valery F. Godinez-Azcuaga, and Richard D. Finlayson, Physical Acoustics Corporation, 195 Clarksville Road, Princeton Junction, NJ 08550; Jeff Sacks, CertainTeed Insulation Group, Blue Bell, PA

---In order to develop an effective and accurate way to monitor and control quality of fiber-glass products, Acoustic Emission (AE) signals generated during compression of fiber-glass samples were studied. These signals were analyzed by using neural network-based pattern recognition software. Distinguishable patterns were found from samples manufactured under different conditions, and compositions resulting in different product quality. AE waveform features, such as absolute energy, average frequency, duration, and risetime showed strong sample dependence, which made classification possible and definitive. A classifier was developed and then applied to data collected on additional test samples. Satisfactory results were achieved. It was further shown that the method and the equipment built are very sensitive to and it can be used as a strict quality control tool in industrial production.

Embedded Ultrasonic Transducer Design and Wireless Communications for Intelligent Monitoring of Structures

---G. Hayward, G. Benny, A. Gachagan, R. Farlow, B. Hailu, and A. McNab, Centre for Ultrasonic Engineering, University of Strathclyde, 204 George Street, Glasgow, G1 1XW; D. Girma, Communications Division, University of Strathclyde, 204 George Street, Glasgow, G1 1XW; J. Hendry, Centre for Advanced Structural Materials, Mechanical Engineering, University of Strathclyde, Glasgow, G1 1XW, United Kingdom

---The application of a number of permanently installed sensors within a structure to accommodate a condition health monitoring system is of considerable interest to a number of industries. Such a system would require an integrated approach, in which the active sensing element, electronics and power source are incorporated into one self-contained unit. Furthermore, a wireless telemetry link to a central processing unit would greatly improve the versatility of the monitoring system. This paper describes the development of a wireless demonstrator system designed for the generation and detection of the fundamental symmetrical Lamb wave (So). Operating in its non-dispersive region, the system performance benefits from the high velocity and low attenuation characteristics associated with the So mode. The demonstrator system comprises two piezoceramic transducers embedded within an epoxy plate, drive and pre-amplification electronics, a microcontroller (to provide timing and signal processing functions) and a communications transceiver/antenna. This arrangement can be configured to operate in an active interrogation mode, with the transducers in either pitch-catch or pulse-echo operation, or as a passive Acoustic Emission (AE) sensor. Data processing of the received signal reduces the information prior to transmission over the wireless link, where the remote central processing unit can record the history of AE incidents, for example.

Wednesday, July 17, 2002

SESSION 21
GUIDED WAVES AND APPLICATIONS
M. Lowe, Chairperson
FRASER 4

- 1:30 PM** **Scattering of the SH_0 Mode from Geometrical Discontinuities in Plates**
---A. Demma, P. Cawley, and M. J. S. Lowe, Department of Mechanical Engineering, Imperial College of Science, Technology and Medicine, London, SW7 2BX, United Kingdom
- 1:50 PM** **Plate Wave Tomography for Structural Health Monitoring**
---L. R. F. Rose and C. H. Wang, Aeronautical and Maritime Research Laboratory, Defense Science and Technology Organization, 506 Lorimer Street, Fishermans Bend VIC 3207, Australia
- 2:10 PM** **Remote Monitoring of Plate-Like Structures Using Guided Waves Arrays**
---P. Fromme and P. Cawley, Department of Mechanical Engineering, Imperial College of Science, Technology and Medicine, London, SW7 2BX, United Kingdom; P. D. Wilcox, Department of Mechanical Engineering, University of Bristol, Queen's Building, University Walk, Bristol, BS8 1TR, United Kingdom
- 2:30 PM** **Models for Crack Detection in a Cylindrical Hole Containing an Elastic Layer and a Fluid-filled Cylindrical Hole**
---J. C. Aldrin, Computational Tools, 6797 Roanoake Ct., Gurnee, IL 60031; J. Achenbach, Northwestern University, 2137 N. Sheridan Road, Evanston, IL 60208
- 2:50 PM** **Reflection of the S_0 Lamb Mode from a 3D Circular Defect in a Plate, When the Incident Wave is Created by a Point Source**
---O. Diligent, M. J. S. Lowe, and P. Cawley, Department of Mechanical Engineering, Imperial College of Science, Technology and Medicine, London, SW7 2BX, United Kingdom; P. D. Wilcox, Department of Mechanical Engineering, University of Bristol, Queen's Building, University Walk, Bristol, BS8 1TR, United Kingdom
- 3:10 PM** **Coffee Break**
- 3:30 PM** **On the Detectability of Fatigue Crack Growth at Fastener Holes Using Guided Waves**
---P. Fromme, B. Masserey, and M. B. Sayir, Institute of Mechanical Systems, ETH Zurich, Zurich, Switzerland
- 3:50 PM** **Model-Based Analysis of 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, Richland, WA 99352
- 4:10 PM** **The Application of Finite Element Modeling to Long-Range Ultrasonic Testing**
---R. M. Sanderson, Finite Element Section, TWI, Granta Park, Great Abington, Cambridge, United Kingdom
- 4:30 PM** **Evaluation of Scale Inside of Water Supplying Pipes Using Guided Waves**
---S.-J. Song, Y. H. Kim, D. H. Lee, and J. S. Park, School of Mechanical Engineering, Sungkyunkwan University, Suwon, 440-746, Korea; H.-D. Lee and C.-H. Bae, Environmental Engineering Division, Korea Inst. Construction Technology, Koyang, Kyonggi, 411-712, Korea
- 4:50 PM** **Long Range Inspection of Rail Using Guided Waves**
---P. D. Wilcox, Department of Mechanical Engineering, University of Bristol, Bristol, BS8 1TR, United Kingdom; P. Cawley and M. J. S. Lowe, Department of Mechanical Engineering, Imperial College of Science, Technology and Medicine, London, SW7 2BX, United Kingdom; D. N. Alleyne, B. N. Pavlakovic³, M. J. Evans³, and K. A. Vine, ³Guided Ultrasonics Ltd., 17 Doverbeck Close, Ravenshead, Nottingham, NG15 9ER, United Kingdom

Scattering of the SH_0 Mode from Geometrical Discontinuities in Plates

---A. Demma, P. Cawley, and M. J. S. Lowe, Department of Mechanical Engineering, Imperial College of Science, Technology and Medicine, London, SW7 2BX, England

---The scattering of the fundamental SH_0 guided mode from steps and notches in plates is analyzed. Both the Finite Element and the modal decomposition methods are used to investigate the case of a step change in the thickness of the waveguide. The possibility of using the results of scattering from steps to predict the scattering from notches of different axial extent is then investigated. The basic idea is to superimpose the reflection from a down step (start of the notch) and an up step (end of the notch) to predict the reflection from the notch. The results obtained using this superposition method are compared with Finite Element simulations of reflections from complete notches of varying axial extent and with different depths, excellent agreement being obtained for all but very narrow notches. Furthermore, the superposition technique provides improved insight into the nature of the reflection behavior by revealing the effect of the non-propagating modes on the scattering from steps. The limits of the method have also been investigated.

Plate Wave Tomography for Structural Health Monitoring

---L. R. F. Rose and C. H. Wang, Aeronautical and Maritime Research Laboratory, Defense Science and Technology Organization, 506 Lorimer Street, Fishermans Bend VIC 3207, Australia

---With the recent development in the field of smart materials and structures, structural health monitoring (SHM) is emerging as a promising technique to significantly transform aircraft maintenance and aircraft structural integrity management. A successful implementation of SHM will need to integrate two distinct strands that have traditionally been pursued separately, viz. damage detection and damage assessment. Here damage detection implies finding the presence, location, type and severity of potential damage. In this regard, considerable effort has been devoted to the development and application of Lamb-waves based techniques for damage detection in plate-like structures, which act as wave guides. Although the Rayleigh-Lamb solution is exact, it is rather unwieldy for characterizing wave scattering at a damage, due to the need to account for the mode conversions among an infinite number of wave modes. Consequently, a new approach is required to quantitatively characterize the location and severity of damage. The purpose of this paper is to present a plate-wave approach, in which the Mindlin plate theory is employed to describe the flexural (anti-symmetric) and membrane (symmetric) waves. The relative simplicity of Mindlin's plate theory as opposed to the exact Rayleigh-Lamb solution renders it possible to reconstruct the image of a damage using a diffraction tomography algorithm. This paper will focus on recently developed theoretical concepts and results for detecting delamination damage in fibre-composite, plate-like structures. The modelling is based on the premise that the primary effect of a delamination is to reduce locally the plate's flexural stiffness. Accordingly, for the purposes of detection, the delaminated region can be treated as an inhomogeneity, having a lower (and generally complex) flexural stiffness. The interaction of plate waves with such inhomogeneities is solved explicitly by appealing to the Born approximation, which is appropriate for detecting relatively low levels of damage (barely visible impact damage). The computational algorithm for implementing the diffraction tomography will be briefly discussed.

Remote Monitoring of Plate-Like Structures Using Guided Waves Arrays

---P. Fromme and P. Cawley, Department of Mechanical Engineering, Imperial College of Science, Technology and Medicine, London, SW7 2BX, England; P. D. Wilcox, Department of Mechanical Engineering, University of Bristol, Queen's Building, University Walk, Bristol, BS8 1TR, England

---Many structures contain large plate-like components, which can suffer from severe corrosion and the development of cracks during their service life. Constant monitoring of such structures can be achieved with permanently attached remote sensors, which are able to monitor the condition of large areas from a single position without the need for moving parts. A self-contained, permanently attached array for the inspection of plates employing the first antisymmetric Lamb wave mode A_0 is designed and a prototype built. The excitation and measurement of the A_0 mode below the cutoff frequencies of the higher Lamb wave modes is performed using piezoelectric transducer elements, achieving good signal to noise ratio. The array design is optimized for the inspection of large areas with minimum power consumption, necessary for long term operation independent of external power sources. Topics addressed are the array layout, transducer elements used, efficient data processing, and the detectability of defects in the presence of a surrounding fluid, like oil. Preliminary measurement results achieved with the first array prototype on an isotropic, homogeneous plate containing simulated model defects are presented.

Models for Crack Detection in a Cylindrical Hole Containing an Elastic Layer and a Fluid-filled Cylindrical Hole

---J. C. Aldrin, Computational Tools, 6797 Roanoke Ct., Gurnee, IL 60031; J. A. Achenbach, Northwestern University, 2137 N. Sheridan Road, Evanston, IL 60208

---Prior work has demonstrated the means of generating 'leaky' Rayleigh waves about cylindrical holes to detect the existence of radial cracks. Current C-141 weep hole inspection requires that the wing be purged of fuel and that a coating be removed from each hole prior to inspection. This paper presents a study of ultrasonic NDE models for both a cylindrical hole containing an elastic layer and a fluid-filled hole. For a cylindrical hole with an elastic annulus, the dispersion relations were first derived and solved numerically for phase velocity and attenuation of the lowest modes. An analytical solution for the scattering response to an incident plane shear wave by a cylindrical hole with an elastic annulus was also derived. Parametric studies were performed to assess the sensitivity of leaky Rayleigh waves to variation in the geometric and material properties of the annulus. A BEM model was formulated for the scattering response of an incident shear wave by a fluid-filled hole with a notch. Through simulated studies, the measurement signals for both the reflected leaky Rayleigh wave and the first reradiated halo wave were found to indicate the presence of a crack. An inspection technique was developed and validated with experimental data.

Reflection of the S_0 Lamb Mode from a 3D Circular Defect in a Plate, When the Incident Wave is Created by a Point Source

---O. Diligent, M. J. S. Lowe, and P. Cawley, Department of Mechanical Engineering, Imperial College of Science, Technology and Medicine, London, SW7 2BX, England; P. D. Wilcox, Department of Mechanical Engineering, University of Bristol, Queen's Building, University Walk, Bristol, BS8 1TR, England

---The detection of corrosion in large plate-like structures such as oil tanks and pressure vessels is being investigated at Imperial College; a technique is being developed using guided waves which are excited and detected by a compact array transducer. In order to make use of the results obtained from such an array, it is necessary to understand the interaction of the guided waves with 3-dimensional defects such as corrosion patches. Initial Finite Element investigations of these interactions have been presented at recent QNDE meetings, assuming the incidence of a plane S_0 wave at low frequency and a circular defect which extends part-way or entirely through the 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 the present paper the studies are extended to consider the incident wave to come from a point source, representative of the practical transducer arrangement. The reflection of the S_0 mode from the defect is investigated using Finite Element simulations and confirmed by experiment. The study includes a range of defect diameters varying between a wavelength and three wavelengths of the S_0 mode at 170 kHz, and assesses the significance of the path lengths, wavelengths and defect sizes on the reflection characteristics.

On the Detectability of Fatigue Crack Growth at Fastener Holes Using Guided Waves

---P. Fromme, B. Masserey, and M. B. Sayir, Institute of Mechanical Systems, ETH Zurich, Zurich, Switzerland

---A common problem in aircraft maintenance is the development of fatigue cracks at fastener holes due to stress concentration. The nondestructive inspection of such aircraft structures using guided waves can result in a significant reduction of inspection time and costs, as guided waves propagate along the structure, thus allowing the inspection of large parts of the structure from a single position of the excitation transducer. In our experiments guided waves are excited by means of piezoelectric transducers and the out-of-plane displacement is measured using a heterodyne laser interferometer. The growth of fatigue cracks in tensile specimens during cyclic loading is monitored using the first antisymmetric Lamb wave mode A_0 . The detectability of small cracks is investigated and quantified by a parameter study at a model system and using finite difference calculations. As the main influence is found to be the ratio of wavelength and defect size, higher excitation frequencies, corresponding to shorter wavelengths should be employed. Measurements employing Rayleigh waves show a good detectability of a small quarter-elliptical fatigue crack, only partially grown through the thickness of the specimen.

Model-Based Analysis of High Frequency Guided Wave Inspection of Curved Shells

---R. Roberts, Center for NDE, Iowa State University, 1915 Scholl Road, Ames, IA 50011; A. Pardini and A. Diaz, Pacific Northwest National Laboratory, Battelle Boulevard, P. O. Box 999/MS K5-26, Richland, 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. In last year's meeting, we reported on the development of a computer model capable of predicting the complex signals observed in experiment. In this years work, we are using the computer model to gain an understanding of the origins of the numerous components comprising the received signal, and how the complex properties of the signal might be exploited to improve flaw characterization. Specifically, due to multiple the guided wave reflections, it is observed that for a single fixed transducer position, the flaw is simultaneously seen at numerous discreet angular aperture positions. This observation suggests the potential for significantly reducing the number of discreet transducer positions necessary to perform synthetic aperture focusing, for the purpose of estimating flaw size. Progress in the development this potential improvement will be summarized.---Funded by the Tank Focus Area Program, Office of Environmental Management, Office of Science and Technology, US Department of Energy.

The Application of Finite Element Modeling to Long-Range Ultrasonic Testing

---Ruth M. Sanderson, Finite Element Section, TWI, Granta Park, Great Abington, Cambridge, United Kingdom

---Long-range ultrasonic testing systems allow pipes to be tested for corrosion with only a small section of insulation removed in an accessible region. Another possible application of the long-range ultrasonic testing technique is for rails. Accidents, such as the one at Hatfield, UK in October 2000, have highlighted the need for substantial improvement of the integrity of rails, and hence also for the further development of long-range ultrasonic testing techniques. Like pipes, it would be time consuming and therefore expensive to use current short range techniques to test rails. Finite element propagation models have been carried out in prismatic components. Both two-dimensional and three-dimensional models have been used to study the effect of variables such as frequency, component geometry, wave mode and flaw size on the reflection coefficients of guided waves. The reflection coefficient indicates the strength of the reflected pulse from a flaw and is therefore an important parameter in long-range ultrasonic testing. The results provide an insight into the behavior of guided waves in different situations and the work aids the continuing development of guided wave systems for testing pipes. The potential application of the long-range ultrasonic method to the large scale screening of rails is also discussed.

Evaluation of Scale Inside of Water Supplying Pipes Using Guided Waves

---S.-J. Song, Y. H. Kim, D. H. Lee, and J. S. Park, School of Mechanical Engineering, Sungkyunkwan University, Suwon, 440-746, Korea; H.-D. Lee and C.-H. Bae, Environmental Engineering Division, Korea Institute of Construction Technology, Koyang, Kyonggi, 411-712, Korea

---Since scale in pipes reduces the flow rate, the quantitative evaluation of scale is essential for the proper maintenance of pipes. Guided waves were employed to estimate the amount of scale in water supplying pipes. Using variable angle wedge, several modes of guided waves were generated, and identified by short time Fourier transforms of received signal. In the experiments, observed were that the amplitude of F(M,2) modes decreased significantly as the amount of scale increased. To interrogate this phenomenon, wave structures were investigated. It was found that energy of F (M,2) modes concentrated on the inside wall of the pipe. Therefore, scale damps out the waves propagating on the inside wall, and reduces the amplitude of F(M,2) modes significantly. The present study recommends that F(M,2) modes are optimal to evaluate scale in water supplying pipes.

Long Range Inspection of Rail Using Guided Waves

---Paul D. Wilcox, Department of Mechanical Engineering, University of Bristol, Bristol, BS8 1TR, England; Peter Cawley and Michael J. S. Lowe, Department of Mechanical Engineering, Imperial College of Science, Technology and Medicine, London, SW7 2BX, England; David N. Alleyne, Brian N. Pavlakovic³, Mark J. Evans³, and Keith A. Vine, ³Guided Ultrasonics Ltd., 17 Doverbeck Close, Ravenshead, Nottingham, NG15 9ER, England

---Ultrasonic techniques have been used for many years for the inspection of rail. These measurements can detect the presence of a wide variety of defects but there are practical difficulties with the technology. For example, large transverse cracks of the type likely to cause catastrophic failure can be detected but these are often masked by small non-critical cracks at shallow angles close to the running surface of the rail. Also, alumino-thermic welds are difficult to inspect due to the attenuation of the weld material at ultrasonic frequencies. The authors have developed a new technique for inspecting rail that makes use of guided acoustic waves. These waves travel along the rail, for tens or hundreds of meters, and are partially reflected by any defects that are present. They are particularly sensitive to transverse defects and because they are used at relatively low frequency they are not significantly attenuated by weld material. The guided wave modes that can exist in a rail are found using a 2-dimensional finite element (FE) technique. Experimental measurements are used to identify a number of candidate modes that are suitable for long range testing. The interaction of these candidate modes with a wide variety of defect geometries is investigated with 3-dimensional time-marching FE models. This study enables characteristic mode conversion signatures for various defects and features to be obtained. A prototype transducer rig has been developed and tested on a variety of rail samples containing artificial defects and also on in-service rails. Results from these tests are presented and compared with FE predictions.

Wednesday, July 17, 2002

SESSION 22
UT TRANSDUCERS, FIELDS, AND SENSORS
I. Komsky, Chairperson
FRASER 3

- 1:30 PM** **New Piezocomposite Transducers for Improvement of Ultrasonic Inspections**
---P. Dumas, J. Pogue, and G. Fleury, Imasonic SA, 15 rue Alain Savary, 25000 Besancon, France
- 1:50 PM** **Application of Ultrasonic Transducers with Flexible Polymer Substrates to Dry-Coupled Inspection of Aircraft Structures**
---I. N. Komsky, Center for Quality Engineering and Failure Prevention, Northwestern University, 2137 N. Sheridan Road, Evanston, IL 60208
- 2:10 PM** **An Effective Generation of Lamb Waves in a Thin Plate Using Laser Line Array Illumination and Their Propagation Characteristics**
---T. S. Jang and J. J. Lee, Department of Mechanical Engineering, Korea Advanced Institute of Science and Technology, Daejeon, Korea; S. S. Lee, Nondestructive Measurement Group, Korea Research Institute of Standards and Science, Daejeon, Korea
- 2:30 PM** **Ultrasonic Array Approach for the Evaluation of Electrofusion Joints of Polyethylene Gas Piping**
---H. J. Shin and Y. H. Jang, INDE System Co., Ltd. 300 Chonchon-dong, Jangan-gu, Suwon, 440-746, South Korea; J.-R. Kwon, Korea Gas Safety Corporation, 332-1, Daeya-dong, Shihung-Shi, Kyunggi-do, 429-712, South Korea
- 2:50 PM** **Guided Wave Beam Steering and Modal Selectivity from Omni-directional Transducer Arrays**
---P. D. Wilcox, Department of Mechanical Engineering, Queens Building, University of Bristol, Bristol BS8 1TR, United Kingdom
- 3:10 PM** **Coffee Break**
- 3:30 PM** **Two-Dimensional Numerical Simulation of Ultrasonic Transmitting and Receiving Transducers Using the Mass-Spring Lattice Model**
---H. Yim and E. Baek, Department of Mechanical Engineering, Hongik University, Seoul, 121-791, Korea
- 3:50 PM** **A Modular Multi-Gaussian Beam Model for Isotropic and Anisotropic Media**
---L. W. Schmerr, Jr., Center for NDE and the Department of Aerospace Engineering and Engineering Mechanics, Iowa State University, Ames, IA 50011; A. Sedov, Department of Mechanical Engineering, Lakehead University, Thunder Bay, Ontario, Canada, P7B 5E1
- 4:10 PM** **Attenuation Coefficient Estimation Using Equivalent Diffraction Points with Multiple Interface Reflections**
---T. P. Lerch, Industrial and Engineering Technology Department, Central Michigan University, Mount Pleasant, MI 48859; S. P. Neal, Mechanical and Aerospace Engineering, University of Missouri – Columbia, Columbia, MO 65211-0001
- 4:30 PM** **Fringing Electric Field Sensors for Non-Destructive Detection of Material Properties**
---S. R. Cantrell and A. V. Mamishev, Department of Electrical Engineering, University of Washington, Building 352500, EE/CSE, Room 253, Seattle, WA 98195-2500
- 4:50 PM** **Practical Application of PVDF Sensors for Damage Detection in Metallic and Composite Structures**
---O.-Y. Kwon and Y.-K. Kang, Department of Mechanical Engineering, Inha University, Incheon 402-751, Korea; D. Brosig and Y. A. Dzenis, Department of Engineering Mechanics, University of Nebraska, Lincoln, NE 68588

New Piezocomposite Transducers for Improvement of Ultrasonic Inspections

---P. Dumas, J. Pogue, and G. Fleury, Imasonic SA, 15 rue Alain Savary, 25000 Besancon, France

---The increasing need for improved productivity and reliability of tests, adaptation to inspection of particular materials due to their shapes, their structures or quite simply of their location, constitutes the new stakes of the ultra sound non destructive testing. Thanks to its electroacoustical and mechanical characteristics, the piezocomposite technology makes possible the manufacturing of new kinds of transducers such as high performances single element, aspherical or phased-array transducers, which allows to face these new challenge. Moreover, the use of this material in a frequency range up to 20 MHz, open the door to new inspections possibilities. After a presentation of this technology and its advantages, this paper describes different examples in sensitive various sectors, such as nuclear or aeronautic, where the realization of phased-array, or single element piezocomposite transducers constituted a performance and reliable solution.

Application of Ultrasonic Transducers with Flexible Polymer Substrates to Dry-Coupled Inspection of Aircraft Structures

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

---The complexity of the couplant delivery and removal systems makes liquid ultrasonic couplants not practical or desirable for the field inspections of aircraft structures. Advanced aircraft materials with porous, curved, or non-uniform surfaces are also very sensitive to the application of such ultrasonic couplants. To overcome the problems associated with the liquid couplant medium, a number of polymer films have been developed to transmit the ultrasound through a dry interface. These materials are very flexible so even low pressure loading is sufficient to adapt the films to the irregular inspection surfaces. Several polymer films have been evaluated to develop dry couplant substrates for the multi-element transducer modules. The modules will be utilized to detect and characterize fatigue cracks and corrosion spots in the multi-layer aircraft structures. Ultrasonic properties of the polymer films were measured and compared with the properties of plastic or rubber-like materials commonly used for ultrasonic applications. Experiments have been carried out to analyze propagation of longitudinal and shear waves in the films. Two different types of the ultrasonic modules with the flexible polymer substrates are being developed. The influence of the surface condition on the module performance was evaluated for both types of the modules.---This material is based upon work supported by the Federal Aviation Administration under Contract # DTFA03-98-D-00008, Delivery Order # DTFA03-01-F-IA049 and performed at Northwestern University as part of the Center for Aviation Systems Reliability program through the Airworthiness Center of Excellence.

An Effective Generation of Lamb Waves in a Thin Plate Using Laser Line Array Illumination and Their Propagation Characteristics

---T. S. Jang and J. J. Lee, Department of Mechanical Engineering, Korea Advanced Institute of Science and Technology, Daejeon, Korea; S. S. Lee, Nondestructive Measurement Group, Korea Research Institute of Standards and Science, Daejeon, Korea

---Generation and detection of Lamb waves can offer a rapid and reliable non-destructive testing technique. In this study, symmetric and antisymmetric Lamb modes are excited in low-frequency-thickness regime by illuminating a thin plate with an array of Q-switched Nd:YAG laser-generated line sources. The propagation of laser-generated Lamb waves is detected by measuring the out-of-plane displacements in a non-contact manner using the fiber optic Sagnac interferometer. A finite element model is established for the explicit dynamic analysis of thermoelastic propagation of laser-generated lamb modes. The numerical simulation of the elastic wave propagation in a thin plate presents the fundamental understanding of Lamb modes generated by laser line array. Characteristics of laser-generated Lamb wave due to the wavelength of the Lamb mode, and the interaction between various defects and symmetric and antisymmetric Lamb modes are investigated experimentally. An effective generation of single Lamb mode with relatively small dispersion and narrow bandwidth is presented. Surface breaking cracks are determined from the mode-converted wave signal, and the sensitivity of the Lamb modes to various defects is investigated experimentally.

Ultrasonic Array Approach for the Evaluation of Electrofusion Joints of Polyethylene Gas Piping

---Hyeon Jae Shin and You Hyun Jang, INDE System Co., Ltd., 300 Chonchon-dong, Jangan-gu, Suwon, 440-746, South Korea; Jeong-Rock Kwon, Korea Gas Safety Corporation, 332-1, Daeya-dong, Shihung-Shi, Kyunggi-do, 429-712, South Korea

---Polyethylene (PE) is one of widely used material for piping. Especially, the demand of PE piping for gas distribution is being increased. Thousands of kilometers of PE piping have joints at every few meters, and the joint is the weak point that should be inspected before the pipe begins service. However, there are not suitable nondestructive testing methods to evaluate the joint of electrofusion (EF) type polyethylene piping. In this study, ultrasonic array technique is applied to obtain the ultrasonic cross section images of the EF joints. In the use of ultrasonic waves to inspect the EF joint, the most difficult challenge is to distinguish the wound heating wire at the joint interface from the joint failure. Ultrasonic focusing with array technology is promising method to increase inspection resolution and sensitivity. Array technique with proper selection of frequency was proved to collect clear digital ultrasonic images of the cross section of EF joints and to tell the wound wire from flaw and imperfect bonding.

Guided Wave Beam Steering and Modal Selectivity from Omni-directional Transducer Arrays

---P. D. Wilcox, Department of Mechanical Engineering, Queens Building, University of Bristol, Bristol BS8 1TR, United Kingdom

---The union of guided wave science with transducer array technology has enabled highly sophisticated sensors to be built that can provide 360 ϕ^a guided wave B scans of the structure on which they are used. Applications for such sensors include portable devices for rapidly inspecting storage tanks and permanently attached sensors for large area structural health monitoring. There are several key differences between the signal processing needed for guided wave arrays and that used in more conventional bulk wave arrays. First, there is the multi-modal nature of guided wave propagation and the need to achieve modal purity. Second, there is the need to account for the dispersion of guided wave modes. Third and most importantly, is the fact that guided waves can be incident on an omni-directional guided wave array from any angle because the array is essentially in the middle of a wave propagation system rather than at an edge. The key to successful array operation is to be able to achieve equally good directionality in all directions with maximum sidelobe suppression. A signal processing technique is presented that addresses all these issues. It is also shown how the technique can be used as a design tool to assess array performance and minimize the number of elements required in the array.

Two-Dimensional Numerical Simulation of Ultrasonic Transmitting and Receiving Transducers Using the Mass-Spring Lattice Model

---Hyunjune Yim and Eunsol Baek, Department of Mechanical Engineering, Hongik University, Seoul, 121-791, Korea

---Two-dimensional numerical models for ultrasonic transducers were developed to simulate ultrasonic testing based upon the mass-spring lattice model (MSLM). Various transmitting transducers were modeled by imposing appropriate traction conditions within a finite region on the mass-points along a specimen boundary. Radiated wave fields from transducers having various center frequencies, bandwidths, and beam angles were computed by adjusting the time-domain profile, duration, and direction of the imposed tractions. Receiving transducers were modeled by using the electro-mechanical reciprocity to find an electrical voltage signal from an elasto-dynamic field that is numerically produced by the MSLM. By combining these models of transmitting and receiving transducers with the existing MSLM, several examples of A-scan results for typical ultrasonic testing setups were obtained and are presented in this paper. Packaging all these components together in the graphic user interface (GUI) environment will provide a very useful simulator for ultrasonic testing that can be run in-situ on now ubiquitous portable personal computers.

A Modular Multi-Gaussian Beam Model for Isotropic and Anisotropic Media

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

--- As is well known, Gaussian beams can be used as fundamental building blocks to model the sound beam generated by circular focused and unfocused piston transducers. Using a superposition of as few as ten Gaussians, for example, one can model the sound from a piston transducer radiating into isotropic and anisotropic elastic media, even through multiple curved interfaces. However, when more than one interface is involved, the expressions governing the propagation and transmission/reflection of Gaussian beams become algebraically rather complex. Here it will be shown that by using the slowness coordinates throughout the beam modeling process, a Gaussian beam can be simply expressed in terms of a single 2x2 matrix, M . Laws governing both the amplitude and phase changes of the Gaussian can be obtained directly in terms of M and placed in a form that allows one to transform a Gaussian beam, in one step, across multiple anisotropic media and through multiple curved interfaces. The form that is used is a generalization of the familiar ABCD matrices of Gaussian optics, where here the A, B, C, D terms are themselves 2x2 matrices. This simplified and modularized Gaussian beam model makes it very convenient to model highly complex inspection problems.---This work was supported by the NSF Industry/University Cooperative Research program.

Attenuation Coefficient Estimation Using Equivalent Diffraction Points with Multiple Interface Reflections

---T. P. Lerch, Industrial and Engineering Technology Department, Central Michigan University, Mount Pleasant, MI 48859; Steven P. Neal, Mechanical and Aerospace Engineering, University of Missouri – Columbia, Columbia, MO 65211-0001

---The ultrasonic attenuation coefficient of a fluid or solid material is an acoustic parameter routinely estimated in nondestructive evaluation (NDE) and biological tissue characterization. In this paper, a new measurement and analysis technique for estimating the attenuation coefficient as a function of frequency for a fluid or solid is described. This new, broadband technique combines two commonly used concepts in ultrasonic NDE: (1) frequency spectrum amplitude ratios of front surface, first back surface, and second back surface reflections from interfaces of materials with plate-like geometries, and (2) equivalent diffraction points within the transducer wave field. The new technique simplifies the attenuation coefficient estimation process by eliminating the need to make diffraction corrections. The approach yields estimates of the attenuation coefficient, reflection coefficient, and material density without the need for the transducer characterization step, i.e., experimental characterization of the effective radius and focal length of the transducer, required when careful calculated diffraction corrections are applied. Attenuation coefficient and reflection coefficient estimates are presented for water and three solids with estimates based on measurements made with two different transducers. This research was supported in part by the Cancer Research Center (CRC), Columbia, MO, the Department of Radiology at the University of Missouri-Columbia (MU), and the National Science Foundation.---This research was performed while Dr. Lerch was a CRC Postdoctoral Fellow in Mechanical and Aerospace Engineering at MU.

Fringing Electric Field Sensors for Non-Destructive Detection of Material Properties

---S. R. Cantrell and A. V. Mamishev, Department of Electrical Engineering, University of Washington, Building 352500, EE/CSE, Room 253, Seattle, WA 98195-2500

---Fringing electric field dielectrometry sensors are commonly used in non-destructive testing of polymeric and organic compounds. The advantages of such sensors include the option of single-sided access to the material under test, high precision of impedance measurement circuits, ability to profile spatial variation of material properties, modularity of sensor design, spectroscopic measurement mode, and relatively low cost. In recent years, non-contact measurement techniques have received increasing attention in a broad range of process control applications. Examples include control of curing dynamics of composite materials, aging status of electrical insulation, and moisture distribution in organic materials, such as paper and food products. The presentation will cover recent work on fringing electric field sensors within this research group. Topics will include the ability of these sensors to non-destructively detect cracks, voids, and moisture concentration within target materials (e.g. power cable insulation); chemometric challenges; approaches to sensor design; the presentation of sample data and analysis; and the future of this fringing electric field sensor research.

Practical Application of PVDF Sensors for Damage Detection in Metallic and Composite Structures

---O.-Y. Kwon and Y.-K. Kang, Department of Mechanical Engineering, Inha University, Incheon 402-751, Korea; D. Brosig and Y. A. Dzenis, Department of Engineering Mechanics, University of Nebraska, Lincoln, NE 68588

---The practical applicability of polyvinylidene fluoride (PVDF) sensors was investigated by employing them to the detection of fatigue damage in aluminum panels with simulated fastener holes and in composite specimens with adhesively bonded joints. The PVDF sensor has several advantages over the lead-zirconate-titanates (PZT) sensor including the cost-effectiveness, the flexibility as plastic films, and the low profile as a few tens of microns. A commercially available PVDF sensor was employed to detect acoustic emission (AE) due to fatigue cracks in the single-lap joints of carbon/epoxy (CFRP) specimens and in the smooth notch root of Al2024-T3 panels. With the acceptable level of the signal-to-noise ratio (SNR), the result appeared useful to determine the crack front during fatigue loading by AE linear location. Composites produce very energetic AE signals as expected so that the very inexpensive and disposable PVDF sensors can be utilized for structural health monitoring of composite structures. Since the SNR of the signals from the aluminum panel was not as high as that from the composites, a special treatment of wavelet transform de-noising was necessary to precisely determine the initiation time and the location of fatigue cracks by two-dimensional AE source location.

Wednesday, July 17, 2002

SESSION 23
DATA FUSION AND SIGNAL PROCESSING TECHNIQUES
S. Udpa, Chairperson
SMATE 150

- 1:30 PM** **Data Fusion Methods for the Optimal Mixing of Multi-Frequency Eddy Current Data**
---Z. Liu, S. Safizadeh, D. S. Forsyth, and B. A. Lepine, Institute for Aerospace Research, National Research Council Canada, Building M14, 1200 Montreal Road, Ottawa, ON Canada K1A 0R6
- 1:50 PM** **Time-of-Flight Measurements from Eddy Current Tests**
---Y. Tian, A. Tamburrino, S. S. Udpa, and L. Udpa, Department of Electrical and Computer Engineering, Michigan State University, 2120 Engineering Building, East Lansing, MI 48824-1226
- 2:10 PM** **Multisensor Fusion of Surface Acoustic Wave and Eddy Current Techniques for Part Inspection**
---T. Braun¹ and E. Blasch², ¹Veridian Engineering Division, Info & Space Systems Group, 2700 Indian Ripple Road, Dayton, OH 45440-3896; ²Air Force Research Laboratory, Sensors Directorate, WPAFB, OH 45433
- 2:30 PM** **Integrated Data Acquisition System for Data Fusion Applications**
---S. C. Chan, L. Udpa, and S. S. Udpa, Department of Electrical and Computer Engineering, Michigan State University, 2120 Engineering Building, East Lansing, MI 48824-1226
- 2:50 PM** **Wavelet for Ultrasonic Image Compressing and Flaw Positioning**
---W. Cheng, K. Tsukada, and K. Hanasaki, Measurement and Evaluation Division, Department of Earth Resources Engineering, Kyoto University, Yoshida-Honmachi, Sakyo-ku, Kyoto 606-8501, Japan
- 3:10 PM** **Coffee Break**
- 3:30 PM** **Crack Detection for Aircraft Holes with Limited Accessibility Containing Fasteners and Sealant**
---J. C. Aldrin, Computational Tools, Gurnee, IL 60031; J. R. Mandeville and D. R. Judd, SAIC Ultra Image Int., New London, CT; R. T. Mullis, WR-ALC/TIEDM, Robins AFB, GA; C. V. Kropas-Hughes, AFRL-MLLP, Wright-Patterson AFB, OH
- 3:50 PM** **Complex Wavelet Transform in TOFD Signal Processing**
---E. P. Moura, I. C. Silva, M. H. S. Siqueira, J. M. A. Rebello, Metallurgy and Materials Department, COPPE, Federal University of Rio de Janeiro, Riode Janeiro, RJ, Caixa Postal 68505, CEP 21945-970, Brazil
- 4:10 PM** **Neural Network Analysis for Evaluating Resistance Spot Welding Process**
---K.-C. Kim, A. Chertov, and R. G. Maev, Physics Department, University of Windsor, 401 Sunset Street, Windsor, Ontario, N9A6Y7, Canada
- 4:30 PM** **New Modular Ultrasonic Signal Processing Building Blocks for Real-Time Data Acquisition and Post Processing**
---W. Weber, Utex Scientific Instruments, 2319 Dunwin Drive, Unite 8, Mississauga, Ontario, Canada L5L 1A3
- 4:50 PM** **Model-Inspired Enhancement of the TIFD for Effective Flaw Signal Identification in Ultrasonic Testing of Welded Joints**
---H. J. Jung, H.-J. Kim, Y. H. Kim, and S.-J. Song, School of Mechanical Engineering, Sungkyunkwan University, Suwon, Korea

Data Fusion Methods for the Optimal Mixing of Multi-Frequency Eddy Current Data

---Z. Liu, S. Safizadeh, D. S. Forsyth, and B. A. Lepine, Institute for Aerospace Research, National Research Council Canada, Building M14, 1200 Montreal Road, Ottawa, ON Canada K1A 0R6

---Eddy current nondestructive inspection methods are very widely used. In many inspection situations, the desired flaw signal is difficult to distinguish from signals arising from common conditions such as varying probe liftoff or changes in the structure of the item under inspection. This is the case in the inspection of splice joints used in transport aircraft fuselage construction; where paint, rivets, liftoff, and interlayer gaps all affect the eddy current signal response. In order to reduce these spurious effects, multiple frequencies are used simultaneously, and then mixed. Mixing eddy current signals is essentially a vector addition, and the inspector must change the phase and amplitude of the vectors in order to achieve the desired result. The optimal mixing can be determined through experiment, through analysis, or a combination. This can be a very difficult problem to optimize. Many data fusion methods can be viewed as optimization methods, and in this paper, we describe the use of data fusion methods to obtain optimal mixing of two eddy current signals from the inspection of service-retired aircraft lap splice joints for the detection and quantification of corrosion damage.

Time-of-Flight Measurements from Eddy Current Tests

---Y. Tian, A. Tamburrino, S. S. Udpa, and L. Udpa, Department of Electrical and Computer Engineering, Michigan State University, 2120 Engineering Building, East Lansing, MI 48824-1226

---Data fusion techniques are employed based on the premise that two or more carefully designed NDE tests are potentially capable of offering additional information concerning the test object relative to what can be garnered from a single test. The ability to extract information from multiple tests is enhanced when tests based on different physical phenomena are employed. However, information from a heterogeneous set of transducers cannot be fused unless the data is mapped to a common 'format'. As an example, information from diffusion phenomena based eddy current tests cannot be directly fused with information from wave based ultrasonic tests. The eddy current method cannot, for example, provide time-of-flight information that can be combined from estimates derived from ultrasonic tests. This paper presents a simple solution to address the problem by employing the so-called Q-transform. The Q-transform can be employed to map diffusive fields, such as those generated by eddy current probes, onto equivalent propagating wave fields generated by sensors that rely on wave phenomena such as ultrasonic NDT sensors. The paper illustrates how the distance between a defect and the source can be extracted from eddy current data generated using carefully selected excitation signals. Numerical results and comparisons with analytical predictions are presented.

Multisensor Fusion of Surface Acoustic Wave and Eddy Current Techniques for Part Inspection

---T. Braun¹ and E. Blasch², ¹Veridian Engineering Division, Info & Space Systems Group, 2700 Indian Ripple Road, Dayton, OH 45440-3896; ²Air Force Research Laboratory, Sensors Directorate, WPAFB, OH 45433

---Multisensor fusion is a technique that combines different sensor modalities to complement sensor types for robust applications. Such an example of multisensor fusion is part inspection for surface defects. We seek to identify methods of integrating the multisensor data elements for optimal defect detection via data fusion techniques. In this paper, we develop a methodology to combine Surface Acoustic Wave (SAW) NDI techniques with Eddy current techniques. SAW are believed to be more applicable than conventional ultrasonic NDI techniques for thin-plate titanium part inspection. In the Eddy current techniques, depth of penetration can be used to detect hidden cracks. We investigate newer Eddy Current technologies such as Meandering Winding Magnetometer (MWM) and Giant Magneto Resistive (GMR) sensors. MWM technology boasts a conformable eddy current probe capable of defect detection in the near-surface and sub-surface range. GMR can detect subsurface flaw detection, as well as adding potential wide area detection capabilities. Upon completion of a SAW inspection, any suspect areas are re-inspected using Eddy current techniques for a more thorough inspection. The combination of the three techniques will enable a more robust part defect inspection that fuses coarse and fine surface area coverage and a preliminary analysis of these techniques using data fusion proposed.

Integrated Data Acquisition System for Data Fusion Applications

---S. C. Chan, L. Udpa, and S. S. Udpa, Department of Electrical and Computer Engineering, Michigan State University, 2120 Engineering Building, East Lansing, MI 48824-1226

---One of the major issues concerned with the implementation of data fusion techniques is related to the issue of data registration. A popular technique employed for registering images involves the minimization of the mean square error between one of the images and an affine transformation version of the second image. Alternately fiducial markers are employed to register the images. This paper describes a data acquisition system that circumvents the problem by using a single scanning platform for acquiring images using two transducers. The system is modular in that it allows future system expansions as well as hardware and software upgrades very easily. Results obtained morphological data fusion approaches on images obtained using the system are presented.

Wavelet for Ultrasonic Image Compressing and Flaw Positioning

---W. Cheng, K. Tsukada, and K. Hanasaki, Measurement and Evaluation Division, Department of Earth Resources Engineering, Kyoto University, Yoshida-Honmachi, Sakyo-ku, Kyoto 606-8501, Japan

---Ultrasonic has been widely used in NDT and medical applications, the form of whose output signal is always image. Then there arises the problem of image compression because of the pressure caused by the mess image data on both storage and transmission. We apply wavelet to get a high compression ratio and serve for the NDT purpose. Based on the knowledge that the image and the ultrasonic characters are far different and complex from pure data, we center on comparing various discrete biorthogonal wavelets to find the best bases that achieve higher compression efficiency and less distortion. Besides, we put "weight" to wavelet transformed coefficients according to the specific frequency characters of the ultrasonic signals. Arithmetic coding method is also employed to further increase the compression ratio. We give a complete and systematic method of compressing and preprocessing the ultrasonic detecting signal from its original form to being ready for NDT analysis. The results show that it can gain ideal compression ratio and the reconstructed images emphasize the parts of interests thus facilitates the flaw detection.

Crack Detection for Aircraft Holes with Limited Accessibility Containing Fasteners and Sealant

---John C. Aldrin, Computational Tools, Gurnee, IL 60031; John R. Mandeville and David R. Judd, SAIC Ultra Image Int., New London, CT; R. T. Mullis, WR-ALC/TIEM, Robins AFB, GA; C. V. Kropas-Hughes, AFRL-MLLP, Wright-Patterson AFB, OH

---Prior work has shown the means of generating 'leaky' Rayleigh waves about aircraft holes containing fasteners to detect the presence of surface breaking cracks. Field testing of an initial ultrasonic NDE methodology for C-141 rib clip holes and C-130 beam cap holes demonstrated issues primarily due to variability of the hole interface condition from fastener loading and sealant condition. Also, variability in the riser width coupled with the requirement to detect small corner cracks provided additional challenges. The focus of this study is to further examine and develop a means of crack detection for holes containing fasteners with variable interface conditions. 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 variable stiffness interface between the hole and the insert. Through simulated and experimental studies, a model-based data classification approach was designed that first characterizes the hole interface condition and then directs the classifier based upon the measured condition. Multidimensional signal processing methodologies were also incorporated to address the characterization of superimposed signals. Through application of this methodology, improvements in crack detection performance are achieved.

Complex Wavelet Transform in TOFD Signal Processing

---E. P. Moura, I. C. Silva, M. H. S. Siqueira, João M. A. Rebello, Metallurgy and Materials Dept., COPPE, Federal University of Rio de Janeiro, Riode Janeiro, RJ, Caixa Postal 68505, CEP 21945-970, Brazil

---Time of Flight Diffraction (TOFD) technique is being widely used in weld inspection. This technique is not based in echoes amplitude, but uses the transit time between different tip-diffracted ultrasonic signals. The separation of diffracted signals from small discontinuities or from discontinuities close to surfaces is a limitation of this technique. Both lateral, diffracted by each crack tips and backwall waves have as characteristic a 180-degree phase shift. The use of Complex Wavelet Transform (CWT) - in contrast to Fourier Transform - is able to detect those signal phase shift without losing time information. In present work the CWT was used to analyze A-Scan signals captured during weld inspection by a 5 MHz and 60 degree probe on steel pipeline 168 mm diameter and 11 mm wall thickness. The results show the versatility of CWT to process that kind of signals, since correct scale in Complex Continuous Wavelet was been selected, to remove high frequency noise components and mainly to visualizes the phase shift of tip-diffracted signals in time domain. In this way the sizing of defects was made by measuring the time between the inversions of phase spectrum. In phase spectrum this measurement become easier and clear, without loss of time information and evaluating the defect position determination.

Neural Network Analysis for Evaluating Resistance Spot Welding Process

---K.-C. Kim, A. Chertov, and R. G. Maev, Physics Department, University of Windsor, 401 Sunset Street, Windsor, Ontario, N9A6Y7 Canada

---In previous research, embedded water-cooled broadband ultrasonic transducers were installed into a pedestal and scissors spot welder. The setup allowed for acquiring data during welding by using through-transmitted and reflected pulsed wave modes. By analyzing experimental data, a number of interesting features have been noticed. Most of all, the relationship between the Maximum Time Of Flight(MTOF) and the actual nugget size measured from peel test showed a strong correlation of about 80%. Such relationship allows us to estimate the nugget size based on only one parameter, MTOF, without peeling. To increase the reliability of the estimated nugget size as higher then 80%, the nugget size should be estimated from multi input parameters, including not only MTOF, but also, welding current, welding cycles and etc. For multi input parameter cases such as this one, we used the neural network analysis. In this research, the back propagation neural network (NN) model used for estimating the nugget size. For this, seven kinds of data series were prepared. Before the neural network calculation, all input parameters and target parameter (nugget size) were normalized. The estimated nugget size was affected on the normalized constant and middle layer. In order to increase the relationship between the actual nugget size measured from the peel test and the estimated nugget size calculated from NN analysis, the normalized constant and the number of middle layer were chosen by trial and error. By the trained NN, we can achieve almost 90% of the relationship between actual and estimated nugget size. The trained NN can achieve almost a 90% correlation between actual and estimated nugget size. Also, two kinds of simulation were performed to find which input parameter gave the strongest effect on the nugget size. As a result of the simulation analyses, it was clarified which one of the sets of input parameters are the most important factor in achieving a strong correlation.

New Modular Ultrasonic Signal Processing Building Blocks for Real-time Data Acquisition and Post Processing

---W. Weber, Utex Scientific Instruments, 2319 Dunwin Drive, Unit 8, Mississauga, Ontario, Canada L5L 1A3

---A suite of basic signal processors has been constructed that can be cascaded together to form more complex processors without the need for programming. The data structures between each of the processors are handled automatically allowing for the processing of images, waveform arrays and single values. The processors are part of Winspect Data Acquisition software. The processors are fast enough to work on A-scan signals while scanning. Their primary use is to extract features or to reduce the volume of data. The cascaded processors work equally well on existing data as a post processing engine. Researchers are able to call their own Matlab or C-code from anywhere within the processor structure. A built-in formula node processor which uses a simple algebraic editor may make external user programs unnecessary. This paper discusses how these processors are constructed and used.

Model-Inspired Enhancement of the TIFD for Effective Flaw Signal Identification in Ultrasonic Testing of Welded Joints

---Hee Jun Jung, Hak-Joon Kim, Young H. Kim, and Sung-Jin Song, School of Mechanical Engineering, Sungkyunkwan University, Suwon, Korea

---Interpretation of ultrasonic testing signals for the quantitative flaw characterization usually involves three steps including identification, classification and sizing. Among these three steps, the identification of flaw signal is the first problem to be considered. However, it is a truly difficult task due to the presence of non-relevant indications caused by various geometric reflectors. To address such a difficulty, previously we have proposed the TIFD (technique for identification of flaw signals using deconvolution). However, the TIFD proposed initially has some drawbacks that prevent practical field application. This paper will describe the enhancement of the TIFD that can overcome these drawbacks of the initial TIFD approach. The enhanced approach adopts only a single reference signal which is the reflection from the circular part of IIW standard block. Furthermore, deconvolution patterns are characterized by use of theoretical ultrasonic testing models. This paper will also describe the performance of this enhanced approach with initial experiments.

Wednesday, July 17, 2002

SPECIAL EVENING SESSION
Location to be Announced

8:00 PM **Opportunities for NDE in Security Problems**

Thursday, July 18, 2002

SESSION 24
LASER ULTRASONICS AND APPLICATIONS
H. Ringermacher and M. Dubois, Co-Chairpersons
FRASER 4

- 8:30 AM** **“Keynote”—Laser Ultrasonic System for On-Line Steel Tube Gauging**
---J.-P. Monchalain, M. Choquet¹, C. Padioleau, C. Néron, D. Lévesque, A. Blouin, C. Corbeil, R. Talbot, A. Bendada, and M. Lamontagne, Industrial Materials Institute, National Research Council of Canada, 75, de Mortagne Boulevard, Boucherville, Québec, J4B 6Y4, Canada; R. V. Kolarik II, G. V. Jeskey², E. D. Dominik², L. J. Duly, K. J. Samblanet, S. E. Agger, K. J. Roush, and M. L. Mester, The Timken Company, 1835 Dueber Avenue Southwest, Canton, OH 44706; ¹Now with Tecnar Automation Ltd., 1321 Hocquart, St.-Bruno, Québec J3V 6B5, Canada, ²Retired from The Timken Company
- 8:50 AM** **Using Computer Vision to Map Laser Ultrasound onto CAD Geometries**
---T. E. Drake, M. A. Osterkamp, and S.-Y. Chuang, Laser Ultrasonics Technology Center, Lockheed Martin Aeronautics, Fort Worth, TX; J. V. Miller, W. D. Turner, and P. H. Tu, Visualization and Computer Vision, GE Research, Niskayuna, NY; C. W. Wilson, Sandia National Labs, Albuquerque, NM; D. L. Kaiser, Computer Science Corporation, Fort Worth, TX
- 9:10 AM** **Laser Ultrasound as a Characterization Tool for Inspection of Soft Porous Low Dielectric-Constant Films for Microelectronic Interconnect**
---C. M. Flannery, Department of Engineering, Colorado School of Mines, Golden, CO 80401; D. C. Hurley, National Institute of Standards and Technology, 325 Broadway, Boulder, CO 80303
- 9:30 AM** **Laser Ultrasonic Characterization of Residual Stresses in Thin Films**
---C. M. Hernandez and S. Krishnaswamy, Northwestern University, Center for Quality Engineering and Failure Prevention, 2137 Sheridan Road, Evanston, IL 60208-3020
- 9:50 AM** **Laser Ultrasonic Inspection of Compositionally Graded Mullite Coatings**
---T. W. Murray and O. Balogun, Aerospace and Mechanical Engineering, Boston University, Boston, MA 02215; S. N. Basu, Manufacturing Engineering, Boston University, Boston, MA 02215
- 10:10 AM** **Coffee Break**
- 10:30 AM** **Review of Laser Generation of Ultrasound in Polymer-Matrix Composites**
---M. Dubois and J. Deaton, General Electric, Research Center, P. O. Box 8, Schenectady, NY 12301; T. E. Drake, S.-Y. Chuang and K. Yawn, Lockheed Martin Aeronautics, Fort Worth, TX
- 10:50 AM** **Doppler Frequency-Shift Compensated Photorefractive Interferometer for Ultrasound Detection on Objects in Motion**
---B. Campagne, C. Néron, A. Blouin, and J.-P. Monchalain, Industrial Materials Institute, National Research Council of Canada, 75 de Mortagne Blvd., Boucherville, J4B 6Y4, Québec, Canada
- 11:10 AM** **Characterization of Attenuation in Lamb Waves Using Laser Ultrasonic Techniques**
---K. Luangvilai and L. J. Jacobs, School of Civil and Environmental Engineering, Georgia Institute of Technology, Atlanta, GA 30332-0355
- 11:30 AM** **A New Thermoelastic Source Model for Non-Metals**
---C. Edwards, T. Stratoudaki, and S. B. Palmer, Dept. Physics, Univ. of Warwick, Coventry, UK
- 11:50 AM** **Laser-Ultrasonic Study of Crack Tip Diffraction**
---M. Ochiai and A. Fukumoto, Power and Industrial Systems R&D Centre, Toshiba Corporation, Yokohama, Kanagawa, Japan; D. Lévesque, R. Talbot, A. Blouin, and J.-P. Monchalain, Industrial Materials Institute, National Research Council Canada, Boucherville, PQ, Canada
- 12:10 PM** **Lunch**

Laser Ultrasonic System for On-Line Steel Tube Gauging

---Jean-Pierre Monchalin, Marc Choquet¹, Christian Padioleau, Christian Néron, Daniel Lévesque, Alain Blouin, Christian Corbeil, Richard Talbot, Abdelhakim Bendada, and Mario Lamontagne, Industrial Materials Institute, National Research Council of Canada, 75, de Mortagne Boulevard, Boucherville, Québec, J4B 6Y4, Canada; Robert V. Kolarik II, Gerald V. Jeskey², Erich D. Dominik², Larry J. Duly, Kenneth J. Samblanet, Steven E. Agger, Kenneth J. Roush, and Michael L. Mester, The Timken Company, 1835 Dueber Avenue Southwest, Canton, OH 44706; ¹Now with Tecnar Automation Ltd., 1321 Hocquart, St.-Bruno, Québec J3V 6B5, Canada, ²Retired from The Timken Company

---A laser-ultrasonic system has been installed on a seamless mechanical steel tubing production line at The Timken Company and is being used for process control. This system includes a Q-switched Nd-YAG laser for generation of ultrasound by ablation, a long pulse very stable Nd-YAG laser for detection, coupled to a confocal Fabry-Perot interferometer. The lasers are optical fiber coupled; with the lasers, data acquisition and processing units being housed in an off-line cabin. Passive optical elements are contained in an inspection head located directly above the processing line. The system also includes a fiber-coupled pyrometer to measure tube temperature profile. Two fiber-coupled optical velocimeters are used for coordinate determination of the measurement location on the passing, rotating hot tube. During the presentation further details of the system will be disclosed, as well as results obtained. These results include a plot of the wall thickness along the tube and its eccentricity.---This work was partially supported by the Department of Energy under Award No. DE-FC07-99ID 13651.

Using Computer Vision to Map Laser Ultrasound onto CAD Geometries

---Thomas E. Drake, Mark A. Osterkamp, and Shu-Yuan Chuang, Laser Ultrasonics Technology Center, Lockheed Martin Aeronautics, Fort Worth, TX; James V. Miller, Wesley D. Turner, and Peter H. Tu, Visualization and Computer Vision, GE Research, Niskayuna, NY; Christopher W. Wilson, Sandia National Labs, Albuquerque, NM; David L. Kaiser, Computer Science Corporation, Fort Worth, TX

---Wide area imaging devices offer many speed and flexibility advantages to NDE applications. They can be reconfigured quickly to accommodate a variety of part geometries and sizes and can be deployed without precise fixturing for the sensor or the part. When the part to be inspected is large or complicated (with many bends); applications use several sensors or move a single sensor to multiple viewpoints to complete an inspection. An operator must then review several images for a single part, spatially relate indications across disparate images, and assume the collection of images completely covers the part. We describe a system which uses Laser Ultrasound as a wide area imaging device. The system also uses a structured light range camera - typically used to measure shape - to locate the part in the work cell. We describe how camera calibration, photogrammetry, triangulation, and registration techniques are used to define coordinate frames that allow us to relate the data from the Laser Ultrasound imaging device to a CAD model of the part. We then map the ultrasound data from various viewpoints onto the CAD model, creating a natural 3D coordinate frame for the operator to relate indications and evaluate scan coverage.

Laser Ultrasound as a Characterization Tool for Inspection of Soft Porous Low Dielectric-Constant Films for Microelectronic Interconnect

---Colm M. Flannery, Department of Engineering, Colorado School of Mines, Golden, CO 80401; Donna C. Hurley, National Institute of Standards and Technology, 325 Broadway, Boulder, CO 80303

---The demand for miniaturization in the microelectronics industry requires that the RC (Resistance-Capacitance) factor be lowered to reduce interconnection delay, crosstalk and power loss. The conventional interconnect dielectric, silica, must therefore be replaced with materials of lower dielectric constant (lower k). The most promising way to achieve this is by introducing porosity into the dielectric film material. However as porosity increases (and k decreases) the stiffness of the films falls drastically. Thus there must be a tradeoff between low k and acceptable film stiffness that the films survive the chemical-mechanical polishing process. A major problem hindering development of low k films is the lack of useful accessible characterization techniques which yield reliable measurements of their critical properties -- density/porosity and stiffness. In this work we show that laser-generated surface acoustic waves can successfully and rapidly characterize the critical properties of low-k films. We present results for porous silica and porous polymer films from two laser ultrasonic systems, one with a piezoelectric sensor (to 200 MHz) and the other with interferometric detection (to 400 MHz), and provide complementary measurements from X-ray reflectivity and Brillouin light scattering which verify our results. Nanoindentation measurements do not give compatible stiffness values and we discuss why this is so.

Laser Ultrasonic Characterization of Residual Stresses in Thin Films

---C. M. Hernandez and S. Krishnaswamy, Northwestern University, Center for Quality Engineering and Failure Prevention, 2137 Sheridan Road, Evanston, IL 60208-3020

---In work reported at last year's QNDE meeting, we showed that laser ultrasonics (photo-acoustics) is a promising tool for the nondestructive and non-contact characterization of thin film structures. In particular it was shown that the modulus and residual stresses in two-layer freestanding Al/Silicon Nitride films could be measured using a narrow-band laser ultrasonic technique. In this technique, a microchip laser deposits pulsed laser energy as 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 can be probed. For the thin films investigated, which were less than a micron in thickness (300-900 nm), only the two lowest order modes were generated and these in turn can be related to sheet and flexural modes in plates. In this paper we present an extension of this approach. The sensitivity of the photo-acoustic system is examined by measuring variable residual stresses. Variable residual stresses are obtained in the thin films by two methods: by varying the growth rates for silicon nitride and by varying the membrane size. The accuracy of modulus measurements is also investigated by using one layer and two layer systems. The Young's modulus for a single layer of aluminum and the modulus of aluminum on silicon nitride that was deposited during the same evaporation procedure are compared to check the accuracy of the measured modulus values. Finally, a comparison is done with modulus and residual stress measurements using an acoustic microscope.

Laser Ultrasonic Inspection of Compositionally Graded Mullite Coatings

---Todd W. Murray and Oluwaseyi Balogun, Aerospace and Mechanical Engineering, Boston University, Boston, MA 02215; Soumendra N. Basu, Manufacturing Engineering, Boston University, Boston, MA 02215

---Mullite ($3\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2$) is an important engineering ceramic exhibiting excellent high-temperature strength, low thermal expansion, and good chemical stability. Mullite is a strong candidate material for corrosion resistant coatings on silicon based ceramics (SiC and Si_3N_4) that are susceptible to hot-corrosion when used in hostile environments. In this work, a laser based ultrasonic system is used inspect mullite films on SiC substrates that are compositionally graded from being silica rich near the coating/substrate interface to alumina rich towards the outer surface of the coating. The laser ultrasonic system allows for generation and detection of high frequency (greater than 250 MHz) surface acoustic waves (SAWs) on 10 μm thick mullite films. The source and detection lasers illuminate the specimen through a single microscope objective and the source-to-receiver distance is controlled (with less than 1 μm resolution) using gimbal mounts allowing for precise velocity measurements over relatively short length scales. In order to estimate the elastic properties as a function of depth, the coating is treated as a multilayer material and the elastic properties are assumed to change uniformly from layer to layer. The functional dependence of the elastic modulus on depth is determined by comparing the experimentally measured dispersion curves with theory. Several coatings with different composition gradients are evaluated. The SAW signals are also compared to a time domain model developed for laser generated ultrasound in multilayer materials and good agreement is seen between theory and experiment.

Review of Laser Generation of Ultrasound in Polymer-Matrix Composites

---M. Dubois and J. Deaton, General Electric, Research Center, P. O. Box 8, Schenectady, NY 12301; T. E. Drake, S.-Y. Chuang, and K. Yawn, Lockheed Martin Aeronautics, Fort Worth, TX

---Laser-ultrasound has now a proven track record for the inspection of composite parts for the aircraft industry. However, in some particular cases, signal-to-noise ratio (SNR) needs to be increased to maintain the savings associated to laser-ultrasound inspection. In the last few years, our team spent a lot of efforts to improve ultrasound generation for laser-ultrasound inspection. Any gain in generated ultrasonic amplitude translates directly into a gain in SNR when the latter is not already limited by material structural noise. In this paper, we will review the progress accomplished so far in understanding the generation mechanism. Experimental measurements obtained with different laser sources will be presented and their performances will be compared to those predicted by mathematical modeling. These results will lead to the choice of the next generation source for laser-ultrasound inspection of composites.

Doppler Frequency-shift Compensated Photorefractive Interferometer for Ultrasound Detection on Objects in Motion

---B. Campagne, C. Néron, A. Blouin, and J.-P. Monchalain, Industrial Materials Institute, National Research Council of Canada, 75 de Mortagne Blvd., Boucherville, J4B 6Y4, Québec, Canada

---Two-wave mixing based interferometry has been demonstrated to be a powerful technique for non-contact, broadband and speckle insensitive measurements of the small surface displacements produced by ultrasonic waves propagating in an object. When the object is in rapid motion along the line-of-sight of the probing laser or when the laser beam is rapidly scanned on a wavy surface, the two-wave mixing photorefractive interferometer loses sensitivity to the point it could become useless. To circumvent the Doppler frequency-shift produced by this relative motion, we propose a dynamic compensation scheme. By inserting along the pump or signal beampaths an acousto-optic shifter driven at the Doppler frequency, it is possible to compensate for the shift so both beams have nearly the same frequency and sensitivity is not reduced. We report a particularly simple scheme to implement this concept by monitoring the low-frequency output signal of a balanced two-wave mixing demodulator whose output is proportional to the frequency difference between the pump and signal beams, and feeding this signal back to the acousto-optic shifter. With this new concept, the two-wave mixing interferometer is allowed to operate on objects in rapid motion while maintaining its sensitivity to low frequency ultrasound. We will also compare the results obtained with this compensated photorefractive interferometer with those obtained with a much shorter response time interferometer, such as the confocal Fabry-Perot. These results demonstrate the overwhelming superiority of the compensated photorefractive interferometer, particularly for detecting low frequency ultrasound.

Characterization of Attenuation in Lamb Waves Using Laser Ultrasonic Techniques

---K. Luangvilai and L. J. Jacobs, School of Civil and Environmental Engineering, Georgia Institute of Technology, Atlanta, GA 30332-0355

---This research uses laser ultrasonic techniques to characterize the attenuation of guided Lamb waves. The objective of this research is to establish the effectiveness of combining a time-frequency representation, the energy density of a short time Fourier transform (spectrogram), with laser ultrasonic methodologies to experimentally measure attenuation in viscoelastic plates. The high fidelity, broad-bandwidth and non-contact nature of laser ultrasonics are critical to the success of this study, making it possible to experimentally measure transient Lamb waves in viscoelastic plates without any frequency biases. The proposed experimental procedure measures transient Lamb waves at a variety of propagation distances and uses the resulting spectrograms to quantify frequency dependent attenuation. Finally, these experimental results are interpreted in terms of an analytical model.

A New Thermoelastic Source Model for Non-Metals

---C. Edwards, T. Stratoudaki, and S. B. Palmer, Department of Physics, University of Warwick, Coventry, United Kingdom

---This paper presents a source model for laser ultrasonic generation in non-metals in the thermoelastic regime. It is shown that the waveforms can be directly related to the optical absorption depth of the material. The longitudinal component due to the buried source is shown to be a bipolar pulse which can be modelled by convolving the temporal form of the laser pulse with the optical absorption profile and its time delayed inverted reflection from the free surface. The heated disc is surrounded by cold constraining material so the radial in-plane forces have Heaviside like time dependence whereas the vertical component only exists during the initial fast rise of the free surface and therefore can be modelled as a delta function. The predications of the model are compared for a TEA CO₂ Laser generation in a plastic, an Excimer laser in glass and a Nd:YAG laser in silicon. This model also explains difference between constrained and unconstrained surfaces for the first time, in the constrained case the vertical force is related to the integral of the laser pulse profile and has Heaviside like time dependence.

Laser-Ultrasonic Study of Crack Tip Diffraction

---M. Ochiai and A. Fukumoto, Power and Industrial Systems R&D Centre, Toshiba Corporation, Yokohama, Kanagawa, Japan; D. Lévesque, R. Talbot, A. Blouin and J.-P. Monchalain, Industrial Materials Institute, National Research Council Canada, Boucherville, PQ, Canada

---The angular variation of the ultrasonic signal produced by diffraction at a crack tip is studied by using laser-generated bulk waves. We report measurements of the signal amplitude of the waves diffracted by an artificial slot having a width of about 0.3 mm in a 304 stainless steel plate, including mode conversion. Incident angles from 0 (deg) to 70 (deg) and diffraction angles from 0 (deg) to 60 (deg) are interrogated. The results show directivity patterns oriented essentially along the normal for the diffracted longitudinal wave and essentially at 45 (deg) for the diffracted shear wave for any incident angles. These diffraction patterns are compared to a theoretical model. These patterns indicate an optimum separation between transmitter and receiver for the time-of-flight diffraction technique, which is a typical method for crack depth evaluation based on crack tip diffraction. A laser-ultrasonic system combined with time-of-flight diffraction analysis demonstrates accurate crack sizing on an artificial slot having a variable depth from 0 mm to 10 mm. An improvement of signal-to-noise ratio by split spectrum processing is also suggested.

Thursday, July 18, 2002

SESSION 25
EDDY CURRENT ARAYS AND PROBES APPLICATIONS
T. Moran, Chairperson
SMATE 150

- 8:30 AM** **Array Eddy Current Sensors for USAF Applications**
---C. Neslen, B. Sanbongi, C. Buynak, and J. Blackshire, AFRL/Materials and Manufacturing Directorate, NDE Branch, Wright-Patterson AFB, OH
- 8:50 AM** **Engine Disk Slot Crack Detection and Mapping Using MWM-Array Eddy Current Sensors**
---N. Goldfine, D. Schlicker, A. Washabaugh, V. Zilberstein, and I. Shay, JENTEK Sensors, Inc., 110-1 Clematis Avenue, Waltham, MA 02453-7013; P. Khandelwal, Rolls Royce, P. O. Box 420, W-5, Indianapolis, IN 46206-0420
- 9:10 AM** **Development of a Real Time Eddy Current Imaging System Using a Staggered Linear Array of Anisotropic Magnetoresistive Sensors**
---R. D. Rempt, The Boeing Company, P. O. Box 3999, Seattle, WA 98124-2499
- 9:30 AM** **GMR Magnetic Sensor Arrays for NDE Eddy-Current Testing**
---C. H. Smith and R. W. Schneider, NVE Corporation, Eden Prairie, MN; T. Dogaru, Albany Instruments, Inc., Charlotte, NC; S. T. Smith, Center for Precision Metrology, UNC Charlotte, NC
- 9:50 AM** **Simulation of Eddy Current Detection of Corrosion Using Sensors Array**
---J. Bowler and V. Katyal, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011
- 10:10 AM** **Coffee Break**
- 10:30 AM** **Development of a Pulsed Eddy Current Array Probe for Imaging of Defect**
---Y. Plotnikov, GE Research & Development, One Research Circle, KW-D254, Niskayuna, NY 12309-1135
- 10:50 AM** **Eddy Current Testing of Thick Aluminum Plates with Hidden Cracks**
---R. Sikora, T. Chady, S. Gratkowski, M. Komorowski, and K. Stawicki, Chair of Theoretical Electrotechnics and Computer Science, Faculty of Electrical Engineering, Technical University of Szczecin, Szczecin, Poland
- 11:10 AM** **Advances in Modeling Eddy-Current NDE of Ferromagnetic Bodies**
--- H. A. Sabbagh, R. K. Murphy, and E. H. Sabbagh, Victor Technologies, LLC, P. O. Box 7706, Bloomington, IN 47407-7706
- 11:30 AM** **Evaluation of Pulsed Eddy-Current Probe Performance Using Various Magnetic-Field Sensing Devices**
---M. J. Johnson, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011
- 11:50 AM** **Multifrequency Eddy Current and Potential Drop Measurements for the Evaluation of Case Hardened Steel Rods**
---Y. Huang, J. R. Bowler, M. J. Johnson, and H. Sun, Iowa State University Center for NDE, 1915 Scholl Road, Ames, IA 50011
- 12:10 PM** **Lunch**

Array Eddy Current Sensors for USAF Applications

---C. Neslen, B. Sanbongi, C. Buynak, and J. Blackshire, AFRL/Materials and Manufacturing Directorate, NDE Branch, Wright-Patterson AFB, OH

---Researchers at the Air Force Research Laboratory and inspectors at USAF Air Logistics Centers recognize several possible advantages of using array eddy current sensors to improve inspection processes on Air Force weapons systems. There exist opportunities to use array eddy current sensors to validate the integrity of the aircraft structure as well as turbine engine components. Current single element eddy current probes have inherent capability limitations that array probes may address and eliminate. The traditional hand wound eddy current coil variability from probe to probe is an issue that has been on the minds of inspectors for some time and a solution is currently being investigated. Also, current single coil eddy current probe inspections are extremely time consuming with the replacement cost of some probes being in the thousands of dollars. As the number of critical inspections and aging weapons systems increases, there will be an increasing need for sensors that can inspect suspect areas faster with a decreasing cost in sensor replacement. Specifically, eddy current arrays are desired to inspect complex geometries such as a dovetail or fir tree slot in turbine engine disks quickly and with the capability to identify cracks on the order of 5 to 10 mils long. In addition to this capability, there is a need to inspect aircraft structures under paint and other special coatings through multiple structural layers with a high degree of spatial resolution that will allow inspectors to confirm cracks, delaminations, and material loss due to corrosion. This briefing will focus on several engine and aircraft structural inspection needs the USAF has which could be addressed with array eddy current sensors.

Engine Disk Slot Crack Detection and Mapping Using MWM-Array Eddy Current Sensors

---N. Goldfine, D. Schlicker, A. Washabaugh, V. Zilberstein and I. Shay, JENTEK Sensors, Inc., 110-1 Clematis Avenue, Waltham, MA 02453-7013; P. Khandelwal, Rolls Royce, P. O. Box 420, W-5, Indianapolis, IN 46206-0420

---The presence of fretting damage on critical surfaces of service-aged aircraft engine disk slots degrades the inspection capability of conventional eddy current testing methods and can lead to unacceptably high numbers of false positive detections. Recent developments in Meandering Winding Magnetometer Arrays (MWM-Arrays) have focused on improved reliability and throughput for inspection of these disk slots. The sensor arrays are designed so that the sensing element responses can be accurately modeled, which permits absolute property measurements with minimal calibration requirements. These scanning arrays permit high-resolution wide-area imaging of the materials for crack detection and characterization. Model-based inversion methods convert response at each sensing element into property measurements and permit independent lift-off measurements with each element. This paper presents recent crack detection measurement results from slots with fretting damage in a military titanium fan disk. Estimates of crack length and crack distance to the slot edge obtained with the MWM-Array are found to be in good agreement with measured dimensions based on acetate replicas of the slot surface. In addition, earlier results are presented from a test on a commercial engine disk provided by Rolls Royce. Detected cracks are compared to crack maps obtained from detailed surface examinations with a stereomicroscope.

Development of a Real Time Eddy Current Imaging System Using a Staggered Linear Array of Anisotropic Magneto-resistive Sensors

---R. D. Rempt, The Boeing Company, P. O. Box 3999, Seattle, WA 98124-2499

---I discuss the development of a real time imaging eddy current array. The full array will be configured with sixty-four of the new high performance anisotropic magneto-resistive sensors. The array is linear, and produces essentially real time subsurface images as the scanning head is pushed along the surface of a test sample, which is intended to be the metallic skin of an aircraft. The sensors are configured to detect the vector field, or one of its spatial gradients in the plane of the sample. In addition to the development of the array, we show some preliminary images taken with less than the full compliment of sensors up and running.

GMR Magnetic Sensor Arrays for NDE Eddy-Current Testing

---C. H. Smith and R. W. Schneider, NVE Corporation, Eden Prairie, MN; T. Dogaru, Albany Instruments, Inc., Charlotte, NC; S. T. Smith, Center for Precision Metrology, UNC Charlotte, NC

--- Solid-state magnetic sensors based on Giant Magnetoresistance (GMR) and Spin-Dependent Tunneling (SDT) effects have high, frequency-independent sensitivity that extends to low frequencies necessary for deep eddy current penetration. The use of these sensors has been demonstrated in NDE detection and magnetic imaging of surface cracks and features, deep cracks, and cracks initiating from edges of holes. The small size and low power consumption of these solid-state magnetic sensors allow them to be used in arrays of multiple sensors facilitating rapid scanning of an area for defects in a single pass rather than by raster scanning. Depending upon the resolution required, the arrays can be fabricated from individual sensor chips mounted on circuit boards with several mm spacing or multiple sensors on single substrates with spacing down to a few μm . GMR sensor elements can be deposited on active silicon substrates facilitating on-chip signal processing and multiplexing. This integration reduces the effect of noise, simplifies the sensor/signal-processing interface, and minimizes the number of leads. This paper will discuss the use of GMR and SDT sensors in NDE testing as well as the progress in X-Y GMR sensors and multiple-sensor arrays.---This work supported by the Department of the Air Force/WPAFB under contract numbers: F33615-01-C-5207, F33615-01-M-5219, and F33615-00-C-5510.

Simulation of Eddy Current Detection of Corrosion Using Sensors Array

---J. Bowler and V. Katyal, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---A computer simulation has been developed to evaluate eddy-current probes containing magnetic field sensor arrays for the detection and evaluation of hidden corrosion. The simulation is used to assess probe designs that incorporate magneto-resistive or Hall devices in a closely-spaced, linear array. These probes will allow rapid data acquisition over a track width determined by the length of the array, typically between 1 cm and 10 cm. A wide track will permit high-speed inspections to be carried out economically by switching the analog to digital conversion input from one sensor channel to the next in a rapid regular sequence.

Magnetic sensor signals have been calculated for a number of trial probe configurations using the computer simulation to determine the array-probe performance for the detection of hidden corrosion in lap joints and in the vicinity of installed fasteners. The advantage of the simulation is that adjustments to the virtual probe parameters are easily made in an effort to improve its sensitivity, imaging capability and resolution. A Number of probe designs have been studied in this way including the "racetrack" probe. Probes are needed that exhibit a signal that varies in response to roughness on the faying surface. The signal variation due to irregularities on a hidden surface can be used to distinguish between loss of material due to corrosion where the surfaces are rough and plate separation where surfaces are smooth. The effects of roughness have been assessed by finding signal variations due to undulating surfaces. In parallel with the development of a computer, experimental measurements have been performed to validate the calculations. The comparisons between predictions from the computer simulation and experimental data demonstrate the validity and accuracy of the calculations. Other results presented show the sensitivity of field sensors to surface roughness.---This work is supported by the AFRL Materials and Manufacturing Directorate at Wright-Patterson under sub contract number 02-S437-031-C1 managed by Tom Moran.

Development of a Pulsed Eddy Current Array Probe for Imaging of Defects

---Y. Plotnikov, GE Research & Development, One Research Circle, KW-D254, Niskayuna, NY 12309-1135

---Eddy Current Array Probes (ECAP) have become popular during the last decade. Use of the ECAP allows improvements in productivity of the eddy current (EC) inspection by covering a larger area in one scan. Different approaches include deposition of printed coils on a flexible substrate, grouping of several conventionally wound coils into an array, and using solid state sensors in array arrangement. In this work an overview of different approaches to form EC array probes is made. Two-dimensional arrays of electromagnetic sensors can be used to produce real-time EC images of a component under test. To obtain the images of high quality the smaller distance between sensors and larger number of sensors must be used. Arrangement of solid state sensors, such as Hall-effect elements or giant magnetoresistors, or printed coils into arrays provides a technological basis for this approach. Utilization of the pulsed excitation can be essential for building a real time imaging system, since the data processing for the transient response is simpler. This approach can lead to development of a new generation of EC probes and systems that will make inspection easier, faster, and more intuitive than the existing practices.

Eddy Current Testing of Thick Aluminum Plates with Hidden Cracks

---R. Sikora, T. Chady, S. Gratkowski, M. Komorowski, and K. Stawicki, Chair of Theoretical Electrotechnics and Computer Science, Faculty of Electrical Engineering, Technical University of Szczecin, Szczecin, Poland

---In this paper results of theoretical analysis and experiments, which give the possibility to determine optimal conditions of thick aluminum specimens' testing are presented. Research on selection of an optimal testing frequency which allows us to detect shallow cracks located on the reverse side of the specimen are carried out. Analytical analysis of eddy current distribution in the specimens having different thickness leads to determine optimal testing frequency in each case. A computer controlled NDT system and an ECT sensor with a magneto-resistor were utilized in laboratory tests. Experiments with two kinds of specimens containing shallow hidden cracks were carried out for a wide spectrum of frequencies. The optimal testing frequencies achieved from the experiments were in a very good agreement with the analytical solution. Application of the optimal frequency creates opportunity to detect shallow defects located on the reverse side of the specimen. Detection of a 15% crack in a plate of 10 mm thickness and a 20% crack in a plate of 20mm thickness were confirmed.

Advances in Modeling Eddy-Current NDE of Ferromagnetic Bodies

---H. A. Sabbagh, R. K. Murphy, and E. H. Sabbagh, Victor Technologies, LLC, P. O. Box 7706, Bloomington, IN 47407-7706

---We apply our proprietary volume-integral eddy-current code, VIC-3D(c), to the solution of challenging NDE problems that involve ferromagnetic anomalies or workpieces. These include problems with 'wear scars and permeable crusts' in steam-generator tubing, characterization of coatings with electrical and magnetic layers, and flaws in ferromagnetic workpieces. Validation of the code by the use of benchmark experiments will also be described. Finally, we will explain the development of the mathematical model in terms of volume-integral equations through the use of Amperian currents for magnetic effects.

Evaluation of Pulsed Eddy-Current Probe Performance using Various Magnetic-Field Sensing Devices

---M. J. Johnson, Center for Nondestructive Evaluation, Iowa State University, 1915 Scholl Road, Ames, IA 50011

---Hall-element sensors are increasingly used for NDE applications due to their good low-frequency response characteristics. For example, some pulsed eddy-current (PEC) instruments utilize Hall-element sensors to measure the magnetic field at the base of an induction coil. Hall sensors based on Si technology are the most common, however, there are new sensors available that are based on GaAs and InSb that may offer improved performance. Some of these Hall-effect sensors has been studied for signal-to-noise and flaw-detection capability. Hall sensors, in both single-ended and differential configurations, were tested and compared with and without various probe-level pre-amplifier circuits. Performance has been compared for the different devices in terms of sensitivity, size, signal-to-noise ratio and thermal stability. The results of these comparisons should direct the future development of PEC probes.---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 Aviation Systems Reliability program.

Multifrequency Eddy Current and Potential Drop Measurements for the Evaluation of Case Hardened Steel Rods

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

---In the process of case-hardening, the near-surface magnetic and electrical properties of steel are modified. In order to observe these changes and evaluate the near surface condition of the steel, small-signal eddy current and potential drop measurements have been carried out over a range of frequencies on case-hardened steel rods. The measurements were performed using small signals in order to ensure that the response could be represented using linear models. In the linear regime, the local electromagnetic properties of the material are determined by the initial permeability and the electrical conductivity. A two layer model represents the case hardened rod as a homogeneous substrate with a single, uniformly thick, homogeneous surface layer. The conductivity and permeability values differ in the substrate and in the surface layer. In this paper, the electromagnetic measurements on cylindrical steel rods are presented, the experimental results are interpreted using the layer model and the sensitivity of the measurements to the case depth is assessed.---The work is supported by the NSF Industry-University Program at Iowa State University.

Thursday, July 18, 2002

SESSION 26
POD JACK LINCOLN MEMORIAL SESSION
R. B. Thompson, Chairperson
FRASER 3

- 8:30 AM** **Improving Probability of Detection in NDE Applications**
---W. D. Rummel, D&W Enterprises, Ltd., 8776 W. Mountainview Lane, Littleton, CO 80125-9406
- 8:50 AM** **Statistical Analysis of Probability of Detection Hit/Miss Data for Small Data Sets**
---C. A. Harding and G. R. Hugo, Defence Science and Technology Organization, 506 Lorimer Street, Fishermans Bend, Victoria 3207, Australia
- 9:10 AM** **Recent Studies on the POD Analysis of “a-hat” Versus “a” NDI Data**
---M. S. Safizadeh, D. S. Forsyth, and A. Fahr, Structures, Materials and Propulsion Laboratory, Institute for Aerospace Research, National Research Council Canada, Building M-14, 1200 Montreal Road, Ottawa, Ontario, Canada
- 9:30 AM** **Reliability Assessment of Ultrasonic Nondestructive Inspection Data Using Monte Carlo Simulation**
---I. K. Park and U. S. Park, R. I. of NDE Tech. Seoul National University of Technology 172, Gongneung-dong, Nowon-gu, Seoul, 139-743, Korea; Hyun-Mook Kim, Precision Mechanical Engineering, Graduate School of Han Yang University, 17 Haengdang-dong, Seoul 133-791, Korea
- 9:50 AM** **The Application of Case Based Reasoning to Ultrasonic Data for Use in Inspection Qualification**
---D. McNab, P. Leggat, and A. McNab, Centre for Ultrasonic Engineering, Department of Electronic and Electrical Engineering, University of Strathclyde, Glasgow, G11XW, United Kingdom; M. W. Toft, Berkley Technology Centre, BNFL-Magnox Generation, Berkley, Gloucestershire, GL13 9PB, United Kingdom
- 10:10 AM** **Coffee Break**
- 10:30 AM** **Evaluation of Multizone Inspection Variability at the Supply Base for 8 Inch Diameter Ti-6Al-4V: A Round-Robin Study**
---W. Hassan, Honeywell Engines, Systems, and Services, 111 S. 34th Street, M/S 503-118, Phoenix, AZ 85072
- 10:50 AM** **Modeling Results and Analyses of Contaminated Billet Study**
---C.-P. Chiou¹, R. B. Thompson, W. Q. Meeker², and Y. Wang², Iowa State University, ¹Center for NDE, 1915 Scholl Road, and ²Department of Statistics, Ames, IA 50011
- 11:10 AM** **Automated Error Interpretation in Flaw Response Models for Ultrasonic NDT**
---R. J. Robinson, A. McNab, D. M. McNab, and P. Leggat, The Department of Electronic and Electrical Engineering, Center for Ultrasonic Engineering, University of Strathclyde, Glasgow, G1 1XW, United Kingdom; M. W. Toft, Berkley Technology Center, BNFL Magnox Generation, Berkley, Gloucestershire, GL 13 9PB, United Kingdom
- 11:30 AM** **Interactive Software Tools for Inspection Qualification**
---D. McNab, P. Leggat, and A. McNab, Centre for Ultrasonic Engineering, Department of Electronic and Electrical Engineering, University of Strathclyde, Glasgow, G1 1XW, United Kingdom; M. W. Toft, Berkeley Technology Centre, BNFL-Magnox Generation, Berkeley, Gloucestershire, GL13 9PB, United Kingdom
- 12:10 PM** **Lunch**

Improving Probability of Detection in NDE Applications

---W. D. Rummel, D&W Enterprises, Ltd., 8776 W. Mountainview Lane, Littleton, CO 80125-9406

---Quantification of Nondestructive Evaluation (NDE) capabilities is necessary for critical applications involving design validation; support of damage tolerance designs, support of "fitness for service" inspection/maintenance applications; and in life extension of aging engineering systems. Probability of Detection (POD) has wide acceptance as an applicable metric for establishing the capabilities of an NDE procedure and application. The reliability of an NDE procedure in a specific application is dependent on: a) the inherent capability of the procedure in the specific application; b) the reproducibility of the procedure that is associated with "calibration" and discipline in calibration; and c) the repeatability of the procedure that is associated with process control and human factors variables. Experience in application has shown that the greatest potential for improvement in overall and long-term applications is offered by improvements in "calibration". This paper focuses on requirements for "calibration" as a primary method of reducing variance in procedure applications. A multiple point "calibration" and a "master gage" reference are described as essential elements in raising the standard on both capability and reliability in application of NDE procedures.

Statistical Analysis of Probability of Detection Hit/Miss Data for Small Data Sets

---C. A. Harding and G. R. Hugo, Defence Science and Technology Organization, 506 Lorimer Street, Fishermans Bend, Victoria 3207, Australia

---Reliability of non-destructive inspections is generally characterized by probability of detection (POD) as a function of crack size. This paper presents an improved analysis method for hit/miss POD data, which gives a lower 95% confidence limit POD curve which is valid for significantly smaller data sets than can be analyzed using previously published methods. The performance and robustness of the new analysis method was validated and compared to previously published methods using an extensive program of Monte Carlo simulations. Up to 2000 simulated POD trials were analyzed using the different methods for each of a number of different hit/miss data set sizes. The new analysis algorithms give similar results to previously published algorithms for large hit/miss data sets. However, the simulations demonstrate that the new method gives robust lower 95% confidence limit POD curves for quite small data sets containing as few as 50 hit/miss observations, whereas previously published algorithms behave poorly for data sets containing fewer than 200 observations. Collection of POD data through experimental trials is expensive and reducing the size of the data set required for analysis offers savings on the cost of trials and may make reliability studies viable for more applications.

Recent Studies on the POD Analysis of “a-hat” Versus “a” NDI Data

---M. S. Safizadeh, D. S. Forsyth, and A. Fahr, Structures, Materials and Propulsion Laboratory, Institute for Aerospace Research, National Research Council Canada, Building M-14, 1200 Montreal Road, Ottawa, Ontario, Canada

---The use of damage tolerance concept for life extension of aircraft components requires the estimation of probability of detection (POD) of nondestructive inspection (NDI) techniques. The standard approach to estimate POD of an NDI process is to perform demonstration tests on simulated or real components. To generate a realistic POD, the MIL-HDBK-1823 suggests that flaw sizes should be uniformly distributed on a log scale covering the expected range of the POD in the transition region. This paper presents an alternative approach that is based on Rayleigh distribution of flaw sizes on a log scale covering the expected range of flaw sizes. This approach is only applicable to NDI methods that provide a signal response or "a-hat" for a given flaw size "a". The use of this new approach increases the precision of POD by optimizing the distribution of flaw sizes in the expected range. The paper also presents a new three dimensional representation of POD versus the false call rate defined by reliability operation characteristic (ROC) that makes it easier to visualize the change in POD and false call rate with the variation of decision threshold set for flaw detection.

Reliability Assessment of Ultrasonic Nondestructive Inspection Data using Monte Carlo Simulation

---Ik Keun Park and Un Su Park, R. I. of NDE Tech. Seoul National University of Technology 172, Gongneung-dong, Nowon-gu, Seoul, 139-743, Korea; Hyun-Mook Kim, Precision Mechanical Engineering, Graduate School of Han Yang University, 17 Haengdang-dong, Seoul 133-791, Korea

---Ultrasonic NDE is one of important technologies in the life-time maintenance of nuclear power plant. Ultrasonic inspection system is consisted of the operator, equipment and procedure. The reliability of results in ultrasonic inspection system is affected by its ability. The performance demonstration round robin test was conducted to quantify the capability of ultrasonic inspection for in-service. The small number of teams who employed procedures that met or exceeded ASME Sec. XI Code requirements detected the piping of nuclear power plant with various cracks to evaluate the capability of detection and sizing. In this paper, the statistical reliability assessment of ultrasonic nondestructive inspection data using Monte Carlo Simulation is presented. The results of the POD analysis using logistic probability model are compared to these of Monte Carlo simulation. The feasibility of the ultrasonic NDE reliability assessment is verified by the analysis of the data obtained from round robin test. In these results, Monte Carlo Simulation was found to be very useful to the reliability assessment of the small number of NDE data.

The Application of Case Based Reasoning to Ultrasonic Data for use in Inspection Qualification

---Douglas McNab, Patricia Leggat, and Alistair McNab, Centre for Ultrasonic Engineering, Department of Electronic and Electrical Engineering, University of Strathclyde, Glasgow, G11XW, United Kingdom; Michael W. Toft, Berkley Technology Centre, BNFL-Magnox Generation, Berkley, Gloucestershire, GL13 9PB, United Kingdom

---This paper describes the development and application of case based reasoning (CBR) to provide decision support for the NDT engineer during Inspection Qualification. A key element of this is to present experimental evidence on the effectiveness of the inspection. This may take the form of theoretical modeling and/or practical trial data from costly test pieces. However, the use of previous modeled data and experimental work in a CBR system can aid the engineer when making decisions about their current situation. The most similar cases, instead of an exact match in conventional database systems, can be retrieved and used. A prototype for the system has been developed as part of this research. It holds past experimental data and can be extended to contain modeled results. Each case in the case-base describes the defect, the probe and response. The paper discusses the motivation for the system, the case structure, similarity measures, retrieval techniques and its design and implementation. The system operates either as a stand alone application or through an internet browser if different locations wish to access the data. The benefits it will provide are detailed.

Evaluation of Multizone Inspection Variability at the Supply Base for 8 Inch Diameter Ti-6Al-4V: A Round-Robin Study

---W. Hassan, Honeywell Engines, Systems, and Services, 111 S. 34th Street, M/S 503-118, Phoenix, AZ 85072

---In a recent round robin study conducted by Honeywell Engines, Systems, and Services, an 8 inch diameter, WC-seeded, Ti-6Al-4V triple melt billet with spherical inclusions of various sizes was sent around to four inspection houses to be inspected using their production Multizone Inspection systems. The purpose of the study was to get a feel to the variability associated with this inspection technique at the supply base and identify some of the root causes of such variability. The collected data has been fully analyzed and will be presented in a sanitized form. The analyzed data indicate that, on the average, there was a 27% variation in the amplitude recorded by the system for a specific indication. The variation in the signal to noise ratio (SNR) is about 33%. These numbers are based on a limited set of only four separate and independent scans of the billet at each facility.

Modeling Results and Analyses of Contaminated Billet Study

---C.-P. Chiou¹, R. B. Thompson, W. Q. Meeker², and Y. Wang², Iowa State University, ¹Center for NDE, 1915 Scholl Road, and ²Department of Statistics, Ames, IA 50011

--- In the past few years, an extensive research effort, known as the Contaminated Billet Study under the Engine Titanium Consortium, was made to investigate the geometry and ultrasonic responses of naturally occurring titanium hard-alpha defects. These defects were inadvertently formed when a power failure occurred during a billet production run. In this effort, extensive ultrasonic measurements were first taken on ten selected hard-alpha defects. Next, the void portions of these defects were geometrically reconstructed based on a series of closely spaced metallographs obtained from destructive sectioning. Using the geometric reconstruction data, ultrasonic models were then developed to predict the defects' responses in a specific experimental configuration. The predicted responses were subsequently compared with the experimental observations, and statistical analyses were performed on the predictions to examine their accuracy and consistency as well as other underlying inter-relationships. In this presentation, we will describe recent new results of this study, including three-dimensional geometric models, the ultrasonic predictions and their comparisons with actual measurements, and the results of analyses. We will also discuss the possible usage of these data in a new statistical probability-of-detection methodology.---This material is based upon work supported by the Federal Aviation Administration under Contract #DTFA03-98-D-00008, Delivery Order IA029 and performed at Iowa State University's Center for NDE as part of the Engine Titanium Consortium program.

Automated Error Interpretation in Flaw Response Models for Ultrasonic NDT

---Robert J. Robinson, Alistair McNab, Douglas M. McNab, and Patricia Leggat, The Department of Electronic and Electrical Engineering, 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

---Theoretical modeling programs are used to aid interpretation of results and to validate test procedures during Inspection Qualification. The programs are based on the Geometrical Theory of Diffraction (GTD) and the Elastodynamic Kirchoff Theory, and are used to model the scattering of ultrasound by a smooth planar defect within the component. "Flags" are generated to warn the user of possible inaccuracies in the predictions generated and occur when the models run outside their range of validity. However, in order to interpret these flags a fair degree of expertise in the theoretical background to the models is required by the user. This paper describes why these flags occur and the steps that can be taken to automatically eliminate them thus simplifying the modeling procedure. It is proposed that flags, which can be eliminated prior to running the model, based on probe parameters selected, can be handled by hard coding rules into the existing application. Flags, which can only be eliminated after a model has been run, are handled by composing a rule base for each flag in conjunction with a suitable inference engine to fire the rules. The outcome is a modeling procedure in which the PC handles all flags, parameters are updated accordingly and valid data files produced which can input into a 3D visualization system.

Interactive Software Tools for Inspection Qualification

---Douglas McNab, Patricia Leggat, and Alistair McNab, Centre for Ultrasonic Engineering, Department of Electronic and Electrical Engineering, University of Strathclyde, Glasgow, G1 1XW, United Kingdom; Michael W. Toft, Berkeley Technology Centre, BNFL-Magnox Generation, Berkeley, Gloucestershire, GL13 9PB, United Kingdom

---The demonstration of inspection reliability through Inspection Qualification is important for non-routine or safety critical tests. However, since testing is time consuming and costly, the provision of interactive software tools to aid the process offers substantial advantages. This paper describes an interactive tool set for ultrasonic testing. Operating within a 3D CAD environment it consists of a ray tracing and coverage map tool. The ray tracing tool allows the creation and adjustment of rays, representing the ultrasound path within the component, using the mouse and keyboard. Parameters describing the ray and probe such as angle, start position and skew can be altered. Defects can be inserted and defect/ray interaction studied. A map of the ray incidence angle can be created on the defect face to define detectability. Ray amplitudes are also calculated and displayed for a ray passing through the component which reflects from internal surfaces. A validated beam model for a crystal probe, based on a simple piston oscillator, is used to calculate initial ray amplitudes. The coverage map tool voxelizes the component and identifies the voxels that the main beam, leading and trailing edge rays have passed through. Raster scans can be conducted to create a 3D map of beam coverage, which can then be displayed and used as evidence for the Inspection Qualification.

Thursday, July 18, 2002

SESSION 27
NEW TECHNIQUES AND SYSTEMS III
E. Madaras, Chairperson
SMATE 140

- 8:30 AM** **Coupled Transient Thermal and Pulsed EC Modeling for NDT of Materials Subjected to Laser Based Heat Treatment**
---S. Veeraraghavan and K. Balasubramaniam, Center for NDE, Indian Inst. of Tech. Madras, Chennai, TN, India
- 8:50 AM** **Up-to-Date Experience in Crack Detection for Aircraft Structures of Different Applications Using Remote Field Eddy Current Technique**
---Y. Sun and T. Ouyang, Innovative Materials Testing Technologies, Inc., 2501 N. Loop Drive, STE 1610, Ames, IA 50010
- 9:10 AM** **Simulation of Ultrasonic and Electromagnetic Nondestructive Evaluation of Corrosion in Aircraft Fuselage**
---M. Spies and A. Yashan, Fraunhofer-Institute for Nondestructive Testing (IZFP), University, Bldg. 37, 66123 Saarbruecken, Germany; C. V. Kropas-Hughes, Materials and Manufacturing Directorate, Air Force Research Laboratory, Wright-Patterson AFB, OH 45433
- 9:30 AM** **Digital Ultrasonic Systems and Signal Processing Techniques for Advanced Flaw Detection and Large Area Scanning**
---R. J. Freemantle, NDT Solutions, Ltd., Dunston Innovation Center, Dunston Road, Chesterfield, S41 8NG, United Kingdom
- 9:50 AM** **Comparison of Ultrasound with Tensile Testing of Thermally Damaged Polyimide Insulated Wiring (MIL-W-81381)**
---E. I. Madaras and R. F. Anastasi, NASA Langley Research Center, Hampton, VA 23681
- 10:10 AM** **Coffee Break**
- 10:30 AM** **A Phased Array for Guided Wave Mode Tuning**
---M. J. Quarry, Lawrence Livermore Nat'l Laboratory, P. O. Box 808, L-333, Livermore, CA 94551
- 10:50 AM** **Development of a Manual Air-Coupled Ultrasonic Inspection Instrument for Use on Aeronautical Structures under In-Service Conditions**
---A. Gachagan, S. Kelly, G. Hayward, T. McCunnie, and D. Skillen, Centre for Ultrasonic Engineering, University of Strathclyde, 204 George Street, Glasgow, G1 1XW; M. Altman and E. Grauvogl, EADS Deutschland GmbH, Werk Manching, MLQM 33, Germany
- 11:10 AM** **Modeling of Effects of Excitation Velocities on the Thermal Image Obtained for Thermosonic Nondestructive Evaluation**
---K. Balasubramaniam, N. V. Nair, V. Sundararaghavan, and S. K. Das, Center for NDE, Indian Institute of Technology Madras, Chennai, Tamil Nadu, India
- 11:30 AM** **Non-Baseline Damage Detection from Changes in Strain Energy Mode Shapes: Experiments on Armored Vehicle Launched Bridge**
---E. S. Sazonov and P. Klinkhachorn, West Virginia University, Morgantown, WV 26506; H. V. S. GangaRao and U. B. Halabe, Constructed Facilities Center, College of Engineering and Mineral Resources, West Virginia University, Morgantown, WV 26506
- 11:50 AM** **High Frequency Ultrasound Generation by Femtosecond Laser Ablation**
---F. Blanchard, F. Martin, J.-C. Kieffer, F. Vidal, T. Johnston, and N. Perret, INRS-Énergie et Matériaux, Varennes, Quebec, Canada; A. Blouin, A. Moreau, and J.-P. Monchalain, National Research Council, Boucherville, Quebec, Canada
- 12:10 PM** **Lunch**

Coupled Transient Thermal and Pulsed EC Modeling for NDT of Materials Subjected to Laser Based Heat Treatment

---S. Veeraraghavan, and Krishnan Balasubramaniam, Center for NDE, Indian Institute of Technology, Madras, Chennai, Tamil Nadu, India

---The pulsed eddy current (PEC) technique is widely used to detect and quantify flaws in conducting plates. This method can be used to test materials subjected to heat treatment also. Material properties such as conductivity show a marked change when subjected to temperature treatment. As the heat diffuses into the material, the probe output changes drastically owing to the rapidly changing material properties. Hence it becomes difficult to obtain consistent results when searching for defects. Such problems can be effectively tackled by combining thermal and pulsed eddy current analysis for getting a reference data for the signals acquired from the probe. In this paper, a model is presented which combines transient thermal analysis and PEC Finite Element Model to track the probe output changes occurring during Laser based heat treatment of thin sheet conducting materials. The first step encompasses modeling of the laser treatment process using a three dimensional Finite Difference method. Properties of the material such as conductivity and specific heat capacity changes with temperature. Such parameters can be averaged over the temperature range of the laser treatment process and used in the model. The thermal model can also be extended to heterogeneous materials like Carbon reinforced composites. At each time step of the transient thermal model, the temperature distribution in the material is obtained which in turn is used as the input data for the axisymmetric PEC Finite element analysis at that time step. Hence the probe output can be tracked over the entire time interval. This forms an effective basis for combining the physics of two diffusive phenomena, i.e. thermal and pulsed eddy current in the NDE of such processes.

Up-to-Date Experience in Crack Detection for Aircraft Structures of Different Applications Using Remote Field Eddy Current Technique

---Yushi Sun and Tianhe Ouyang, Innovative Materials Testing Technologies, Inc., 2501 N. Loop Drive, STE 1610, Ames, IA 50010

---The remote field eddy current (RFEC) technique for inspection of flat geometry objects has been known for several years for its high sensitivity to flaws deeply hidden in multi-layer metallic structures. In last two years the author has had chance to work on aircraft specimens of different applications with either real fatigue cracks or EDM notches. Several new probe prototypes have been developed and exercised on the specimens. The testing results have clearly shown the advantages of the RFEC technique over the conventional eddy current techniques. It is the goal of this paper to introduce the newly developed probe prototypes and the results obtained on testing these aircraft specimens.

Simulation of Ultrasonic and Electromagnetic Nondestructive Evaluation of Corrosion in Aircraft Fuselage

---Martin Spies and Andriy Yashan, Fraunhofer-Institute for Nondestructive Testing (IZFP), University, Bldg. 37, 66123 Saarbruecken, Germany; Claudia V. Kropas-Hughes, Materials and Manufacturing Directorate, Air Force Research Laboratory, Wright-Patterson AFB, OH 45433

---In military and civil aircraft operations, there is an increasing need to detect and characterize corrosion at an early stage. To overcome limitations of current NDE methods and to enhance the interpretation and reliability of NDE results, computer modeling is advisable. The objective of the presented work is to simulate the influence of corrosion on ultrasonic and electromagnetic NDE results, addressing the mapping of the faying surfaces in 2-layer aluminum aircraft fuselage. With respect to ultrasonic time-of-flight measurements aiming on the detection of corrosion at the backwall of the first aluminum layer, a point source superposition technique has been applied to model the experimental set-up. Both the depth and the profile of the corroded area, which has been assumed to be in the shape of a half-ellipsoid, have been varied in the modeling procedures. Focusing on longitudinal wave propagation, parameter variations have been performed to elaborate frequency, bandwidth and type of the transducer (focused, unfocused) to be applied to ensure the ability to detect corrosion depths of at least 10% wall thickness. For an a priori optimization of the detection of corrosion using eddy current (EC) methods, a self-developed code for modeling the pick-up EC probe over the inspected specimen has been applied, where the structure under concern is treated as a multi-layered structure with piecewise constant conductivity values. Since the electrical conductivity of the adhesive and of the aluminum oxide (corroded Al) is negligible in comparison to the electrical conductivity of aluminum, the three-layer model of Al-air-Al has been used. In this way, an increase of the corrosion can be represented by a decrease in the wall thickness of the first and/or the second layer. Calculations of the EC probe response will be presented, where the thickness of the first and second layer and also the probe-to-specimen lift-off at several EC operating frequencies have been varied.

Digital Ultrasonic Systems and Signal Processing Techniques for Advanced Flaw Detection and Large Area Scanning

---Richard J. Freemantle, NDT Solutions, Ltd., Dunston Innovation Center, Dunston Road, Chesterfield, S41 8NG, United Kingdom

---New ultrasonic systems developed by NDT Solutions are described that utilize digital transmit and receive electronics and advanced signal processing techniques. The focus of our research and development program has been to develop software configurable hardware systems that employ signal processing techniques for filtering, feature extraction and data interpretation. Circuits for digitally controlled arbitrary waveform excitation for specifying the spectral content of pulser sources and performing noise (PRBS) based measurements are described. Recent results showing the application of this technology for Lamb wave excitation and dynamic range improvement on low amplitude signals are presented. Practical examples from the automotive and aerospace industry are used to demonstrate the application of digital signal processing methods to overcome the challenges of interpreting complex ultrasonic signals from multi-layer joints. It is demonstrated that these techniques can perform robust and quantitative measurements that decrease inspection time, allowing the operator to concentrate on probe placement and data logging. Furthermore, processing methods can be used for data reduction of high bandwidth (> 35 Mbyte per second) ultrasonic data streams generated by large area scanning devices. Results are presented which show the practical application of signal processing to C-scans generated by a novel prototype portable scanning system.

Comparison of Ultrasound with Tensile Testing of Thermally Damaged Polyimide Insulated Wiring (MIL-W-81381)

---E. I. Madaras and R. F. Anastasi, Nondestructive Evaluation Sciences Branch, NASA Langley Research Center, Hampton, VA 23681

---Aging wiring is a critical problem in aviation. Currently there is no simple method to quantify the condition of wire insulation before it fails. A quantitative method that would be simple to apply and be of value to NASA, Navy, Air Force, Army, FAA, and industry is highly warranted. In an effort to develop a quantitative process, the use of guided ultrasonic waves to evaluate the physical condition of aviation wiring is being investigated. Three different gauges of MIL-W-81381 wires (Polyimide insulation) were exposed to 399°C for one hour, while another set of each gauge was exposed to 399°C for 49 hours, which damaged the wire insulation. The damage was measured ultrasonically and mechanically. As an example, the ultrasonic guided wave velocity of the lowest order axisymmetric mode for 12 gauge wires were measured as 3352, 3596, and 3712 m/s for baseline, one hour, and 49 hours at 399°C respectively. Mechanically, the tensile moduli of these wires were also measured. For the 12 gauge wires, the moduli were 8025, 10882, and 15894 ksi for baseline, one hour, and 49 hours at 399°C respectively. The results suggest that the ultrasonic guided wave measurement method is detecting degradations in wire insulation.

A Phased Array for Guided Wave Mode Tuning

---Michael J. Quarry, Lawrence Livermore National Laboratory, P. O. Box 808, L-333, Livermore, CA 94551

---One method for utilizing ultrasonic guided wave modes involves mode tuning, or searching the dispersion curve space for a suitable inspection mode. Characteristics of a suitable mode are often based upon the application and criteria for the inspection. Each mode on a dispersion curve behaves differently in a waveguide as a result of its unique displacement pattern and dispersive characteristics. Flaws, such as corrosion pits, often have unknown geometry and orientation, so scattering is difficult to predict. As a result, the mode and frequency with optimal sensitivity is generally unknown. Hence, mode tuning is an approach to find a mode that satisfies the inspection criteria. Performing mode tuning requires a source with the flexibility to excite a variety of modes. This is achieved in this study with a 32 element array with arbitrary waveform inputs. The array is driven with an appropriately phased set of inputs for a desired mode. A comparison between the theoretical excitation between an angle beam and array is made showing the requirements for the parameters of an array to achieve similar mode control to an angle beam. Experimental results confirm that a larger number of elements enhances mode control.

Development of a Manual Air-Coupled Ultrasonic Inspection Instrument for Use on Aeronautical Structures under In-Service Conditions

---A. Gachagan, S. Kelly, G. Hayward, T. McCunnie, and D. Skillen, Centre for Ultrasonic Engineering, University of Strathclyde, 204 George Street, Glasgow, G1 1XW; M. Altman and E. Grauvogl, EADS Deutschland GmbH, Werk Manching, MLQM 33, Germany

---Conventional ultrasonic inspection techniques employ some form of liquid coupling to efficiently transfer the energy between the ultrasonic sensor and the structure under test. The requirement for this coupling layer is a severe hindrance on acquiring fast, convenient in-service inspection data. Over the past decade, there has been significant research activity in the field of non-contact inspection techniques. Of particular interest is the application of ultrasonic Lamb wave inspection techniques for interrogation of materials when access is restricted to one plane. This paper describes the development program through which a portable non-contact inspection system, suitable for in-service inspection of aeronautical structures, has been produced. The instrument is powered from a re-chargeable battery pack which provides over six hours of continuous usage. The transducer front end is a lightweight, hand-held assembly in which a pair of piezocomposite transducers are housed. Angular adjustment of the transducers enables the instrument to operate into a variety of materials, with metallic and composite materials of primary interest. Importantly, a single channel oscilloscope has been incorporated to provide visual interpretation of the processed received signal. The instrument performance has been evaluated using both laboratory and industrial measurements. Defect detection is demonstrated in a number of aerospace samples, with the resultant C-scans presented where appropriate.

Modeling of Effects of Excitation Velocities on the Thermal Image Obtained for Thermosonic Nondestructive Evaluation

---Krishnan Balasubramaniam, Naveen V. Nair, Veeraraghavan Sundararaghavan, and Sarit K. Das, Center for NDE, Indian Institute of Technology Madras, Chennai, Tamil Nadu, India

---Thermosonics is a hybrid ultrasonic - thermal technique in which the sample is excited using a low frequency ultrasonic wave. This excitation, on interaction with the crack surface causes frictional heating at the crack surface as a result of which thermal energy is generated. This heat is transferred to the surface and the transient thermal image at the surface can be mapped to detect and classify the defect. Since the heat is generated as a result of friction at the crack surfaces simple heat sources can be constructed at the crack, for modeling purposes, as a function of the excitation velocity using basic friction equations. A finite difference model is then constructed to study the heat transfer characteristics through the material into which different source characteristics can be introduced. Various types of heat sources that might be created due to friction are mathematically generated for various excitation velocities of the ultrasound source and the corresponding predicted thermal images are obtained.

Non-Baseline Damage Detection from Changes in Strain Energy Mode Shapes: Experiments on Armored Vehicle Launched Bridge

---Edward S. Sazonov and Powsiri Klinkhachorn, Lane Department of Computer Science and Electrical Engineering, College of Engineering and Mineral Resources, West Virginia University, Morgantown, WV 26506; Hota V.S. GangaRao and Udaya B. Halabe, Constructed Facilities Center, College of Engineering and Mineral Resources, West Virginia University, Morgantown, WV 26506

---There are several existing methods for damage detection based on identifying changes in strain energy mode shapes. Most of these methods require knowing strain energy mode shapes for a structure without damage in order to establish a baseline for damage detection. Usually, the mode shapes from the structure under test should be compared to the baseline mode shapes to identify and locate damage. However, these methods of damage detection are not very suitable for application on structures where baseline mode shapes cannot be readily obtained, for example, structures with preexisting damage. Conventional methods, like building a finite element model of a structure to be used as a baseline, might be an expensive and time-consuming task that can be impossible for complex structures. A new (non-baseline) method for the extraction of localized changes (damage peaks) from strain energy mode shapes based on Fourier analysis of the strain energy mode shapes has been developed and analytically proven for the cases of a pinned-pinned and a free-free beam. The new method looks for characteristic changes in the power spectrum of the strain energy mode shapes in order to locate and identify damage. The analytical results have been confirmed both by the finite element model and impact testing experiments on a free-free aluminum beam, including single and multiple damage scenarios. This paper presents results of testing the non-baseline method on a complex structure - Armored Vehicle Launched Bridge, which consists of loosely coupled hinged beams with variable cross-section. The results of testing confirm applicability of the non-baseline method to damage detection in complex structures and highlight certain particularities of its use.

High Frequency Ultrasound Generation by Femtosecond Laser Ablation

---F. Blanchard, F. Martin, J.-C. Kieffer, F. Vidal, T. Johnston, and N. Perret, INRS-Énergie et Matériaux, Varennes, Quebec, Canada; A. Blouin, A. Moreau, and J.-P. Monchalain, National Research Council, Boucherville, Quebec, Canada

---We present experimental measurements of ultrasound generated by ablation using an ultra-short laser pulse. The source is a Ti-Sapphire laser (800 nm) producing pulses of 60 fs to 300 fs (compressed) or 270 ps (uncompressed) duration, with adjustable energy up to 600 mJ. The targets are common aluminum freestanding foils with thickness between 5 μm and 100 μm . The ultrasound echoes are detected by measuring surface displacements on the side opposite to the ablation surface. To this end, we use a CW Nd:YAG laser (500 mW) coupled to a confocal Fabry-Perot interferometer in reflection mode. The measurement bandwidth is limited by the photodetector/amplifier electronics. The InGaAs-based detection system we used has a 3 dB high frequency cut-off of 500 MHz. A high pass filter (>20 MHz) is used to maximize the high frequency response. Data acquisition is achieved using a 4 GSamples/s scope. Single shot measurements indicate high frequency (>300MHz) ultrasound longitudinal wave. We have measured thicknesses down to 5 μm , and concluded that the present setup allows to measure thickness down to the micron. Laser-produced ultrasound pulses are modeled by means of a one-dimensional fluid code featuring a realistic material equation of state and laser energy absorption. Surface displacements as a function of time are obtained for various laser parameters, including possible removal of material on both surfaces of a freestanding foil. Predictions of the model are compared to experimental data.

Thursday, July 18, 2002

SESSION 28 – POSTERS
MATERIAL PROPERTIES, X-RAY, SIGNAL PROCESSING,
EDDY CURRENTS, COMPOSITE MATERIALS AND COMPONENTS, ULTRASONICS
Viking Union

1:30 PM

Material Properties

Ultrasonic Backscattering Profiles on Periodically Rough Interface

---S. D. Kwon and S. S. Yoon, Department of Physics, Andong National University, Andong P. O. Box 203, Andong 760-747, Korea

Effect of Surface Curvature on Backscattered Ultrasonic Grain Noise in Titanium Forgings

---F. J. Margetan and R. B. Thompson, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011; A. Degtyar and H. Wasan, United Technologies, Pratt & Whitney, East Hartford, CT 06108

Correlation Between Local Ultrasonic Properties and Grain Size 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

Characterization of Solutionizing Treatment in Titanium Alloys by Ultrasonic Velocity Measurements

---A. Kumar, T. Jayakumar, and B. Raj, Metallurgy and Materials Group, Indira Gandhi Center for Atomic Research, Kalpakkam, Tamil Nadu, India; K. K. Ray, Department of Metallurgical and Materials Engineering, Indian Institute of Technology, Kharagpur, West Bengal, India

Accuracy Measurement of Rayleigh Wave Velocities by Laser Ultrasonics for Residual Stress Profiling

---W.-J. Xu, F. Jenot, and M. Ourak, IEMN Département d'Opto-Acousto-Electronique, Université de Valenciennes, Le Mont Houy, 59313 Valenciennes Cédex, France; Y.-D. Pan and M.-L. Qian, Institute of Acoustics, Tongji University, Shanghai 200092, China

Stress Evaluation by Chaotic Characteristic of Barkhausen Noise

---Y. Tsuchida and M. Enokizono, Faculty of Engineering, Oita University, 700 Dannoharu, Oita 870-1192, Japan

Investigation of Thermal Diffusivity of Nano-Structured TiO₂ Films

---X. R. Zhang, S. Lin, and J. He, Laboratory of Modern Acoustics and Institute of Acoustics, Nanjing University, Nanjing 210093, China; G. H. Li and L. D. Zhang, Institute of Solid State Physics, Chinese Academy of Sciences, Hefei 230031, China

A Study on Point Defects of ZnSe/GaAs Epilayer Obtained from Photoluminescence Measurement

---K. J. Hong, S. H. You, J. W. Jeong, and H. W. Baek, Department of Physics, Chosun University, Kwangju 501-759, South Korea; C. S. Park, Division of Metallurgical and Material Science Engineering, Chosun University, Kwangju 501-759, South Korea; K. H. Im, Department of Automotive Engineering, Woosuk University, Wanju-kun Chonbuk 565-701, South Korea; F. S. Ohuchi, Department of Materials Science and Engineering, University of Washington, Seattle, WA 98195-2180

Thursday, July 18, 2002

A Study on Properties of Infrared Detector for a HgCdTe Epilayers Using Photocurrent Measurement

---C. S. Park, Metallurgical and Material Science Engineering, Chosun University, Kwangju 501-759, South Korea; K. J. Hong, S. Y. Lee, J. W. Jeong, and H. W. Baek, Department of Physics, Chosun University, Kwangju 501-759, South Korea; K. H. Im, Department of Automotive Engineering, Woosuk University, Wanju-kun Chonbuk 565-701, South Korea; R. K. Bordia, Department of Materials Science & Engineering, University of Washington, Seattle, WA 98195-2120

X-Ray

Calibration of X-Ray Computed Tomography Systems for Field Applications

---T. J. Roney, T. A. White, and R. J. Pink, Physics Department, Idaho National Engineering and Environmental Laboratory (INEEL), Idaho Falls, ID 83415-2209; M. Smith, Idaho Accelerator Center, Idaho State University, Pocatello, ID; F. Noo and R. Clackdoyle, Department of Radiology, University of Utah, Salt Lake City, UT

Signal Processing

Statistical Characterization of Multiphase Flow by Dynamic Tomography

---G.-R. Tillack and V. Samodurov, Federal Institute for Materials Research and Testing (BAM), Division VIII.3, Berlin Germany, V. Artemiev, Institute of Applied Physics, Minsk, Belarus

Identification of Thermal and Optical Effects for the Detection of Open-Crack in Photothermal Non Destructive Testing

---M. Joubert and M. Decitre, Laboratory LESiR/SATIE, Ecole Normale Supérieure, 94235 Cachan, France; M. Hermosilla-Lara, Centre Technique de FRAMATOME-ANP, Department Contrôle Non Destructif/TFCE, ZIP, 71380 St. Marcel, France

Swept Frequency Multiplication (SFM) Techniques for Improved Air-coupled Ultrasonic NDE

---T. H. Gan, D. A. Hutchins, and R. J. Green, School of Engineering, University of Warwick, Coventry CV4 7AL, United Kingdom

Eddy Current Image Fusion by Combining Spatial Frequency and Wavelet Transform

---L. Li, W. Cheng, K. Tsukada, and K. Hanasaki, Earth Resources Engineering, Graduate School of Engineering, Kyoto University, Kyoto, Japan

Eddy Currents

Development of Eddy Current Probe for Thick-Walled Plates and Quantitative Evaluation of Cracks

---T. Takagi, T. Uchimoto, K. Sato, and H. Huang, Institute of Fluid Science, Tohoku University, 2-1-1 Katahira, Aoba, Sendai 980-8577, Japan

An RFECT Probe with a Superconducting Shield

---N. Yusa and Z. Chen, International Institute of Universality, 1-4-6-801, Nezu, Bunkyo, Tokyo, 113-0031, Japan; K. Demachi, Nuclear Research Engineering Laboratory, University of Tokyo, 2-22 Shirakata-Shirane, Ibaraki, Japan

A New Eddy Current Surface Probe for Short Flaws with Minimal Lift-off Noise

---H. Hoshikawa, K. Koyama, and M. Maeda, Nihon University, Izumicho Narashino Chiba 275-8575, Japan

Eddy Current Array Probe for Crack on Rivet Hole

---R. Leclerc, R/D Tech Incorporated, 505, boul. du Parc-Technologique, Québec, G1P 4S9, Canada

Thursday, July 18, 2002

Composite Materials and Components

Nondestructive Evaluation of Ceramic Matrix Composite Combustor Components

---J. Sun, Argonne National Laboratory, Argonne, IL; R. R. Stephan, Pratt & Whitney, East Hartford, CT; M. J. Verilli, NASA Glenn Research Center, Cleveland, OH; T. R. Barnett, Southern Research Institute, Birmingham, AL; G. C. Ojard, United Technologies Research Center, East Hartford, CT

An Experimental Study on the Impact Collapse Characteristics of CF/Epoxy Circular Tubes

---Y. N. Kim, Department of Mechanical Design Engineering, Chosun University, 375 Seosuk-dong, Dong-gu, Kwangju, 501-759, Korea; K. H. Im, Department of Automotive Engineering, Woosuk University, Wanju-gun, Chonbuk, 565-701, Korea; J. W. Park and I. Y. Yang, Factory Automation Research Center for Parts of Vehicles, Chosun University, 375 Seosuk-dong, Dong-gu, Kwangju, 501-759, Korea

Optical Absorption of Epoxy Resin and its Role in the Laser Ultrasonic Generation Mechanism in Composite Materials

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

Identification of Delamination Onset in Quasi-Isotropic CRFP Laminates Under Fatigue Using Modal Analysis of Acoustic Emission Signals

---C. Mattei, CSM Materialteknik AB, Saab Aerospace Group, Linköping, Sweden

Ultrasonics

Equivalence of Gaussian and Piston Transducer Voltages

---D. E. Chimenti, Iowa State University, Center for NDE and Aerospace Engineering & Engineering Mechanics Department, Ames, IA 50011; O. I. Lobkis, Department of Theoretical and Applied Mechanics, University of Illinois, Urbana, IL 61801

Optimization of Lamb and Rayleigh Waves Generation Using Wideband-Low-Frequency EMATs

---S. Dixon, C. Edwards, and S. B. Palmer, Department of Physics, University of Warwick, Coventry, United Kingdom

Investigation of Velocity Surface of Bulk Acoustic Waves for Proton-Exchanged LiNbO₃ Crystal

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

Calculation of the Saw Velocity Change of Proton-Exchanged LiNbO₃ Crystal

---B. Lin, G. Chen, X. R. Zhang, D. Zhang, and J. C. Chen, State Key Laboratory of Modern Acoustics and Institute of Acoustics, Nanjing University, Nanjing 210093, China

Ultrasound Excited by a Pulsed Thermal Source Distributed Along the Depth Direction

---J. He and X. R. Zhang, State Key Laboratory of Modern Acoustics and Institute of Acoustics, Nanjing University, Nanjing 210093, China; Y. Huang and D. C. Xian, Synchrotron Radiation Laboratory, Institute of High Energy Physics, Chinese Academy of Sciences, Beijing, China

3:10 PM

Coffee Break

Ultrasonic Backscattering Profiles on Periodically Rough Interface

---S. D. Kwon and S. S. Yoon, Department of Physics, Andong National University, Andong P. O. Box 203, Andong 760-747, Korea

---The angular dependence of backscattered ultrasound was measured for steel and brass specimens with periodical surface roughness (Ra:1-71micro, Sm:88-520 micro) using ultrasonic goniometer changing continuously an incident angle. Normal reflection, direct backward radiation(BR), and averaging BR profiles were compared and analyzed. Backward radiations showed more linear dependency than normal profile so that direct amplitude increased and averaging amplitude decreased with surface roughness. SAW generation and BR conversion efficiencies explained these dependencies. Specially the profile area of direct backward radiation could be more meaningful quantity than intensity to assess the regional roughness. The decrease of SAW intensity during propagation on rough surface was mainly due to leaky energy to water involving missing effect of high frequency component below roughness of $(1/6)$ wavelength. Abnormal behavior of multiply reflected wave trains by bottom was explained by multiple reflection of transverse wave which converted from longitudinal wave on effectively inclined interface by periodic roughness. In addition, the interfacial modes on periodically rough surface and painting effect will be discussed.

Effect of Surface Curvature on Backscattered Ultrasonic Grain Noise In Titanium Forgings

---F. J. Margetan and R.B. Thompson, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011; Andrei Degtyar and Harpreet Wasan, United Technologies Pratt & Whitney, East Hartford, CT 06108

---The Engine Titanium Consortium is studying the ultrasonic properties of titanium-alloy forgings used in the fabrication of rotating jet-engine components. The goal is to better understand the influence of the titanium microstructure on inspectability, and to use that understanding to improve ultrasonic inspection practices. One limiting factor in the detection of small or subtle internal defects is backscattered microstructural noise ("grain noise"). In this paper we investigate the interplay between the observed grain noise level and the curvature of the forging surface. In pulse/echo immersion inspections, the surface curvature modifies the incident sound profile within the forging, thus changing the statistical properties of the backscattered grain noise. Six specimens, having roughly similar microstructures, were machined from different angular positions within a forged disk of Ti 6-4 alloy. The "upper" surfaces of the six specimens each have a different curvature. The opposite "lower" surfaces are flat and contain linear arrays of flat-bottomed hole (FBH) reference reflectors. Using focused ultrasonic transducers, backscattered noise and FBH responses were measured through the "upper" surfaces. Noise measurements were also made through the "lower" surfaces to quantify the effects of the minor microstructural differences between the six specimens. Experimental results are presented and discussed. Measured grain noise properties are compared with predictions of an "independent scatterer" noise model.--- 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 and United Technologies Pratt & Whitney as part of the Center for Aviation Systems Reliability program.

Correlation Between Local Ultrasonic Properties and Grain Size 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

---Nickel-alloy billets destined for the fabrication of rotating jet engine components are ultrasonically inspected prior to use. As part of its effort to improve billet inspections, the Engine Titanium Consortium is studying the ultrasonic properties and microstructures of typical Nickel-alloy billets. This paper continues the survey work first reported at last year's QNDE conference. Ultrasonic velocity, attenuation, and back-scattered grain noise have been measured in rectangular coupons cut from representative 10"-diameter billets of IN718 and Waspaloy. Ultrasonic attenuation and backscattered noise were found to vary significantly with position within a billet, principally with radial depth. However, at a given measurement site there was little dependence of ultrasonic properties on inspection direction, suggesting an approximately equiaxed, untextured microstructure. Subsequent metallographic examinations revealed equiaxed grain structures in which the average grain diameter varied with position, tending to be largest at sites with large attenuations and large grain noise levels. The manner in which attenuation or backscattered-noise capacity (FOM) grows with increasing average grain diameter is similar to that expected for Pure-Ni microstructures. However, the rise rates are somewhat smaller for the jet-engine alloys, likely due to differences between the single-crystal elastic constants of the alloys and those of pure Ni. This paper reviews the methods used for ultrasonic measurements and metallographic analyses, and summarizes the primary findings. The tendency of measured grain generating noise capacity to increase with measurement depth (within a region of uniform microstructure) is also 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 Engine Titanium Consortium program.

Characterization of Solutionizing Treatment in Titanium Alloys by Ultrasonic Velocity Measurements

---A. Kumar, T. Jayakumar and B. Raj, Metallurgy and Materials Group, Indira Gandhi Center for Atomic Research, Kalpakkam, Tamil Nadu, India; K. K. Ray, Department of Metallurgical and Materials Engineering, Indian Institute of Technology, Kharagpur, West Bengal, India

---Various specimens of two Ti-alloys, Ti-6Al-4V and Ti-4.5Al-3Mo-1V (VT 14 alloy), were solution treated at different temperatures starting from 923 K to 1323 K at an interval of 50 K for 1 h followed by water quenching. These treatments generated the specimens with different volume fractions of various phases, viz., alpha, beta, unstable beta and/or alpha-dash phases. Ultrasonic longitudinal and shear wave velocities and hardness measurements and optical metallography were carried out on all these specimens. In both the Ti-alloys, ultrasonic longitudinal and shear wave velocities and hardness have been found to decrease with increase in solutionizing temperature up to 1123 K, and beyond that, it has been found to increase. Ultrasonic velocities were found to be constant above beta transus temperature i.e. 1223 K and 1273 K in VT14 and Ti-6Al-4V alloys respectively. The amount of alpha phase stabilizer (Al) is more in Ti-6Al-4V, and hence the beta transus temperature is higher than that in VT14 alloy. The present study has also revealed that ultrasonic velocity measurements can be used not only for characterization of microstructural features obtained by different solutionizing treatments, but also for the determination of beta transus temperature in Ti-alloys.

Accuracy Measurement of Rayleigh Wave Velocities by Laser Ultrasonics for Residual Stress Profiling

---W.-J. Xu, F. Jenot, M. Ourak, IEMN, Département d'Opto-Acousto-Electronique, Université de Valenciennes, Le Mont Houy, 59313 Valenciennes Cédex, France; Y.-D. Pan, and M.-L. Qian, Institute of Acoustics, Tongji University, Shanghai 200092, China

---A method is presented to measure the Rayleigh wave velocity with high accuracy by laser ultrasonics for the determination of residual stress profiling on the surface of an aluminum alloy. A laser ultrasonic system is set up and full automated for applying this method with efficiency and stability. Three aluminum alloys thought to have different residual stress profiles on the detection surface are chosen to demonstrate the capability of this technique. It's show that the best relative accuracy of the measurement is about 0.05% corresponding to the absolute accuracy in velocity of 1.5m/s.

Stress Evaluation by Chaotic Characteristic of Barkhausen Noise

---Yuji Tsuchida and Masato Enokizono, Faculty of Engineering, Oita University, 700 Dannoharu, Oita 870-1192, Japan

---It is well known that the movement of the 180-degree magnetic domain inside magnetic materials generates Barkhausen noise. The stress condition can be evaluated by Barkhausen noise before a crack appears on the surface because the dislocation induced by the stress affects the movement of the magnetic domain. However, it is difficult to quantify the amount of the stress by Barkhausen noise because Barkhausen noise is a very complicated nonlinear signal. So, the special evaluation method should be established to use it for the stress evaluation effectively. We paid attention for the chaos of Barkhausen noise because the chaos theory could treat a signal as non-linear one. In this paper, the quantitative change of Barkhausen noise after a tensile stress test is examined by the fractal dimension of the chaotic attractors constructed by the measured Barkhausen noise.

Investigation of Thermal Diffusivity of Nano-Structured TiO₂ Films

---X. R. Zhang, S. Lin, and J. He, Laboratory of Modern Acoustics and Institute of Acoustics, Nanjing University, Nanjing 210093, China; G. H. Li and L. D. Zhang, Institute of Solid State Physics, Chinese Academy of Sciences, Hefei 230031, China

---We investigate the thermal diffusivity of nano-structured TiO₂ and TiO₂ with 3% ZnFe₂O₄ ceramic films (nm films) sputtered on a <111> cut Si substrates by using the Mirage effect method. Two series of films are prepared by the magneto-rf-sput method. One series of films are sputtered on two substrates <111> Si single crystal disks by using sputtering time of 6 h and are annealed under 450 °C and 900 °C respectively. The other series of films are sputtered on four substrates <111> Si single crystal disks by using sputtering time of 12 h and are annealed under 450 °C, 650 °C, 750 °C and 900 °C respectively. The investigation results show that: the thicker the film, the lower thermal diffusivity of the sample is. The thermal diffusivity of nano-structured film depends on the thickness of film and the annealing temperature. The value of thermal diffusivity increases with the increasing of the annealing temperature. It means that the thermal diffusivity depends on the phase structure of the film. The detail results, analyses and discussions will be presented in this paper.

A Study on Point Defects of ZnSe/GaAs Epilayer Obtained from Photoluminescence Measurement

---K. J. Hong, S. H. You, J. W. Jeong, and H. W. Baek, Department of Physics, Chosun University, Kwangju 501-759, South Korea; C. S. Park, Division of Metallurgical and Material Science Engineering, Chosun University, Kwangju 501-759, South Korea; K. H. Im, Department of Automotive Engineering, Woosuk University, Wanju-kun Chonbuk 565-701, South Korea; Fumio S. Ohuchi, Department of Materials Science & Engineering, University of Washington, Seattle, WA 98195-2180

---The ZnSe epilayers were grown on the GaAs substrate by hot wall epitaxy. After the ZnSe epilayers treated in the vacuum-, Zn-, and Se-atmosphere, respectively, the defects of the epilayer were investigated by means of the low-temperature photoluminescence measurement. The dominant peaks at 2.7988 eV and 2.7937 eV obtained from the PL spectrum of the as-grown ZnSe epilayer were found to be consistent with the upper and the lower polariton peak of the exciton, I₂ (D₀, X), bounded to the neutral donor associated with the Se-vacancy. This donor-impurity binding energy was calculated to be 25.3 meV. The exciton peak, I_{1d}, at 2.7812 eV was confirmed to be bound to the neutral acceptor corresponded with the Zn-vacancy. The I_{1d} peak was dominantly observed in the ZnSe/GaAs:Se epilayer treated in the Se-atmosphere. This Se-atmosphere treatment may convert the ZnSe/GaAs:Se epilayer into the p-type. The SA peak was found to be related to a complex donor like a (VSe - VZn) - VZn.

A Study on Properties of Infrared Detector for a HgCdTe Epilayers Using Photocurrent Measurement

---C. S. Park, Metallurgical and Material Science Engineering, Chosun University, Kwangju 501-759, South Korea; K. J. Hong, S. Y. Lee, J. W. Jeong, and H. W. Baek, Department of Physics, Chosun University, Kwangju 501-759, South Korea; K. H. Im, Department of Automotive Engineering, Woosuk University, Wanju-kun Chonbuk 565-701, South Korea; R. K. Bordia, Department of Materials Science & Engineering, University of Washington, Seattle, WA 98195-2120

---Hg_{1-x}Cd_xTe (MCT) was grown by hot wall epitaxy. Prior to the MCT growth, the CdTe (111) buffer layer was grown on the GaAs substrate at the temperature of 590°C for 15 min. When the thickness of the CdTe buffer layer was 5 μm or thicker, the full width at half maximum values obtained from the x-ray rocking curves were found to significantly decrease. After a good quality CdTe buffer layer was grown, the MCT epilayers were grown on the CdTe (111) /GaAs substrate at various temperatures in situ. The crystal quality for those epilayers was investigated by means of the x-ray rocking curves and the photocurrent experiment. The photoconductor characterization for the epilayers was also measured. The energy band gap of MCT was determined from the photocurrent measurement and the x composition rates from the temperature dependence of the energy band gap were turned out.

Calibration of X-Ray Computed Tomography Systems for Field Applications

---Tim J. Roney, Tim A. White, and Robert J. Pink, Physics Department, Idaho National Engineering and Environmental Laboratory (INEEL), Idaho Falls, ID 83415-2209; Mike Smith, Idaho Accelerator Center, Idaho State University, Pocatello, ID; Frederic Noo and Rolf Clackdoyle, Department of Radiology, University of Utah, Salt Lake City, UT

---Inspection of suspicious packages and detection of illicit materials often must occur at the site where an object is first noticed. In these cases it is important to have field deployable inspection equipment that may be set up rapidly and is easy to use. Determination of package contents may be obtained with conventional transmission radiography, but if information about the distribution of contents is necessary to confirm presence of potentially explosive materials or to precisely locate wiring and fuses, multiple views or tomographic imaging may be required. In these situations the image quality and the dimensional accuracy may be crucial for successfully disabling a device. Precise measurements may be limited by the package configuration, environmental conditions limiting access, and imaging system misalignments. For situations where access to the object is unlimited, we have developed methods to characterize and correct for misalignments in field deployable x-ray computed tomography systems for munitions inspection. These methods involve the measurement of a calibration object and analysis to estimate key parameters such as source-to-detector distance, source-to-object distance and detector orientation. In this paper we will describe linear-diode-array (LDA) based 3-D inspection systems successfully deployed in field environments, characterization of system parameters critical for high quality 2-D and 3-D imaging with LDAs and area detectors, and how these techniques may be used in limited data situations.

Statistical Characterization of Multiphase Flow by Dynamic Tomography

---Gerd-Ruediger Tillack and Vladimir Samodurov, Federal Institute for Materials Research and Testing (BAM), Division VIII.3, Berlin, Germany; Valentin Artemiev, Institute of Applied Physics, Minsk, Belarus

---The paper intends to present special reconstruction algorithm that is capable to monitor density differences in multiphase flows. The flow cross section is represented as discrete dynamic random field with fixed values of its brightness equal to the number of flow phases. The image model is given by a set of non-linear stochastic difference equations. The corresponding inversion task is not accessible by common tomographic techniques applying reconstruction algorithms like filtered backprojection or arithmetic reconstruction technique (ART). The developed algorithm is based on the Kalman filter technique adopted to nonlinear phenomena. The average velocity distribution together with the corresponding covariance matrix of the liquid flow through a pipe serves as prior information in statistical sense. To overcome the non-linearity in the process model as well as in the measurement model the statistical linearization technique is applied. Moreover the Riccati equation, given the error covariance matrix, and the equation for optimal gain coefficients can be solved in advance and later used in the filter equation. It turns out that the resulting reconstruction or filter algorithm is recursive, i.e. yielding the quasi-optimal solution to the formulated inverse problem at every reconstruction step by successively counting for the new information collected in the projections. The applicability of the developed algorithm is discussed in terms of characterizing or monitoring a multiphase flow in a pipe.

Identification of Thermal and Optical Effects for the Detection of Open-Crack in Photothermal Non Destructive Testing

---M. Joubert and M. Decitre, Laboratory LESiR/SATIE, Ecole Normale Supérieure, 94235 Cachan, France; M. Hermosilla-Lara, Centre Technique de FRAMATOME-ANP, Department Contrôle Non Destructif/TFCE, ZIP, 71380 St. Marcel, France

---In this paper, the images provided by a photothermal camera (flying-spot camera) dedicated to open-crack detection are considered. In this type of active thermography, thermal effect and the optical effects contribute to the elaboration of photothermal images. Here the thermal effect is relative to the presence of open-cracks and the optical effects are due to surface conditions. In the case of open-cracks detection, the optical effects are high magnitude perturbation signals. In this contribution a signal processing method is proposed in order to separately identify both thermal and optical effects from the raw images. The method lies on multiple principal component analysis combined with a continuous wavelet transform. It is used to enhance the open-crack detection for the inspection of an industrial mockup showing open-cracks in severe surface conditions. The detection performance enhancement is characterized thanks to Receiver Operating Characteristic curves. The proposed method shows high detection performances and could be extended to a classification scheme.

Swept Frequency Multiplication (SFM) Techniques for Improved Air-coupled Ultrasonic NDE

---Tat Hean Gan, David A. Hutchins, and Roger J. Green, School of Engineering, University of Warwick, Coventry CV4 7AL, United Kingdom

---A new technique has been investigated for improving the signals that can be obtained in air-coupled NDE. This relies on the broad bandwidth available from polymer-filmed capacitive transducers. The technique relies on a swept-frequency "chirp" signal, which is transmitted from a transducer in air, passes through the sample under test, and is then detected at the far side using a separate receiver in through-transmission. The new technique differs from existing time-domain correlation techniques, such as pulse compression, in that a single multiplication process is performed in the time domain to give a difference frequency signal. This can then be easily isolated in the frequency domain. It will be demonstrated that this new Swept Frequency Multiplication (SFM) approach gives excellent resolution between overlapping signals, and indeed has several potential advantages over pulse compression. Examples will be shown of air-coupled images, obtained using SFM processing, which demonstrate the wide application of the technique to air-coupled NDE.

Eddy Current Image Fusion by Combining Spatial Frequency and Wavelet Transform

---Lingqi Li, Wei Cheng, Kazuhiko Tsukada, and Koichi Hanasaki, Earth Resources Engineering, Graduate School of Engineering, Kyoto University, Kyoto, Japan

---In eddy current technique, the depth of eddy current suffers from the so-called skin-effect in such a way that the lower exciting frequency penetrates deeper than the higher one does. Therefore the two-dimensional C-scan ECT image at different frequency carries limited information and is not enough to reveal the whole characters of the test materials. One possible solution is to take several C-scan signals with different frequency and then combine them together to form a single image. In this paper, a new method for image fusion by combining spatial frequency with wavelet transform is investigated. Its application to multi-frequency eddy current C-scan image fusion is studied as well. The spatial frequency algorithm has the advantage of simple computation, while the wavelet transform shows its compactness, orthogonality and the availability of directional information in the fusion procedure. Our experimental results and the related discussion show its superior performance to the algorithms based on the two mentioned above individually.

Development of Eddy Current Probe for Thick-Walled Plates and Quantitative Evaluation of Cracks

---T. Takagi, T. Uchimoto, K. Sato, and H. Huang, Institute of Fluid Science, Tohoku University, 2-1-1 Katahira, Aoba, Sendai 980-8577, Japan

---This paper reports an innovative eddy current testing probe newly developed for testing of thick-walled plates. The present probe consists of two exciting coils carrying current opposite to each other and a differential pick-up coil arranged between the exciting coils. This arrangement enables strong eddy current opposite to scan surface and weak decay of eddy current in the thickness direction. The geometry and size of the components of the probe was decided through the numerical computation using 3D fast eddy current code so that the probe induce eddy current with appropriate distribution. Experimental results showed that the probe can detect a back artificial defect with depth of 0.5mm on a INCONEL718 specimen with thickness of 7.0mm. Reconstruction of crack shapes was also performed based on the experimental eddy current signals with the inverse problem code developed by authors. The length and depth of reconstructed defects approximately agree with those of the real cracks, which supports for high capability of quantitative evaluation of the proposed probe.

An RFECT Probe with a Superconducting Shield

---N. Yusa and Z. Chen, International Institute of Universality, 1-4-6-801, Nezu, Bunkyo, Tokyo, 113-0031, Japan; K. Demachi, Nuclear Research Engineering Laboratory, University of Tokyo, 2-22 Shirakata-Shirane, Ibaraki, Japan

---The remote field eddy current testing (RFECT) is efficient in inspecting outer defects in a magnetic material. The principle of the RFECT is to detect magnetic flux that once penetrates the specimen and diffuses back. Since detectors should be located far enough from the exciter, the amplitude of the RFECT signals is very small. In addition, the length makes handling RFECT probes difficult. Several papers proposed RFECT probes with a shield made of conductive materials such as copper. The direct flux is attenuated by the eddy current induced in the shield set between the exciter and the detector, which makes it possible to shorten the probe length. However the shield is not always sufficiently effective, especially in the case the exciter is driven at a low frequency. This study proposes an RFECT probe equipped with a superconducting shield. The Meissner effect prevents magnetic flux from penetrating superconductor, which implies that a superconductor works as a very effective shield. Several RFECT probes equipped with the superconducting shield are fabricated based on the results of numerical simulations. Experimental results also show effectiveness of superconducting shield and agree well with the simulated results.

A New Eddy Current Surface Probe for Short Flaws with Minimal Lift-off Noise

---H. Hoshikawa, K. Koyama, and M. Maeda,
Nihon University, Izumicho Narashino Chiba
275-8575, Japan

---The authors have developed a new surface eddy current probe named plus probe for detecting short flaws with minimal lift-off noise. The probe comprises of a tangential exciting coil and two tangential detecting coils arranged both side of the exciting coil. Those detecting coils pick up only the eddy current circulating perpendicular to the exciting coil. Thus the probe generates signals only when flaws in the material perturb the eddy current to circulate perpendicular to the exciting coil. The probe generates no signal when the material has no flaw and the eddy current flows along parallel to the tangential exciting coil. As a result, the new probe generates only minimal lift-off noise. The experimental results have indicated that the probe can detect short surface flaws with minimal lift-off noise. The new probe generates a figure-eight-like signal pattern as it scans over a flaw. The phase of the signal changes according to the depth of flaws with little influence from the length, width, and direction of the flaws. Thus the probe make it possible to evaluate the depth of flaws based on the signal phase, which makes eddy current testing more reliable and quantitative than the conventional method. The eddy current testing using the new probe provides the phase information on the depth of flaws just like the inner bobbin coil probe used for the eddy current inspection of tubing.

Eddy Current Array Probe for Crack on Rivet Hole

---R. Leclerc, R/D Tech Incorporated, 505,
boul. du Parc-Technologique, Québec, G1P 4S9,
Canada

---Crack in rivet hole are one of the biggest problem in today's aircraft. Rivet gives a large signal that mask the defect signal. Because of that, this inspection is very time-consuming and required a lot of attention. The eddy current array probe eases the manipulation by scanning the entire area around the rivet with a one-line scan. This technology has the ability to give C-scan as an output simulating a raster scan. The resolution of the C-scan will be in direct correlation with the design of the probe itself. The inspection is then reduced to a few second and gives a good mapping of the area around the rivets. The analysis is done directly on the C-scan with the corresponding impedance plane for a more precise analysis with classic analysis tool. Eddy current array probe is a solution for time consuming inspection.

Nondestructive Evaluation of Ceramic Matrix Composite Combustor Components

---J. Sun, Argonne National Laboratory, Argonne, IL; R. R. Stephan, Pratt & Whitney, East Hartford, CT; M. J. Verilli, NASA Glenn Research Center, Cleveland, OH; T. R. Barnett, Southern Research Institute, Birmingham, AL; G. C. Ojard, United Technologies Research Center, East Hartford, CT

---The pursuit of lower emissions and higher performance from gas turbine engines requires the development of innovative concepts, such as use of advanced materials for key engine components. One key engine component is the combustor, where liners fabricated from a ceramic matrix composite, silicon carbide fibers in a silicon carbide matrix (SiC/SiC), are under evaluation. SiC/SiC composite technology has progressed from fabrication of simple coupons to subelements and now to actual components. This last area posed a significant challenge to nondestructive evaluation (NDE) techniques due to the complex geometries involved. Components fabricated out of SiC/SiC composite were nondestructively interrogated before and after combustion rig testing. The combustor liners were inspected by X-ray, ultrasonic and thermographic techniques. Each NDE technique had advantages and disadvantages. The combustor testing showed that attachment issues were a concern, as found by NDE techniques. More importantly, NDE indications were found to correlate with reduced material properties. The results of NDE testing, along with mechanical properties, will be shown and discussed.---This work was supported by NASA contract NAS3-26385.

An Experimental Study on the Impact Collapse Characteristics of CF/Epoxy Circular Tubes

---Y. N. Kim, Department of Mechanical Design Engineering, Chosun University, 375 Seosuk-dong, Dong-gu, Kwangju, 501-759, Korea; K. H. Im, Department of Automotive Engineering, Woosuk University, Wanju-gun, Chonbuk, 565-701, Korea; J. W. Park and I. Y. Yang, Factory Automation Research Center for Parts of Vehicles, Chosun University, 375 Seosuk-dong, Dong-gu, Kwangju, 501-759, Korea

---This study is to investigate the energy absorption characteristics of CF/Epoxy (Carbon-Fiber/Epoxy Resin) circular tubes in static and impact tests. The experimental results varied significantly as a function of interlaminar number, orientation angle of outer and trigger. When a CFRP composite tube is crushed, static/impact energy is consumed by friction between the loading plate and the splayed fronds of the tube, by fracture of the fibers, matrix and their interface, and the response is complex and depends on the interaction among the different mechanisms, such as transverse shearing, laminar bending and local buckling. The collapse mode depended upon orientation angle of outer of CFRP tubes and loading status(static/impact). Typical collapse modes of CFRP tubes are wedge collapse mode, splaying collapse mode and fragmentation collapse mode.

Optical Absorption of Epoxy Resin and its Role in the Laser Ultrasonic Generation Mechanism in Composite Materials

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

---Epoxy resins are used in various applications and are essential to the fabrication of carbon fiber reinforced composite materials (CFRCs). This paper investigates the laser generated ultrasound in epoxy resins using three different lasers. A TEA CO₂ laser a Nd:YAG laser emitting at the fundamental wavelength and a XeCl excimer laser. In these partially transparent materials the ultrasonic generation mechanism is directly related to the optical absorption depth. The later can be directly measured by using a Michelson interferometer. The present work aims firstly to relate the observed amplitude and frequency content of the longitudinal wave to the optical absorption depth of the epoxy and secondly to evaluate the role of the epoxy resin to the generation of the ultrasound in CFRCs. In order to achieve the former, results from ultrasonic measurements are compared with optical transmission measurements. For the later, comparative results of generation efficiency between the three wavelengths are presented and an attempt is made to the understanding of the way that the resin matrix influences the generation mechanism of ultrasound in composite materials.

Identification of Delamination Onset in Quasi-Isotropic CRFP Laminates Under Fatigue Using Modal Analysis of Acoustic Emission Signals

---Christophe Mattei, CSM Materialteknik AB, Saab Aerospace Group, Linköping, Sweden

---Acoustic emission (AE) is often considered as one of the best candidate for in-situ health monitoring of CFRP composite structures. Recent developments have focused on the possibilities to identify the type of damage (matrix cracking, fiber-matrix debonding, delamination, fiber rupture, etc.) from AE waveforms. Classification techniques such as neural network processing and wavelet transform were proposed. In this paper the performances of a simple and robust frequency domain analysis are evaluated for the precise detection and identification of delamination onset in quasi-isotropic composite under fatigue loading. A criterion is defined based on the frequency corresponding to the maximum signal energy and is used sorted out acoustic events in real time. It is experimentally observed that before delamination all the AE events are distributed between a limited number of frequencies (i.e. modes). As delamination onsets a clear change in the modes frequencies is detected including the appearance of lower frequency modes. Appearance of such frequency shifts is used to stop the fatigue loading. Amplitude C-scans are then performed on each samples to confirm the initiation of the delamination. This technique allows detecting delamination initiation within 2 to 5 fatigue cycles and has a good potential as a robust health monitoring system.

Equivalence of Gaussian and Piston Transducer Voltages

---D. E. Chimenti, Center for NDE and Aerospace Engineering & Engineering Mechanics Department, Iowa State University, Ames, IA 50011; O. I. Lobkis, Department of Theoretical and Applied Mechanics, University of Illinois, Urbana, IL 61801

---A straightforward plane-wave decomposition of collimated beams and electromechanical reciprocity relations are used to demonstrate fundamental differences and unusual similarities about transducer fields and transducer voltages under various conditions. It is shown that the voltage induced by a transmitting acoustic piston transducer radiating into an ideal fluid medium on a second identical piston transducer operating as a receiver is nearly identical to the voltage observed when the two transducers have instead a Gaussian radial surface velocity distribution. The strong similarity in induced voltage begins when the two devices are separated by only a dozen or so acoustic wavelengths from each other, still well within the nearfield of both transducers. The similarity in the two lateral voltage dependences increases with separation, and the two become nearly identical beyond about one fourth the Rayleigh distance. Cases for which the transducer velocity distributions are different from piston, such as Lorentzian or triangular, yield nearly identical results to the piston case. Transducers of differing size are also treated. It is further shown that an "equivalent transducer" can be derived for any combination of radiators, whose field is identical to the voltage measured using the pair. Moreover, with this concept the calculation of voltage in two-probe experiments is as simple as well known farfield approximations to the Rayleigh integral.

Optimization of Lamb and Rayleigh Waves Generation Using Wideband-Low-Frequency EMATs

---Steve Dixon, Christopher Edwards, and Stuart B. Palmer, Department of Physics, University of Warwick, Coventry, United Kingdom

---This paper describes a non-contact Electromagnetic Transducer (EMAT) that can be used to generate both Lamb and Rayleigh waves on metal samples. The generated waves are wideband and low frequency with a dominant frequency content centered on approximately 200kHz extending to around 500kHz. Detection of the waves is achieved using a linear coil detection EMAT. The transducers (generator & detector) have been used on both aluminum and steel, but operate more efficiently on aluminum due to its lower electrical resistance and density and higher stiffness when compared to steel. Some considerations are described for the design of the generation EMAT including applications where the dynamic field from the coil alone is used to obtain the Lorentz interaction with the sample surface eddy current.

Investigation of Velocity Surface of Bulk Acoustic Waves for Proton-Exchanged LiNbO₃ Crystal

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

---The proton-exchange (PE) technique has recently become a convenient method for the fabrication of optical and acoustic waveguides and devices in lithium niobate (LiNbO₃) substrates. The velocity change of longitudinal wave was measured by using Brillouin Scattering method. However, there was no calculation about this problem. We calculate the velocity surface of bulk acoustic waves propagating in the YZ-, XY- and ZX- planes of proton-exchanged LiNbO₃, based on the theory of acoustic wave in anisotropic solid with piezoelectricity. By comparison between the calculated velocity surfaces of bulk waves for pure and proton-exchanged LiNbO₃, the calculation results show that the value of velocity change due to proton-exchange when the wave propagating along X-axis is larger than that along Z- axis for Y-cut substrate, in spite of Longitudinal or Transverse wave. The curve of velocity surface for PE Z-cut substrate is near to a circle, while that for pure Z-cut LiNbO₃ is a hexagonal. The velocity surface for PE X-cut LiNbO₃ seems to be turned an angle from that for pure X-cut LiNbO₃. The detail results, discussions and comparison with the experiment will present in this paper.

Calculation of the Saw Velocity Change of Proton-Exchanged LiNbO₃ Crystal

---B. Lin, G. Chen, X. R. Zhang, D. Zhang, and J. C. Chen, State Key Laboratory of Modern Acoustics and Institute of Acoustics, Nanjing University, Nanjing 210093, China

---The velocity change of surface acoustic wave (SAW) due to proton-exchange were measured by several researchers by using Brillouin Scattering, ultrasonic microscope V(z) and SAW techniques respectively, to measure the propagation velocity of SAW excited by Laser beam or interdigital transducer. However, there were a few calculations about this problem. We calculate the velocity of SAW propagating in the YZ-, XY- and ZX- planes of proton-exchanged LiNbO₃ as the function of propagation direction (angle), based on the theory of SAW propagating in thin film and considering the anisotropic and piezoelectricity of the film and substrate. The calculation results can be compared with the measured results. The value of SAW velocity change when the wave propagating along X-axis is larger than that along Z- axis for Y-cut substrate. The detail results, the comparison between theoretical and experimental results and discussions will present in this paper.

Ultrasound Excited by a Pulsed Thermal Source Distributed Along the Depth Direction

---J. He and X. R. Zhang, State Key Laboratory of Modern Acoustics and Institute of Acoustics, Nanjing University, Nanjing 210093, China; Y. Huang and D. C. Xian, Synchrotron Radiation Laboratory, Institute of High Energy Physics, Chinese Academy of Sciences, Beijing, China

---We investigate the pulsed ultrasonic waveform excited by a thermal source distributed along the depth direction. When an intensive pulsed laser or ion beam impinging a material surface, gradually loses its energy and heating the material along the passing path of the beams, a pulsed ultrasonic wave can be excited. By dividing the distribution layer into many sublayers (sub sources), and considering the waves excited at different positions can only be reflected when it arrived the surface of sample, as a first approximation. We deduce an expression and calculate the epicenter displacement of ultrasound by weight addition of the contributions coming from the sublayers. Investigation results show that: the waveform of displacement depends on the distribution depth and type of thermal source, the properties of samples, and the ratio between the thickness of the absorption layer and the duration of excitation beam. The shorter the thermal source the duration of ultrasound is the narrower, when the temperature increase and the sample thickness are fixed. The double polarity of the waveform decreases with the increasing the duration of the thermal source even change into a single polarity. The detail process, results and discussions will be presented.

Thursday, July 18, 2002

SESSION 29
INTERFACES AND COMPOSITES
J. Peters, Chairperson
SMATE 150

- 3:30 PM** **Mapping Ply Layup of Composite Laminates Using Ultrasonic Full-Waveform B-Scan**
---D. K. Hsu, D. Fei¹, and Z. Liu², Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011; ¹Caterpillar, Inc., Peoria, IL; ²Chinese Academy of Space Technology, Beijing, China
- 3:50 PM** **A Modified Transfer Matrix Approach for Modeling Ultrasonic Wave Reflection/Transmission from Thick Bonded Structures**
---V. Mukundan, V. M. Reddy, and K. Balasubramaniam, Centre for Nondestructive Evaluation, MDS/MEMH 312, Indian Institute of Technology, Chennai 600 036, India
- 4:10 PM** **Application of Fast Multipole Boundary Element Method to Scattering Analysis of SH Lamb Waves by Lap Joint**
---T. Saitoh, Civil Engineering, Tokyo Institute of Technology, Meguro-ku, Tokyo, Japan; A. Gunawan and S. Hirose, Mechanical and Environmental Informatics, Tokyo Institute of Technology, Meguro-ku, Tokyo, Japan
- 4:30 PM** **Infrared Scanning of FRP Composite Members**
---U. B. Halabe, G. Bangalore, H. V. S. GangaRao, Department of Civil and Environmental Engineering, Constructed Facilities Center, West Virginia University, Morgantown, WV 26506-6103; P. Klinkhachorn, Lane Department of Computer Science and Electrical Engineering, Constructed Facilities Center, West Virginia University, Morgantown, WV 26506-6104
- 4:50 PM** **Non-Contact Inspection of Composites Using Air-Coupled Ultrasound**
---J. Peters, V. Kommareddy, Z. Liu¹, D. Fei², and D. K. Hsu, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011; ¹Chinese Academy of Space Technology, Beijing, China; ²Caterpillar, Inc., Peoria, IL

Mapping Ply Layup of Composite Laminates Using Ultrasonic Full-Waveform B-Scan

---D. K. Hsu, D. Fei¹, and Z. Liu², ¹Center for NDE, Iowa State University, 1915 Scholl Road, Ames, IA 50011; ¹Caterpillar, Inc., Peoria, IL; ²Chinese Academy of Space Technology, Beijing, China

---A method for nondestructively mapping out the ply layup of a composite laminate is presented. The method employs normal-incidence longitudinal ultrasound but exploits the presence of small structural imperfections that are always present at the interfaces between plies. It was found that C-scan images of ply interfaces contain streaking features that correspond with the fiber orientations primarily of the two neighboring plies. However, for ply interfaces buried at a greater depth, their C-scan images were usually quite noisy and the fiber orientations difficult to discern visually. To overcome these difficulties, 2D FFT was applied to the C-scan image of an interface, and the resultant amplitude-versus-angle plot was used to determine the fiber orientation. Since the ply thickness was an unknown and the interface echoes were usually not distinct even at fairly high frequencies, the placement of time windows was impractical. Therefore, the entirety of full-waveform B-scan data were used. 2-D FFT was performed on C-scan slices with small time (depth) increments regardless of the actual location of the ply interfaces. This method was more robust and worked successfully on a large variety of composite laminates. Finally, a wave propagation model for the laminate as a multi-layered system was invoked to explain some of the experimental findings.---This work was supported by the NSF Industry/University Cooperative Center for Nondestructive Evaluation at Iowa State University.

A Modified Transfer Matrix Approach for Modeling Ultrasonic Wave Reflection/Transmission from Thick Bonded Structures

---Vikram Mukundan, Vikram M. Reddy, and Krishnan Balasubramaniam, Centre for Nondestructive Evaluation, MDS/MEMH 312, Indian Institute of Technology, Chennai 600 036, India

---This work deals with the modeling of Ultrasonic Waves in Multi-layered Isotropic materials. Two algorithms for the modeling of ultrasonic reflection/transmission coefficients from isotropic multi-layer structure, (a) Modified transfer matrix method, and (b) stiffness matrix method, are compared in terms of numerical stability when modeling thick structures. A modification has been applied to the transfer matrix approach to enhance its computational stability, especially at higher frequency and thickness values. The modification proves to be stable, and the results are compared with the unconditionally stable stiffness matrix algorithm. The interface bonding properties has been incorporated using the well known spring model for the transverse and normal stiffness have been incorporated. The stability of the algorithms for large number of layers are also presented with the other results and verifications. Modeling of attenuation and damping have also been incorporated. The simulation of reflected/transmitted RF signals from the multilayered isotropic structures will also be discussed.

Application of Fast Multipole Boundary Element Method to Scattering Analysis of SH Lamb Waves by Lap Joint

---Takahiro Saitoh, Civil Engineering, Tokyo Institute of Technology, Meguro-ku, Tokyo, Japan; Arief Gunawan and Sohichi Hirose, Mechanical and Environmental Informatics, Tokyo Institute of Technology, Meguro-ku, Tokyo, Japan

---A lap joint is an important structural component in aircraft. Quantitative information on the lap joint may be obtained by investigating the properties of reflected and transmitted Lamb waves generated by a lap joint. Since Lamb waves show the steady propagation in a plate far from the lap joint, the large scale analysis is required for solving the scattering by a lap joint as well as the steady propagation of the Lamb waves in a portion far from the lap joint. In this paper, therefore, the Fast Multipole Boundary Element Method (FMBEM) in conjunction with mode decomposition procedure is applied to solve the scattering of SH Lamb waves by a lap joint. In a numerical calculation, reflection and transmission coefficients are obtained as a function of frequency for each SH Lamb mode. The results show the possibility of nondestructive evaluation for hidden defects in the lapjoint structure caused by fatigue, corrosion and so on.

Infrared Scanning of FRP Composite Members

---U. B. Halabe, G. Bangalore, H. V. S. GangaRao, Department of Civil and Environmental Engineering, Constructed Facilities Center, West Virginia University, Morgantown, WV 26506-6103; P. Klinkhachorn, Lane Department of Computer Science and Electrical Engineering, Constructed Facilities Center, West Virginia University, Morgantown, WV 26506-6104

---Fiber Reinforced Polymer (FRP) is rapidly emerging as an alternative material for the infrastructure industry, and as a supplement to the conventional material such as steel, concrete, and timber. However, the long-term behavior of these materials have not been fully understood. In order to study the durability issues, it is important to develop a nondestructive evaluation (NDE) system for continuous monitoring of structural members built with FRP materials. This paper presents the results of an experimental study on delamination detection in Fiber Reinforced Polymer (FRP) composite members using infrared thermography. Simulated delaminations of various sizes were inserted into several FRP box sections and deck sections during the pultrusion process to create subsurface defects. The defective specimens were then tested using infrared thermography to predict the location and planar extent of these subsurface delaminations. The infrared tests yielded good results, which indicates that the technique can be developed for long-term in-service monitoring of FRP structural members in the field environment.

**Non-Contact Inspection of Composites
Using Air-Coupled Ultrasound**

---J. Peters, V. Kommareddy, Z. Liu¹, D. Fei²,
and D. K. Hsu, Center for NDE, Iowa State
University, 1915 Scholl Road, Ames, IA 50011;
¹Chinese Academy of Space Technology,
Beijing, China; ²Caterpillar, Inc., Peoria, IL

--- Conventional ultrasonic tests are conducted using water as a transmitting medium. Water-coupled ultrasound cannot be applied to certain water-sensitive or porous materials and is more difficult to use in the field. In contrast, air-coupled ultrasound is non-contact and has clear advantages over water-coupled testing. The technology of air-coupled ultrasound has gained maturity in recent years. Some systems have become commercially available and researchers are pursuing several different modalities of air-coupled transduction. This paper reports our experience of applying air-coupled ultrasound to the inspection of flaws, damage and normal internal structures of composite parts. Through transmission C-scans at 400 kHz using a focused receiver, the resolution was sufficient to image honeycomb cells in the sandwich core. With transmitter and receiver on the same side of a laminate, Lamb waves were generated and used for the imaging of substructures. Air-coupled scan results will be presented for flaw detection and damage imaging in aircraft composite structures; in addition, results will also be shown for ceramic composites and wood products.---This work was supported by the NSF Industry/University Cooperative Center for Nondestructive Evaluation at Iowa State University.

Thursday, July 18, 2002

SESSION 30
NDE FOR BIO MATERIALS
F. Inanc, Chairperson
SMATE 140

- 3:30 PM** **Noninvasive Imaging for Tissue Characterization and Hyperthermia Thermometry**
---H. A. Sabbagh, R. K. Murphy, and E. H. Sabbagh, Victor Technologies, LLC, P. O. Box 7706, Bloomington, IN 47407-7706
- 3:50 PM** **Neural and Decision Theoretic Approaches for the Automated Segmentation of Radiodense Tissue in Digitized Mammograms**
---R. E. Eckert, J. T. Neyhart, R. Polikar, and S. A. Mandayam, Electrical and Computer Engineering, Rowan University, Glassboro, NJ 08028; M. Tseng, Fox Chase Cancer Center, Philadelphia, PA 19111
- 4:10 PM** **CT Based Radiography Simulations for Both Industrial and Medical Radiography**
---F. Inanc, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011
- 4:30 PM** **Ultrasonic Determination of the Optimum Processing Temperature for Frozen Meat Products**
---B. Bridge, Research Centre for Automated and Robotic Non-Destructive Testing, School of Engineering, South Bank University, 103 Borough Road, London SE1 0AA
- 4:50 PM** **Wavelet Transform and Neural Network Technology Application for Bio-Impedance Signal Analysis**
---V. M. Batutina, Physics Department, Krasnoyarsk State Technical University, Krasnoyarsk, Russia

**Noninvasive Imaging for Tissue
Characterization and Hyperthermia
Thermometry**

---H. A. Sabbagh, R. K. Murphy, and E. H. Sabbagh, Victor Technologies, LLC, P. O. Box 7706, Bloomington, IN 47407-7706

---We extend volume-integral eddy-current models that have been developed for conventional nondestructive evaluation (NDE) to tissue characterization and hyperthermia thermometry. Hyperthermia is a method of cancer treatment in which the tumor is selectively heated electromagnetically relative to the surrounding tissue. The problem is to noninvasively measure the temperature of the tumor, so that the treatment can be properly handled. In past research we have reported on inverse methods in eddy-current NDE, and we demonstrate how these inversion algorithms can be applied to solve this problem.

**Neural and Decision Theoretic Approaches
for the Automated Segmentation of
Radiodense Tissue in Digitized
Mammograms**

---R. E. Eckert, J. T. Neyhart, R. Polikar, and S. A. Mandayam, Electrical and Computer Engineering, Rowan University, Glassboro, NJ 08028; M. Tseng, Fox Chase Cancer Center, Philadelphia, PA 19111

---Mammography is the best method available as a non-invasive technique for the early detection of breast cancer. 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. Previously, we have shown that the use of statistical models is a reliable technique for segmenting radiodense tissue. This paper presents improvements in the model that allow for the further development of an automated system for segmentation of radiodense tissue. The segmentation algorithm employs a two-step process. In the first step, segmentation of tissue and non-tissue regions of a digitized X-ray mammogram image are identified using a radial basis function neural network. The second step uses a constrained Neyman-Pearson algorithm, developed especially for this research work, to determine the amount of radiodense tissue. Results obtained using the algorithm have been validated by comparing with estimates provided by a radiologist employing previously established methods.

CT Based Radiography Simulations for Both Industrial and Medical Radiography

---F. Inanc, Center for NDE, Iowa State University, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

---One of the important issues in the simulation work is proper representation of the objects used in the simulations. The target objects in the simulations may have geometrical shapes ranging from simple geometries to very complicated geometries. In addition, a lot of objects come with heterogeneous material properties that need to be included into simulations. These two issues play important roles in both industrial and medical radiography simulations. Computed tomography became widely available to the radiography community in the recent years. Since this technology provides two-dimensional images, CT images can be used to build models toward using in simulation work. In this work, we developed a CT image based algorithm to account for object shape complexities and heterogeneities. The resulting algorithm and absorbed energy doses in a human body part and ideal detector images obtained through the algorithm will be presented.---This work was funded by the Roy J. Carver Charitable Trust.

Ultrasonic Determination of the Optimum Processing Temperature for Frozen Meat Products

---B. Bridge, Research Centre for Automated and Robotic Non-Destructive Testing, School of Engineering, South Bank University, 103 Borough Road, London SE1 0AA

---Low quality meat such as the tough neck muscle of beef cattle can be processed to achieve a comparable texture and taste of much better cuts of steak. However is temperature at which the reprocessing, which can include cutting and machining, takes place is quite critical. It must be hard enough and so cool enough to be workable by machining tools without disintegration but it would not machine at all well if, for example, it had the hardness of ice. Hardness tests give a poor indication because they only give local indications at points on the surface and not of any variations throughout the bulk of a sample. Ultrasonic wave velocity measurements might give a more useful indication of the suitability for machining of a sample as a whole. Using cubic samples with 100 mm edges the temperature dependence of the velocity of 500KHz compressional waves from dry contact probes was measured over the range starting from deep frozen conditions to a defrosted condition. The velocity correlated well with hardness measurements.

**Wavelet Transform and Neural Network
Technology Application for Bio-Impedance
Signal Analysis**

---Vera M. Batutina, Physics Department,
Krasnoyarsk State Technical University,
Krasnoyarsk, Russia

---Methods of impedance encephalography and ophthalmology are among the few non-invasive methods that are able to work in real time and automatic mode. The application of bio-impedance signal data in early stage diagnostics of diseases connected with brain and eye vessel system pathology where there are no distinct clinical and functional deviations are of particular interest, for instance, early diagnostics of primary open-angle glaucoma using neuronet technologies. To design and train a neuronet classifier it is necessary to present the original signals as a database, consisting of a small number of the most informative parameters, characterizing the disease condition. Conventionally, in clinical practice the patients condition was analyzed on the basis of the so-called physiological parameters, taken from bio-impedance signal according to the given empirical rule. We have investigated the possibilities of Fourier transforms application for pre-processing of this signal and the formation of informative data base to design and train the neural network classifiers for the primary open angle glaucoma diagnostics. In this paper the procedure of filtering the most informative parameters on the basis of wavelet transform of signal and building an expert systems using neuroimitator program is suggested. For testing the procedure the base of the original bio-impedance signal of patients was used. At present these methods are being tested and introduced into practical work of Krasnoyarsk Regional Ophthalmologic Clinical Hospital.

Thursday, July 18, 2002

SESSION 31
UT BENCHMARK
M. Spies, Chairperson
FRASER 4

- 3:30 PM** **Ultrasonic Modeling of Benchmark Problems**
---L. W. Schmerr, Jr., Center for NDE and the Department of Aerospace Engineering and Engineering Mechanics, Iowa State University, Ames, IA 50011; A. Sedov, Department of Mechanical Engineering, Lakehead University, Thunder Bay, Ontario P7B 5E1, Canada
- 3:50 PM** **Predication of Insonifying Velocity Fields and Flaw Signals of the 2002 Ultrasonic Benchmark Problems**
---S.-J. Song, J.-S. Park, and H.-J. Kim, School of Mechanical Engineering, Sungkyunkwan University, Suwon, Korea
- 4:10 PM** **Prediction of Transient Flaw Signals of the Ultrasonic Benchmark Problem**
---M. Spies, Fraunhofer-Institute for Nondestructive Testing (IZFP), University, Bldg. 37, 66123 Saarbruecken, Germany
- 4:30 PM** **Ultrasonic Benchmark Problem: Application of a Paraxial Model to Side-Drilled Holes and Oblique Incidence**
---T. A. Gray, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011
- 4:50 PM** **Results Obtained with CIVA Software Developed at the French Atomic Energy Commission**
---N. Gengembre, R. Raillon, and A. Lhémy, Commissariat à l'Énergie Atomique, French Atomic Energy Commission, Laboratoire de Simulation Ultrasonore et de Traitement, Ultrasonic Modeling and Processing Techniques Laboratory, CEA-Saclay, bât. 611, 91 191 Gif-sur-Yvette Cedex, France

Ultrasonic Modeling of Benchmark Problems

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

---This work is part of a study designed to compare the ultrasonic models used in various organizations around the world on a simple set of benchmark problems. The purpose of the study is to demonstrate the consistency (or lack thereof) in current ultrasonic modeling approaches and to test a variety of modeling approximations. In the first part of the study, conducted at the 2001 RPQNDE meeting, models were tested for focused and unfocused piston transducers radiating at normal incidence (to a planar interface) into a component that contained on-axis spherical pores or circular cracks. Here, the same normal incidence configuration will be used for on-axis side-drilled holes and a series of oblique incidence problems will also be solved for on-axis spherical pores and side-drilled holes. As in last year's study, our modeling of these inspection problems will be done with a combination of paraxial beam models and exact/approximate flaw scattering models.---This work was supported by the NSF Industry/University Cooperative Research program.

Prediction of Insonifying Velocity Fields and Flaw Signals of the 2002 Ultrasonic Benchmark Problems

---Sung-Jin Song, Joon-Soo Park, and Hak-Joon Kim, School of Mechanical Engineering, Sungkyunkwan University, Suwon, Korea

---This paper will describe the approaches and the results of Sungkyunkwan University (SKKU), Suwon, Korea to solve the ultrasonic benchmark problems of year 2002. For the prediction of the amplitude of the velocity fields with four different refraction angles, we will use the multi-Gaussian beam model and Rayleigh-Sommerfeld integral with high frequency approximation. In addition, we will predict the flaw signals from two kinds of flaws through following steps; 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 results to be presented are velocity fields in the frequency- domain and flaw signals in the time-domain predicted by the models.

Prediction of Transient Flaw Signals of the Ultrasonic Benchmark Problem

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

---The simulation of experimental results without time and cost of constructing specimens and performing measurements requires the validation of respective physical models. As a first step within the process of comparing model-based simulations to benchmark experiments, a simple problem has been addressed to allow for a preliminary comparison of the various models available. In this contribution, the transient signals from spherical and cylindrical reflectors observed in a pulse-echo measurement are predicted. Normally incident longitudinal waves as well as transverse and longitudinal waves of oblique incidence, generated by circular focused and unfocused transducers, respectively, of 5 MHz center frequency are assumed in an immersion geometry. Two sets of scattering objects are considered: spherical and cylindrical scatterers of diameters ranging from 0.125 mm to 4 mm centered at a distance of 25.4 mm into an aluminum block. For oblique incidence, the transducers are assumed to be inclined at an angle such that waves are excited at refracted angles of 30°, 45°, 60° and 70°. Using a point source superposition technique, the generation, propagation and refraction of the incident signal is simulated, where an appropriate spectral function is considered to characterize the reference waveform. To predict the electric voltage signal generated in the transducer, Auld's reciprocity formula is used, while the scattering process at the defect is modeled using Kirchhoff's theory. The calculations are performed in frequency domain with subsequent inverse Fourier transform into the time domain.

Ultrasonic Benchmark Problem: Application of a Paraxial Model to Side-Drilled Holes and Oblique Incidence

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

---This presentation will demonstrate the application of an ultrasonic measurement model developed at the Center for Nondestructive Evaluation to two benchmark problems. The first problem is to calculate RF waveforms for normal incidence longitudinal wave measurements on a planar sample containing side-drilled holes (SDH) of several diameters and at a given depth. Both planar and focused immersion ultrasonic transducers will be considered. The second problem uses the same two transducers, but now tilted to generate refracted longitudinal or shear waves at several angles. The calculations will use both the sample containing SDH from the first problem and a second sample containing spherical voids at the same depth and with the same range of diameters as the SDH. Results will include simulated RF waveforms from the reflectors as well as the amplitude of the incident ultrasonic fields at the location of the flaw centers. For both problems, numerical predictions will be made both when small flaw approximations are applied as well as when numerical integration of the ultrasonic fields over the surface of the reflector is considered. The use of the paraxial approximation in the ultrasonic beam model will be discussed, along with its impact on speed of computation and on accuracy of results.---This work was supported by the NSF Industry/University Cooperative Research program.

**Results Obtained with CIVA Software
Developed at the French Atomic Energy
Commission**

---Nicolas Gengembre, Raphaële Raillon, and
Alain Lhémy, Commissariat à l'Énergie
Atomique, French Atomic Energy Commission,
Laboratoire de Simulation Ultrasonore et de
Traitement, Ultrasonic Modeling and Processing
Techniques Laboratory, CEA-Saclay, bât. 611,
91 191 Gif-sur-Yvette cedex, France

---The CIVA software developed at the French
Atomic Energy Commission (CEA) for
processing , imaging and simulating NDT data
(ultrasonics, eddy-current, radiography) includes
tools for simulating the whole inspection of a
component (possibly made of anisotropic
heterogeneous materials and of complex
geometry defined by CAD) in which virtual
defects (simple standard or complex shape) are
positioned. Simulated images are directly
comparable with measured ones, the same
imaging tools being used for both. The field
radiated into the component and generated by
refraction by an arbitrary transducer (standard,
phased-array) from a coupling medium
(immersion, contact) is computed using a model
of elastodynamic pencils and accounts for
transducer diffraction effects under the
approximations of Rayleigh integral formulation.
Various scattering theories can be used to
compute the beam / defect interaction. For the
cases in hand, Kirchhoff's approximation was
applied. Reciprocity principle allows to predict
the reception by the transducer of waves
scattered by the defect (and component
boundaries). Results given and discussed are
those obtained for the various problems of the
02' benchmark session. To more easily interpret
them, results of field computation for the various
transducers considered are also given. A
comparison with results for problems of
01'benchmark session is presented.

Thursday, July 18, 2002

SESSION 32
BENCHMARK – MAGNETIC FLUX LEAKAGE AND EDDY CURRENT
A. Pignotti, Chairperson
FRASER 3

- 3:30 PM** **MFL Benchmark Problem II: Laboratory Measurements**
---A. Pignotti, G. Sánchez, and P. Stickar, Center for Industrial Research, FUDETEC, Campana, Buenos Aires, Argentina
- 3:50 PM** **Simulation of the Magnetic Flux Leakage NDE Benchmark Problem**
---Y. Tian, Y. Li, L. Udpa, and S. S. Udpa, Department of Electrical and Computer Engineering, Michigan State University, East Lansing, MI 48824
- 4:10 PM** **Numerical Prediction of Signal for Magnetic Flux Leakage Benchmark Task**
---V. Lunin, D. Alexeevsky, and K. Miakushev, Moscow Power Engineering Institute (TU), Moscow, Russia
- 4:30 PM** **Evaluation of Standard Configurations for Nondestructive Eddy-Current Testing**
---R. Sikora, Technical University of Szczecin, ul. Sikorskiego 37, 70-313 Szczecin, Warsaw, Poland; H. May and R. Palka, Institute of Electrical Machines, Traction and Drives, Technical University Braunschweig, Braunschweig, Germany
- 4:50 PM** **Simulation of the World Federation's Second Eddy Current Benchmark Problem**
---Y. Tian, Y. Li, L. Udpa, and S. S. Udpa, Department of Electrical and Computer Engineering, Michigan State University, 2120 Engineering Building, East Lansing, MI 48824

MFL Benchmark Problem II: Laboratory Measurements

---A. Pignotti, G. Sánchez, and P. Stickar, Center for Industrial Research, FUDETEC, Campana, Buenos Aires, Argentina

---A second Magnetic Flux Leakage Benchmark Problem was submitted to the members of the World Federation of Nondestructive Evaluation Centers, and any other interested party, with the idea of comparing model results from different Centers with laboratory measurements. In this report, the measured values of the leaked field are reported. The problem consists in calculating/measuring the radial component of the magnetic field leaked from a rotating steel pipe, on which two notches have been machined. One notch is on the external, and one on the internal pipe surface, and both are oriented in the longitudinal pipe direction. The dimensions are approximately the following: depth 1mm, width 1mm, and length 25 mm. The external and internal pipe radii are 88.7 and 81.1 mm, respectively, and the pipe rotates at 20 and 40 RPM. The field is measured by a Hall probe located at either 1 or 2 mm above the pipe surface, with a sampling rate of 4KHz. The full problem is three-dimensional, nonlinear, and time-dependent, but we believe that a reasonable approximation can be obtained in two dimensions. Nonlinearity is, however, essential, because the applied DC magnetic field (20KA/m) is in the steel magnetic saturation region. A table of the value of the magnetic induction flux density B versus magnetic field H for the steel used was provided (neglecting hysteresis).

Simulation of the Magnetic Flux Leakage NDE Benchmark Problem

---Y. Tian, Y. Li, L. Udpa, and S. S. Udpa, Department of Electrical and Computer Engineering, Michigan State University, East Lansing, MI 48824

---The World Federation of Nondestructive Evaluation Centers has proposed a series of benchmark problems in order to facilitate comparison of simulation models. The results will eventually be compared with experimentally obtained results. The second magnetic flux leakage problem involves the calculation of the radial component of the magnetic flux leakage field around notches machined on a rotating steel pipe. An external field excites the pipe, whose magnetization characteristics are known. Transducers take field measurements as the pipe rotates about its central axis. This paper presents leakage field predictions around a number of notches obtained using a finite element model.

Numerical Prediction of Signal for Magnetic Flux Leakage Benchmark Task

---V. Lunin, D. Alexeevsky, and K. Miakushev, Moscow Power Engineering Institute (TU), Moscow, Russia

---Numerical results predicted by the finite element code MagNum3D developed at MPEI are presented. The nonlinear magnetostatic benchmark problem proposed by the World Federation of Nondestructive Evaluation Centers, involves numerical prediction of normal (radial) component of the leaked field in the vicinity of two practically rectangular notches machined on a rotating steel pipe (with known nonlinear magnetic characteristic). One notch is located on external surface of pipe and other is on internal one, and both are oriented axially. The problem was considered at first as two-dimensional (plane) for predicting signal for central cross-section. The boundary conditions for magnetic vector potential in the numerical models were selected so that satisfy to the required field level (tangential component) on the pipe surface in the absence of any notch. The rotation effect was replaced by movement of a notch-model circumferentially with small step adjusted to a sampling rate of field measurement. Results obtained will be presented at a special session and compared with predictions from other Centers.

Evaluation of Standard Configurations for Nondestructive Eddy-Current Testing

---R. Sikora, Technical University of Szczecin, ul. Sikorskiego 37, 70-313 Szczecin, Warsaw, Poland; H. May and R. Palka, Institute of Electrical Machines, Traction and Drives, Technical University Braunschweig, Braunschweig, Germany

---This paper discusses some practical configurations for finding cracks in well-conducting materials using the eddy current nondestructive testing method (NDT). The first fundamental measurement configuration consists of two identical coils connected differentially which move along the tube. The second arrangement consists of one single coil which can be moved along the tube as well. The coils are energized by an impressed high frequency AC current and the changes of their impedances depend on the position of the flaws in the tube. Sensitiveness of the impedance on the crack position is the main parameter for all configurations to be examined. In order to increase this sensitivity the optimization of all properties of these systems e.g. dimensions of the coils, their positions and frequency has been carried out. Magnetic field distribution within the above configurations has been determined using an appropriate finite-element software. These calculations require an adjusted (very fine) finite element grid, because of extremely small diffusion depth of electromagnetic field at high frequencies for well-conducting regions. The proper field calculation in such structures leads usually to large equation systems and results in long computation time and possible instabilities and inaccuracy of obtained solutions. All these features of the calculation algorithm show the limits of the eddy-current evaluation methods. By means of the above mentioned evaluations it is possible to estimate the usefulness of the different measurement configurations for eddy current NDT and to formulate some requests for the developer of NDT-sensors.

Simulation of the World Federation's Second Eddy Current Benchmark Problem

---Y. Tian, Y. Li, L. Udpa, and S. S. Udpa,
Department of Electrical and Computer
Engineering, Michigan State University, 2120
Engineering Building, East Lansing, MI 48824-
1226

---This paper presents results obtained by simulating the second eddy current benchmark problem proposed by the World Federation of Nondestructive Evaluation Centers. The problem involves the prediction of the change in impedance of a pancake coil as it scans the inside surface of an inconel tube. The tube contains a flaw on the outer surface. The geometry is similar to those encountered in the eddy current of steam generator tubes in nuclear power plants. Simulation results presented include impedance plots obtained by scanning along the axial and circumferential directions for a variety of flaws at different excitation frequencies.

Friday, July 19, 2002

SESSION 33
CIVIL MATERIALS AND STRUCTURES
G. Washer, Chairperson
SMATE 150

- 8:30 AM** **Three-Dimensional Steady-State Green's Functions for a Layered Isotropic Plate**
---H. Bai, A. H. Shah, and N. Popplewell, Faculty of Engineering, University of Manitoba, Winnipeg, Manitoba R3T 5V6, Canada
- 8:50 AM** **Calculation and Measurement of Ultrasonic Attenuation for Distributed Cracks in a Solid**
---M. Kitahara and T. Takahashi, Department of Civil Engineering, Tohoku University, Sendai, Japan
- 9:10 AM** **Ultrasound Diffusion for Crack Depth Determination in Concrete**
---S. K. Ramamoorthy, Y. Kane, and J. A. Turner, Department of Engineering Mechanics, University of Nebraska, Lincoln, NE 68588-0526
- 9:30 AM** **NDE of FRP-Reinforced Concrete Structures Using Acousto-Ultrasonic Imaging**
---V. F. Godínez-Azcuaga, R. D. Finlayson, and R. K. Miller, Physical Acoustics Corporation, Princeton Junction, NJ 08550; J. Berman, U.S. Army Construction Engineering Research Laboratory, Champaign, IL
- 9:50 AM** **Improved Imaging for Ground Penetrating Radar Measurements of Concrete Specimens**
---H. C. Rhim, Department of Architectural Engineering, Yonsei University, Seoul 120-749, Korea; S.-K. Woo and Y.-C. Song, Korea Electric Power Research Institute, Taejeon, Korea
- 10:10 AM** **Coffee Break**
- 10:30 AM** **Nondestructive Evaluation of Double Bevel T-joint by Tandem Array Ultrasonic Transducer**
---H. Shirahata, Musashi Institute of Technology, Department of Civil and Construction Engineering, Iowa State University, 405 Town Engineering Building, Ames, IA 50011; C. Miki and R. Yamaguchi, Tokyo Institute of Technology, 2-12-1 Oookayama, Meguroku, Tokyo 152-8552, Japan
- 10:50 AM** **Improving the Accuracy of Impact-Echo in Testing Post-Tensioning Ducts**
---C. Colla, via Piacenza 51, 29016 Cortemaggiore, Italy
- 11:10 AM** **Axisymmetric Modes that Propagate in Buried Iron Water Pipes**
---R. Long, P. Cawley, and M. J. S. Lowe, Department of Mechanical Engineering, Imperial College of Science, Technology and Medicine, London, SW7 2BX, United Kingdom
- 11:30 AM** **Inverse Synthetic Aperture Radar Measurements of Concrete Specimens with Various Inclusions**
---H. C. Rhim, Department of Architectural Engineering, Yonsei University, Seoul 120-749, Korea
- 12:10 PM** **Lunch and Adjourn**

Three-Dimensional Steady-State Green's Functions for a Layered Isotropic Plate

---H. Bai, A. H. Shah, and N. Popplewell, Faculty of Engineering, University of Manitoba, Winnipeg, Manitoba R3T 5V6, Canada

---The elastodynamic response of a layered isotropic plate to a source point load having an arbitrary direction is studied in this paper. The study is motivated by the need to develop a quantitative ultrasonic technique to characterize properties of cracks in unreinforced concrete bridge deck (slab). The elastodynamic response represents the input waves generated by a transmitting transducer. A decomposition technique is developed within each homogeneous isotropic lamina to simplify the general three-dimensional plane-wave propagation problem as a separate plane-strain problem and an anti-plane-wave propagation problem. Explicit forms of the Green's function are constructed first by summing the wave modes of a plane-wave and then superposing the plane-wave solutions in the circumferential direction. Results are checked numerically for a vertical point load acting on a homogeneous and a layered plate by a hybrid method. On the other hand, results are checked for a horizontal point load by using dynamic reciprocal identities.

Calculation and Measurement of Ultrasonic Attenuation for Distributed Cracks in a Solid

---Michihiro Kitahara and Takuma Takahashi, Department of Civil Engineering, Tohoku University, Sendai, Japan

---An experimental measurement of the ultrasonic attenuation provides useful information on the damaged state of structural components. Often an increase of the ultrasonic attenuation is an indication of the overall stiffness degradation. In this paper, the ultrasonic attenuation caused by the scattering is studied from theoretical and experimental viewpoints for the distributed cracks in an elastic material. First, the attenuation is calculated from the scattering cross-section by giving the number of cracks in the unit volume, provided that the distribution of cracks is dilute. Here, the scattering cross-section is evaluated from the far-field integral representation of the scattered waves by cracks and the crack opening displacement in the integrand is calculated from BEM. Then, a cement-based specimen that contains penny shaped cracks is prepared and the experimental measurement of scattered waveforms is performed. In this experiment, the radius of cracks and the number of cracks per unit volume are selected so that the first peak of the ultrasonic attenuation is in the transducer bandwidth. After the processing of measured waveforms, the measured attenuation is obtained and it is compared with the numerically calculated attenuation. A relatively good agreement is obtained for the measured and numerically calculated attenuations in the range of transducer bandwidth.

Ultrasound Diffusion for Crack Depth Determination in Concrete

---Sathish Kumar Ramamoorthy, Yogesh Kane, and Joseph A. Turner, Department of Engineering Mechanics, University of Nebraska, Lincoln, NE 68588-0526

---The determination of the depth of surface-breaking cracks in concrete specimens using an ultrasound diffusion technique is discussed. Experiments were carried out on pre-cracked concrete specimens of varying crack depth (0 - 40% of the specimen thickness). Contact transducers were placed at the specimen surface with source and receiver separated by the crack. Tone burst excitations over a frequency range of 400-600 kHz were used. At these frequencies, ultrasound is scattered considerably by the heterogeneities in the concrete. In the limit of many scattering events, the evolution of energy may be modeled as a diffusion process. The arrival of the peak diffuse energy at the receiver is delayed due to the presence of crack. This delay is the prime indicator used for determining crack depth. Several data reduction methods were explored and are discussed. Numerical and analytical analyses were also both used for comparison. These results are in basic agreement with the experiments. In addition, these analyses are used to study the limits of this technique. In particular, it is shown that this technique is applicable to cracks greater than the scattering mean free path, which is estimated at 1 cm for these specimens. Aspects for practical implementation are also discussed.---Work supported by NSF.

NDE of FRP-Reinforced Concrete Structures Using Acousto-Ultrasonic Imaging

---Valery F. Godínez-Azcuaga, Richard D. Finlayson, and Ronnie K. Miller, Physical Acoustics Corporation, Princeton Junction, NJ 08550; Justin Berman, U.S. Army Construction Engineering Research Laboratory, Champaign, IL

---A common solution to increase or maintain the capacity of buildings, bridges, and concrete water and sewer pipes for carrying loads is to introduce additional tension-carrying materials such as Fiber Reinforced Plastic (FRP) composites. Efficient use of FRP composites, to increase the strength of concrete components, depends on the proper bonding between the FRP plate and the rehabilitated structure. It is therefore very important that defects (such as delaminations) present at the interface or within the composite be detected in order to maintain the structural integrity of the reinforced concrete component. Since composites are very sophisticated materials with complex structures and anisotropic material properties, they are very difficult to inspect using conventional NDE methods. Physical Acoustics Corporation (PAC) has tested and developed a unique Acousto-Ultrasonic (AU) technology, which has shown to be a powerful tool for the inspection of these FRP retrofitted concrete structures. In this paper the successful use of this technology in the detection and imaging of delaminations and steel reinforcement in FRP-Concrete structure is discussed. This structure was subjected to different seismic loads and damaged in order to study its performance under seismic excitation. PAC has also developed a conceptual design for a field-portable, battery-powered AU system. This system, which would allow field engineers to routinely inspect FRP-reinforced systems, is currently being developed.

Improved Imaging for Ground Penetrating Radar Measurements of Concrete Specimens

---H. C. Rhim, Department of Architectural Engineering, Yonsei University, Seoul 120-749, Korea; S.-K. Woo and Y.-C. Song, Korea Electric Power Research Institute, Taejeon, Korea

---Ground Penetrating Radar (GPR) has been used to image inside concrete specimens embedded with steel bars and delamination. An imaging algorithm has been developed to improve measurement output generated from a commercial radar system. 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 results have shown improved output of the radar measurements compared to commercially available processing methods. Antennas of 900, 1000, and 1500 MHz are used.

Nondestructive Evaluation of Double Bevel T-Joint by Tandem Array Ultrasonic Transducer

---H. Shirahata, Musashi Institute of Technology, Department of Civil and Construction Engineering, Iowa State University, 405 Town Engineering Building, Ames, IA 50011; C. Miki and R. Yamaguchi, Tokyo Institute of Technology, 2-12-1 Oookayama, Meguroku, Tokyo 152-8552, Japan

---Double bevel T-joint is one of the most fundamental joints of steel bridges. Double bevel T-joint can be seen at beam-column connection of bridge pier. In the Japanese specifications, the welding should be full penetration. However, weld defect of incomplete penetration could be left in the joint due to the lack of quality control in welding. Fatigue cracks can be propagated from the weld defects. Incomplete penetration should be avoided and detected. When ultrasonic test is applied to detect the incomplete penetration, it is difficult to detect by one probe technique because incomplete penetration is a planar defect. The authors developed a tandem array transducer. The tandem array transducer consists of 10 elements aligned in the same direction. Each element is an ultrasonic transducer of 5MHz and 70 degrees. Tandem scanning can be simulated by the transducer. Specimens of double bevel T-joint were made. Parameters of specimen were thickness of plate and height of incomplete penetration. Ultrasonic test was conducted for those specimens, changing position of the transducer. At each position of the transducer, detectability of incomplete penetration was investigated. Image reconstruction of incomplete penetration by synthetic aperture focusing technique (SAFT) was carried out. Height of incomplete of penetration could be estimated accurately for some cases.

Improving the Accuracy of Impact-echo in Testing Post-tensioning Ducts

---C. Colla, via Piacenza 51, 29016
Cortemaggiore (Pc), Italy

---Concern exists worldwide over the safety and durability of post-tensioned structures as a result of voids around the tendons in the ducts. Considerable difficulties have arisen in terms of inspection techniques for these structures and also NDT has had so far a limited success. The aim of the work reported herein was to apply a single NDT technique, for reliably detecting the lateral position of post-tensioning metal ducts, their concrete cover and for assessing their grouting condition. Impact-echo, an acoustic reflection technique, has previously been used with these purposes obtaining encouraging preliminary results. Nevertheless the need has arisen for greater accuracy in duct's lateral and depth position, and in detecting grouting faults around the tendons. The scanning impact-echo method, a further development of the traditional impact-echo technique, was applied for testing on site on a post-tensioned beam from a concrete bridge. Measurements are carried out along survey lines and data can be displayed as 2-dimensional cross-sections of the element tested. Thanks to detailed analysis of a large amount of impact-echo data, a novel understanding of wave propagation around ducts in concrete is proposed, thus improving data interpretation accuracy with regard to depth values. Further, 2-dimensional data visualisation allowed recognition of signal patterns in the impactechograms produced. It was possible to identify voiding in the post-tensioning ducts and to discriminate reliably between fully grouted and partially grouted ducts. Impact-echo findings were compared satisfactorily with large samples cored from the tested areas.

Axisymmetric Modes that Propagate in Buried Iron Water Pipes

---R. Long, P. Cawley, and M. J. S. Lowe,
Department of Mechanical Engineering, Imperial
College of Science, Technology and Medicine,
London, SW7 2BX, England

---An investigation is being conducted into the characteristics of acoustic wave propagation in buried iron water mains. The established acoustic leak location technique used on buried water pipes assumes that leak noise propagates as a single non dispersive mode. By contrast, predicted dispersion curves presented in this paper suggest that a number of non-torsional axisymmetric modes may propagate with significant dispersion, which would lead to leak location errors. The dispersive mode shapes and mode attenuation due to leakage have been investigated to predict whether a mode will propagate over any significant distance at low frequencies. Experiments have been conducted on buried water mains at three test sites in the UK to ascertain what modes propagate and to verify the velocity dispersion predictions. The predicted dispersion curves obtained using soil properties measured on site show excellent agreement with the experimental measurements. The dominant mode in the signals received over long distances is the mode that at low frequencies approximates to a plane wave in the water within the pipe. It has also been confirmed that a mode with significant energy in the soil adjacent to the pipe can propagate over long distances with low attenuation; this is analogous to the Scholte wave in a fluid loaded plate.

**Inverse Synthetic Aperture Radar
Measurements of Concrete Specimens with
Various Inclusions**

---H. C. Rhim, Department of Architectural
Engineering, Yonsei University, Seoul 120-749,
Korea

---Radar measurement results of laboratory size
concrete specimens are presented in this paper.
The radar system used for the study is an
Inverse Synthetic Aperture Radar (ISAR).
Concrete targets used for the measurements
have the dimensions of 304.8 mm (width) x
304.8 mm (height) x 101.6 mm (thickness) with
different inside configurations. Comparisons are
made for dry and wet specimens, specimens
with and without inclusions at three different
frequency ranges of 2-3.4, 3.4 - 5.8, and 8-12
GHz.

Friday, July 19, 2002

SESSION 34
NDE FOR PROCESS CHARACTERIZATION AND CONTROL
R. Pappas, Chairperson
FRASER 3

- 8:30 AM** **Using Ultrasonic Diffraction Grating Spectroscopy to Characterize Liquids and Slurries**
---M. S. Greenwood, Nondestructive Measurement and Characterization Sciences, Pacific Northwest National Laboratory, Richland, WA 99352; L. Burgess and A. Brodsky, Center for Process Analytical Chemistry, University of Washington, Seattle, WA
- 8:50 AM** **Characterization of Solid Liquid Suspensions Utilizing Ultrasonic Measurements**
---P. D. Panetta, R. A. Pappas, S. Ahmed, J. Bamberger, and L. J. Bond, Pacific Northwest National Laboratory, 902 Battelle Boulevard, P. O. Box 999, Mail Stop K5-26, Richland, WA 99352
- 9:10 AM** **Artificial Neural Network Based Algorithm for Acoustic Impact Based Non Destructive Process Monitoring of Composite Products**
---N. V. Nair, V. Srivatsan, and K. Balasubramaniam, Center for NDE, Indian Institute of Technology Madras, Chennai, Tamil Nadu, India
- 9:30 AM** **Locating LCD Glass for Robotic Handling**
---J. A. Smith, Corning Incorporated, SP-TD-02-1, Corning, NY 14831
- 9:50 AM** **The Consistency of Phenomenological Models of Ultrasonic Wave Propagation in a Curing Thermoset**
---R. E. Challis and M. E. Unwin, School of Electrical and Electronic Engineering, University of Nottingham, University Park, Nottingham, NG7 2RD, United Kingdom
- 10:10 AM** **Coffee Break**
- 10:30 AM** **A Laboratory Laser-Ultrasonic Instrument for Measuring the Mechanical Properties of Paper Webs**
---E. F. Lafond, T. Jackson, and C. C. Habeger, Institute of Paper Science and Technology, 500 10th Street, N. W., Atlanta, GA 30318-5794; P. R. Ridgway and R. Russo, L. Berkeley, National Laboratory, Berkeley, CA
- 10:50 AM** **Inspection of Wear in Machine Tool Using Laser Ultrasound Technique Based on the Dispersion Behavior of Wedge Waves**
---C. H. Yang and M. F. Huang, Department of Mechanical Engineering, Chang Gung University, Taiwan
- 11:10 AM** **Defect Signal Enhancement in MFL Inspection Lines**
---J. Etcheverry, A. Pignoti, G. Sánchez, and P. Stickar, Applied Physics Department, Centro de Investigación Industrial, Campana, Buenos Aires, Argentina
- 11:30 AM** **On-Line NDE for Advanced Reactor Designs**
--- N. Nakagawa, F. Inanc, and R. B. Thompson, Ames Laboratory and Center for NDE, Iowa State University, Ames, IA 50011; W. R. Junker, R. H. Ruddy, J. M. Beatty, and N. G. Arlia, Science and Technology Department, Westinghouse Electric, Pittsburgh, PA 15235
- 11:50 AM** **An Ultrasonic Meter to Characterize Degree of Fouling and Cleaning in Filters**
---L. J. Bond and M. Morra, Non-Destructive Measurements Characterization Sciences, Pacific Northwest National Laboratory, Richland, WA 99352; G. R. Golcar, Fluid and Computational Engineering, Pacific Northwest National Laboratory, Richland, WA 99352
- 12:10 PM** **Lunch and Adjourn**

Using Ultrasonic Diffraction Grating Spectroscopy to Characterize Liquids and Slurries

---Margaret S. Greenwood, Nondestructive Measurement and Characterization Sciences, Pacific Northwest National Laboratory, Richland, WA 99352; Lloyd Burgess and Anatol Brodsky, Center for Process Analytical Chemistry, University of Washington, Seattle, WA

---The objective is to use ultrasonic diffraction grating spectroscopy to measure the speed of sound in a liquid and the particle size of a slurry. The ultrasonic diffraction grating is formed by machining parallel triangular-shaped grooves on the flat surface of a stainless steel half-cylinder. The grating is placed in contact with the fluid. Ultrasound from a send transducer travels through the stainless steel and strikes the back of the diffraction grating where it is reflected to a receive transducer. Anomalies in the signal from the receive transducer are used to determine properties of the liquid or slurry. Results for liquids will be presented. In addition, the amplitude of the receive signal using sugar water solutions shows that the density can be easily determined within 0.5%. The goal is to develop a non-invasive method for characterizing liquids and slurries, which can be used in a pipeline for many types of applications.

Characterization of Solid Liquid Suspensions Utilizing Ultrasonic Measurements

---P. D. Panetta, R. A. Pappas, S. Ahmed, J. Bamberger, and L. J. Bond, Pacific Northwest National Laboratory, 902 Battelle Boulevard, P. O. Box 999, Mail Stop K5-26, Richland, WA 99352

---Rapid, on-line characterization of the particle size and concentration of highly concentrated slurries is required for the efficient process measurement and control for many processes in government and industrial applications such as waste remediation for the Department of Energy sites and chemical and pharmaceutical manufacturing. However, existing methods based on ultrasonic attenuation can become inaccurate for highly concentrated suspensions due to the complicated mathematics required to describe the multiple scattering that controls the attenuation and careful transducer alignment. Two measurement that help to overcome these difficulties are the ultrasonic backscattering and diffuse field. The backscattering measurement is attractive because the single scattering theories are simpler than attenuation theories and lend themselves for more stable inversion processes, and the measurement of backscattering and diffuse fields do not require long travel distances and can be made with a single transducer thus eliminating alignment problems. We will present ultrasonic measurements on solid liquid suspensions designed to elucidate the particle size and concentration at high concentration.---Pacific Northwest National Laboratory is operated for the U.S. Department of Energy by Battelle under Contract DE-AC06-76RLO18310.

Artificial Neural Network Based Algorithm for Acoustic Impact Based Non Destructive Process Monitoring of Composite Products

---Naveen V. Nair, Vijay Srivatsan, and Krishnan Balasubramaniam, Center for NDE, Indian Institute of Technology Madras, Chennai, Tamil Nadu, India

---Damages like cracks, delaminations, etc., in composite parts have traditionally been evaluated using manual methods like acoustic impact (using measurements in the audio frequencies). This technique is currently used during manufacturing for product quality testing and later for maintenance and assurance of structural integrity. The automation of this technique will significantly improve the reliability of inspection. The signals obtained from the composites using signal-processing techniques in the time frequency domain to build a robust algorithm for detection and identification of defects. A feature vector is constructed using these techniques and then applied to a neural network for defect detection. Comparative studies are conducted to search for the best and most comprehensive feature vector. Results are presented using different signal processing techniques. Similarly comparative results are presented between two different kinds of neural networks (namely Radial Basis Functions and MLP) and various architectures in each kind. A low cost data acquisition system for acquiring audio signals using the sound card and microphone, that is standard in a multi-media PC, was used in the experiments.

Locating LCD Glass for Robotic Handling

---J. A. Smith, Corning Incorporated, SP-TD-02-1, Corning, NY 14831

---Corning and Corning's customers are trying to improve yields by refining the automation processes in the manufacturing of Liquid Crystal Display (LCD) Glass. To help achieve better yields, it is necessary to locate with better precision the LCD panels with respect to robotic tools. As LCD glass becomes thinner, the structural rigidity of the glass goes down and the LCD panels deform more under the panels own weight and during process steps. The unique characteristics of LCD glass makes optical and vision based sensing challenging because LCD glass is optically transparent, optically smooth and particulate free. By combing the characteristics of LCD glass and the harsh manufacturing environment, the sensing of position and orientation is challenging. This paper will discuss two approaches which Corning is currently pursuing to make ranging measurements on LCD Glass. The first approach to locating LCD glass is based on commercial ultrasonic ranging sensors and is intended to be used as an in-process sensor. The second approach is based off a laser confocal displacement sensor. This optical sensor will be used offline to measure the mechanical deformation of the glass when supported on two edges. The knowledge gained from these measurements will improve the positioning of the robotic tools with respect to the LCD glass during the manufacturing process.

The Consistency of Phenomenological Models of Ultrasonic Wave Propagation in a Curing Thermoset

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

---Techniques to track and model the cure of thermoset materials are required as an aid to manufacturing process control, particularly in the context of safety critical structures in the aerospace and automotive industries. Compression and/or shear wave attenuation and phase velocity measurements provide a means to achieve this in many circumstances although there remains a requirement for a model which provides a link between what is measurable by ultrasound and the progress of polymerisation. As a stage in developing such a model it is useful to consider classical phenomenological models of viscoelasticity in the context of ultrasonic wave propagation. We review the implications of the Maxwell, Kelvin-Voigt and Zener models for lossy solids. The Zener model, corresponding to a simple Debye process, is then addressed in an extended form (Cole-Davidson) to account for molecular polydispersity in a curing resin. We investigate the extent to which the model is self-consistent by using derived ultrasonic attenuation data to predict phase velocity dispersion and vice-versa. We have developed a limited description of the state of a curing resin as a function of cure time by using only three parameters – relaxation time τ , relaxation strength a and a molecular dispersion parameter β which represents a distribution of relaxation times corresponding to a distribution of molecular arrangements in the curing material. We show how this description can be used to identify key stages in the cure process such as gelation and vitrification. We investigate its potential for detecting miscure in situations such as where the stoichiometric ratio of the resin and hardener is outside of a specified range.

A Laboratory Laser-Ultrasonic Instrument for Measuring the Mechanical Properties of Paper Webs

---E. F. Lafond, T. Jackson, and C. C. Habeger, Institute of Paper Science and Technology, 500 10th Street, N. W., Atlanta, GA 30318-5794; P. R. Ridgway and R. Russo, L. Berkeley, National Laboratory, Berkeley, CA

---Laser-based ultrasound systems are now penetrating little by little the factory floors and the testing laboratories in the area of process control. For the paper industry, stiffness properties are an important parameter for producing more efficiently a fibrous material like paper. Some of the critical stiffness properties of paper webs can be obtained by entirely non-contact ultrasonic measurements using two different lasers. The authors have developed an interferometer using a photorefractive crystal for non-contact point detection of Lamb waves. The two-wave mixing technique used with the photorefractive crystal has a flat and broad frequency response to ultrasonic waves, in addition to being very sensitive to small amplitudes of displacement, in the nanometer range. In this instrument, both the generation and the detection of ultrasonic waves are carried through fiber optics to allow more flexibility. The results of non-contact laser generation and detection of ultrasound are also presented. Different paper grades have been investigated. The paper grades were heavy grades like linerboard (used in the paper industry to produce cardboard boxes), as well as light-weight paper (copy paper, etc...). The measurements provided interesting information on the variation of the local stiffness properties across a paper web on a millimeter scale.

Inspection of Wear in Machine Tool using Laser Ultrasound Technique Based on the Dispersion Behavior of Wedge Waves

---C. H. Yang and M. F. Huang, Department of Mechanical Engineering, Chang Gung University, Taiwan

---This study describes a method for a non-contact inspection for the sharpness of machine tool using a laser-based ultrasound technique. The basic measurement principle is the dispersion behavior of anti-symmetric flexural (ASF) mode of wedge wave influenced by the sharpness of the machine tool. Wedge waves are guided acoustic waves propagating along the tip of a wedge, with energy tightly confined around the apex. Without apex truncation, the ASF mode is dispersion-free. When apex truncation is introduced, the wear in machine tool in this study, substantial dispersion behavior can be observed. With this principle, machine tool in fresh and worn conditions can be clearly distinguished.

Defect Signal Enhancement in MFL Inspection Lines

---J. Etcheverry, A. Pignotti, G. Sánchez, and P. Stickar, Applied Physics Department, Centro de Investigación Industrial, Campana, Buenos Aires, Argentina

---Magnetic flux leakage is one of the preferred techniques for nondestructive defect detection in ferromagnetic materials. In particular, it is used as one of the basic tools in steel pipe inspection. In this application, it is usually necessary to detect very small flaws in the pipe wall, i.e. as small as 5% of the wall thickness. For tubes of thick walls, and internal defects inspected from the outside, this 5% detection is difficult to achieve, without remanding for manual analysis a huge number of tubes that have only minor imperfections. Several alternatives have been proposed in the literature in order to denoise the signal or increase the amplitude of meaningful signals. Most common alternatives involve filtering, neural-network based recognition, etc. Many available techniques are unsuitable for practical implementation because of their computational complexity, the large number of data needed for calibration (or training), or both. In this work we focus on a relatively straightforward technique, based on obtaining the characteristic signature of the relevant defects, and projecting the actual signal on these 'standard' defect signals. It turns out that only a very small number of standard defects is needed, making this alternative very attractive for industrial implementation. This usually increases the signal-to-noise ratio, but has to be complemented with some technique to reject large signals that are attributable to other causes. We discuss several alternatives, and show examples of signals and noise obtained at an industrial MFL inspection line. We also analyze different possibilities that are computationally less expensive, in order to implement the algorithms on line.

On-Line NDE for Advanced Reactor Designs

---N. Nakagawa, F. Inanc, and R. B. Thompson, Ames Laboratory and Center for NDE, Iowa State University, Ames, IA 50011; W. R. Junker, R. H. Ruddy, J. M. Beatty, and N. G. Arlia, Science and Technology Department, Westinghouse Electric, Pittsburgh, PA 15235

---This paper introduces the concept of on-line sensor methodologies for monitoring structural integrity of next generation power systems, and explains general benefits of the approach, while describing early conceptual developments of suitable NDE methodologies. This expository paper first explains the philosophy behind this approach, i.e. the design-for-inspectability concept, and specifically where and how decades of accumulated knowledge and experience in nuclear power system maintenance are utilized in Generation IV power system designs, in order to advance the safety and economy of the next generation power systems as their designs are being actively developed. Second, we explain that Generation IV reactor design features call for the replacement of the current outage-based maintenance by on-line inspection and monitoring. Third, the model-based approach toward design and performance optimization of on-line sensor systems, using electromagnetic, ultrasonic, and radiation detectors, will be explained. Fourth, general types of NDE inspections that are considered amenable to on-line health monitoring will be listed. Fifth, we will describe specific modeling developments to be used for radiography, EMAT UT, and EC detector design studies.---This work is supported by the US DOE Nuclear Energy Research Initiative (NERI) Program, (Project Number 2001-076).

An Ultrasonic Meter to Characterize Degree of Fouling and Cleaning in Filters

---Leonard J. Bond and Marino Morra, Non-Destructive Measurements Characterization Sciences, Pacific Northwest National Laboratory, Richland, WA 99352; Gita R. Golcar, Fluid and Computational Engineering, Pacific Northwest National Laboratory, Richland, WA 99352

---For the optimization of spiral wound reverse osmosis filters used for desalination it is necessary to quantify system condition in terms of a degree of fouling, during both fouling and cleaning. Current technologies employ indirect measures that monitor either or both pressures or permeate flux and do not provide data during the cleaning cycle. This paper will report an on-line real-time ultrasonic fouling meter that can be used to monitor both fouling and cleaning, including early stage contamination which does not result in either a pressure or permeate flux change. It provides a measure for degree of fouling. A suit of ultrasound transducers is mounted to operate through the filter-housing wall and they were deployed on a pilot-plant scale service water system during operation to process saline solutions (simulated sea and brackish waters). Combinations of both pulse-echo and transmission measurements are employed. Transducers operate with a multiplexer, digitization and distributed signal processing to give feature extraction that forms the bases for an index that quantifies "Degree of Fouling." This index can be measured during both fouling and cleaning. The fouling index is then transmitted to a central computer where it is integrated in a system level prognostic algorithm.

Friday, July 19, 2002

SESSION 35
EFFECTS OF TEXTURE AND STRESS
D. Price, Chairperson
FRASER 4

- 8:30 AM** **Experimental Studies on a Constitutive Relation for Elastic Polycrystals with Quadratic Texture Dependence**
---C.-S. Man and X. Fan, Department of Mathematics, University of Kentucky, Lexington, KY 40506; K. Kawashima, School of Engineering, Tokyo University of Technology, Hachioji, Tokyo 192, Japan
- 8:50 AM** **Experimental Observation of Linear and Non-Linear Guided Wave Propagation in Rolled Aluminum Sheets**
---D. A. Scott and D. C. Price, CSIRO Telecommunications and Industrial Physics, Lindfield, NSW, Australia
- 9:10 AM** **Theoretical Aspects of Linear and Non-Linear Guided Wave Propagation in Rolled Aluminium Sheets**
---D. C. Price and D. A. Scott, CSIRO Telecommunications and Industrial Physics, Lindfield, NSW, Australia
- 9:30 AM** **Characterization of Plastically Deformed Steel Utilizing EMAT Ultrasonic Velocity Measurements**
---P. D. Panetta¹, G. A. Alers², B. Francini¹, A. Diaz¹, and K. Johnson¹, Pacific Northwest National Laboratory, 902 Battelle Boulevard, P. O. Box 999, Mail Stop, K5-26, Richland, WA 99352
- 9:50 AM** **Nondestructive Evaluation of Residual Stresses by Photoacoustic Thermoelastic Method**
---K. L. Muratkov and A. L. Glazov, Physical-Technical Institute of RAS, St. Petersburg, Russia; D. N. Rose and J. E. Dumar, U.S. Army Tank-Automotive and Armaments Command AMSTA-TRD/MS263, U.S. Army TACOM, Warren, MI 48397-5000
- 10:10 AM** **Coffee Break**
- 10:30 AM** **A New Model Equation for Interpreting the Magnetomechanical Effect Using a Generalization of the Rayleigh Law**
---L. Li and D. C. Jiles, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011
- 10:50 AM** **The Influence of Geomagnetic Field to the Formation of Stress Induced Magnetic Flux Leakage**
---H. Songling, L. Luming, and W. Xiaofeng, Department of Mechanical Engineering, Tsinghua University, Beijing 100084, P. R. China
- 11:10 AM** **The Effect of Plastic Deformation and Residual Stress on Magnetic Barkhausen Noise Signals in Mild Steel**
---T. A. Rahim and L. Clapham, Department of Physics, Queen's University, Stirling Hall, Kingston, Ontario, K7M 3N6, Canada
- 11:30 AM** **Analysis Stress Concentration in Ferromagnetic Material with Unexcited Magnetic Signals**
---L. Luming, W. Xiaofeng, H. Songling, and Y. Haiqing, Tsinghua University, Department of Mechanical Engineering, Beijing 100084, P. R. China
- 11:50 AM** **Residual Stress Relaxation Due to Fretting Fatigue in Shot Peened Surfaces of Ti-6Al-4V**
---S. A. Martinez and S. Satish, University of Dayton Research Institute, Dayton, OH 45469-0127; M. P. Blodgett, S. Namjoshi, and S. Mall, Air Force Research Laboratory, Wright Patterson Air Force Base, OH 45433-7817
- 12:10 PM** **Lunch and Adjourn**

Experimental Studies on a Constitutive Relation for Elastic Polycrystals with Quadratic Texture Dependence

---Chi-Sing Man and Xingyan Fan, Department of Mathematics, University of Kentucky, Lexington, KY 40506; Katsuhiko Kawashima, School of Engineering, Tokyo University of Technology, Hachioji, Tokyo 192, Japan

---To terms linear in the texture coefficients, all constitutive equations for textured elastic polycrystals have the same form (*) with the anisotropic part equal to $c\Phi$, where c is a material parameter, and Φ is a fourth-order harmonic tensor whose components are well-defined linear combinations of the texture coefficients. It is problematic whether the class of constitutive equations (*) would work for strongly textured polycrystalline aggregates whose constituting crystallites are strongly anisotropic. To cover such situations, Huang and Man have recently proposed a constitutive relation (HM) with a term quadratic in the texture coefficients added to (*). The objective of our present work is to compare some predictions of (HM) with the corresponding ultrasound measurements on orthorhombic sheets of copper. Let V_L , V_{S1} , and V_{S2} be the speed of the through-thickness longitudinal and shear waves, respectively, and let ρ be the density. Our investigations include the texture dependence of the quantity $A \equiv \rho(V_L^2 + V_{S1}^2 + V_{S2}^2)$, which is independent of texture under (*). Under (HM), the quantity A is texture dependent, and it assumes its minimum value when the polycrystal is isotropic.

Experimental Observation of Linear and Non-Linear Guided Wave Propagation in Rolled Aluminum Sheets

---D. A. Scott and D. C. Price, CSIRO Telecommunications and Industrial Physics, Lindfield, NSW, Australia

---The propagation of ultrasonic guided waves in plates has been used for many years as the basis of a number of NDE techniques, and in particular for characterizing the properties of materials. Non-linear guided waves have been used to detect the early stages of fatigue, microcracking and other microstructural features in a wide range of applications. Central to the interpretation of such measurements is an understanding of the characteristics of propagating linear and non-linear guided waves in plates. An experimental investigation of guided waves in rolled aluminum sheets has been undertaken, and a companion paper reports on theoretical work aimed at designing the experiments outlined here and interpreting their results. Transmitting and receiving transducers were coupled to one side of an aluminum sheet and the propagation characteristics of linear and non-linear elastic waves were measured. Scans of frequency and transducer separation showed the effects of mode coupling and anisotropy in the aluminum sheets, and indicated the presence of cumulative resonant harmonic generation.

Theoretical Aspects of Linear and Non-Linear Guided Wave Propagation in Rolled Aluminium Sheets

---D. C. Price and D. A. Scott, CSIRO
Telecommunications and Industrial Physics,
Lindfield, NSW, Australia

---Non-linear ultrasonic wave propagation has been shown to be sensitive to the presence of distributions of microstructural defects in various engineering materials, which cannot be adequately detected using conventional linear ultrasonic techniques. Examples that have been reported include early stages of fatigue, microcracking, hydrogen embrittlement and distributions of microscopic inclusions and pores. There have been a number of reports of the use of non-linear ultrasonic techniques to the detection of degraded adhesion in fusion bonds and adhesive joints, the latter being an application in which we are particularly interested. In order to increase the sensitivity of non-linear ultrasonic inspection of planar structures (sheets, bonded plates, laminates, etc.) over that of normal incidence techniques, studies of non-linear guided wave propagation have been commenced. This paper reports on preliminary theoretical work aimed at designing and interpreting the results of experiments on guided wave propagation in rolled aluminium sheets. Experimental results are reported in a companion paper. Conditions for the generation of propagating harmonics in isotropic planar plates are outlined. It was found that, under the particular conditions of frequency and wavenumber at which propagating harmonics can be generated, effects of the rolling-induced anisotropy of the aluminium are important. This complicates the problem enormously: its implications will be discussed.

Characterization of Plastically Deformed Steel Utilizing EMAT Ultrasonic Velocity Measurements

---P. D. Panetta¹, G. A. Alers², B. Francini¹, A. Diaz¹, and K. Johnson¹, Pacific Northwest National Laboratory, 902 Battelle Boulevard, P. O. Box 999, Mail Stop, K5-26, Richland, WA 99352

---There is a desire to characterize plastically deformed regions in structures to monitor their integrity. Of particular importance is the accurate prediction of the lifetime of damaged pipelines due to outside force. In order to accurately predict the remaining life it is essential to accurately determine the degree stress and strain in the damaged region for input into fracture mechanics models. Currently, determination of the degree of stress and strain in damaged regions utilizing ultrasonic velocity measurements is complicated by the inherent texture in the materials and the difficulty in separating these effects from the stress and strain contributions. We will report ultrasonic velocity measurements on plastically deformed steel specimens to elucidate the state of damage. Specifically, we have found the shear wave birefringence and SH wave velocity are sensitive to the degree of plastic deformation. Ultrasonic results will be compared with finite element modeling calculation of the stress and strain distributions.---¹Pacific Northwest National Laboratory is operated for the U.S. Department of Energy by Battelle under Contract DE-AC06-76RLO18310. ²EMAT Consulting.

Nondestructive Evaluation of Residual Stresses by Photoacoustic Thermoelastic Method

---Kyrill L. Muratikov and Alexej L. Glazov, Physical-Technical Institute of RAS, St. Petersburg, Russia; Douglas N. Rose and John E. Dumar, U.S. Army Tank-Automotive and Armaments Command AMSTA-TRD/MS263, U.S. Army TACOM, Warren, MI 48397-5000

---Detection of residual stresses is an important problem of modern NDE. Numerous methods such as ultrasonic, optical, X-ray and neutron diffraction, magnetic, etc. are proposed and developed for solution of this problem. However, all of these methods have an essential limitations. In this work a possibility to use photoacoustic thermoelastic method for residual stresses detection in solids at mesoscopic and microscopic levels is discussed. An important advantage of this method consists in its universal character and applicability to objects of different nature. Both theoretical and experimental investigations of the photoacoustic thermoelastic effect in solids with residual stresses are presented. In theoretical part the original non-linear thermoelastic model of the photoacoustic effect in solids is given. The obtained results are applied to analysis of photoacoustic signal properties under different conditions. It is shown that in the near surface measurements the dependence of the photoacoustic thermoelastic signal on residual stresses is the same as that in the case of Stress Pattern Analysis by measurement of Thermal Emission (SPATE). In the experimental part of the work photoacoustic thermoelastic images of the Vickers indented areas in silicon nitride and Al₂O₃-SiC-TiC ceramics have been obtained. The influence of annealing and external loading on the photoacoustic thermoelastic images is investigated. By analyzing the behavior of the photoacoustic signal near vertical crack tips it is shown that the photoacoustic thermoelastic method is sensitive both for normal and shear residual stresses.

A New Model Equation for Interpreting the Magnetomechanical Effect Using a Generalization of the Rayleigh Law

---L. Li and D. C. Jiles, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---Development of a model description of the magnetomechanical effect, which refers to the change of magnetization of a magnetic material resulting from application of stress, has attracted scientific interest because of its importance in the development of stress sensors using magnetostrictive materials and applications of magnetic measurements to non-destructive evaluation of stress in materials. A new model equation for interpreting the magnetomechanical effect has been derived using a generalization of the Rayleigh law. According to the existing theory of the magnetomechanical effect which is based on the 'law of approach', application of stress induces irreversible changes in magnetization towards anhysteretic magnetization which itself is stress-dependent, and the rate of change of magnetization with the input elastic energy is proportional to the displacement of the prevailing magnetization from the anhysteretic magnetization. The theory has recently been refined by including a new linear reversible term in the model equation. It was found that the modified theory can better describe the magnetization changes under variable stress, in particular at small applied stress amplitudes and when the stress changes sign.---This work was supported by the NSF Industry/University Cooperative Research Program at the Center for Nondestructive Evaluation.

The Influence of Geomagnetic Field to the Formation of Stress Induced Magnetic Flux Leakage

---Huang Songling, Li Luming, and Wang Xiaofeng, Department of Mechanical Engineering, Tsinghua University, Beijing 100084, P. R. China

---Residual stresses in ferromagnetic material affect the direction and structure of domains and generates magnetic flux leakage on the surface. In the formation of stress induced magnetic flux leakage, the influence of geomagnetic field is unclear. Residual stress specimen was produced by tight matching of a round ring and a peg. The magnetic fields of two contrast specimens, which were produced in geomagnetic field or in shielding geomagnetic field, were inspected with constant lift-off. The testing results showed that mean amplitude of magnetic flux leakage of the specimen produced in geomagnetic field was larger 0.85% than that of specimen produced in shielding geomagnetic field. So in the formation of stress induced magnetic flux leakage above the surface of inspected ferromagnetic material geomagnetic field gives little contribution.

The Effect of Plastic Deformation and Residual Stress on Magnetic Barkhausen Noise Signals in Mild Steel

---T. A. Rahim and L. Clapham, Department of Physics, Queen's University, Stirling Hall, Kingston, Ontario, K7M 3N6, Canada

---This study was conducted to investigate the effects of plastic deformation on magnetic Barkhausen noise (MBN) signals in mild steel. A number of mild steel samples were subjected to different degrees of uniaxial plastic deformation up to 30% strain. Angular MBN measurements were conducted on those samples. The results indicated that plastic deformation introduces a magnetic easy axis depending on the degree of plastic deformation. Initially, the MBN signals were found to increase with increasing plastic deformation then tended to decrease with higher plastic deformation. A significant progression towards magnetic isotropy (no magnetic easy axis) was observed after heat-treating the samples at low temperatures 450o C, 475o C, and 500o C. The activation energy associated with the anisotropy decrease was calculated from the low temperature annealing results using an Arrhenius-type analysis. This was found to be 99.3Kcal/mol, which is consistent with recovery-type processes.

Analysis Stress Concentration in Ferromagnetic Material with Unexcited Magnetic Signals

---Li Luming, Wang Xiaofeng, Huang Songling, and Yang Haiqing, Tsinghua University, Department of Mechanical Engineering, Beijing 100084, P. R. China

---Stress concentration of ferromagnetic materials can be measured by many various magnetic methods, such as Barkhausen noise method, magnetic flux leakage method, magnetostrictive effect method and so on. These methods will not be available if measured materials are not excited by magnetizing. The magnetic signals used in this paper to analysis the ferromagnetic material stress concentration were unexcited and this can make the process of testing simple, speedy and real time. The studied sample was a steel flat with an elliptical hole on the center to simulate a resource of stress concentration when the flat was tensed highly enough to create a plastic deformation. The study with the unexcited magnetic signals showed that the position and value of significant stress concentration could be measured satisfactorily.

Residual Stress Relaxation Due to Fretting Fatigue in Shot Peened Surfaces of Ti-6Al-4V

---S. A. Martinez and S. Satish, University of Dayton Research Institute, Dayton, OH 45469-0127; M. P. Blodgett, S. Namjoshi, and S. Mall, Air Force Research Laboratory, Wright Patterson Air Force Base, OH 45433-7817

---Fretting fatigue is a surface damage that occurs between two contacting surfaces subjected to cyclic loading. In order to increase the resistance, to initiation of cracks at the surface due to fretting fatigue, the surface of the components are usually shot peened. In general, shot peening produces a layer of compressive stress on the surface of the material there by increasing the resistance to crack initiation. Although shot peening is known to produce positive benefits in enhancing the life of the material through imparted residual stress the relaxation of the stress under fretting fatigue conditions has not been addressed. This paper examines the relaxation of residual stress caused during fretting fatigue. X-ray diffraction has been utilized to measure the residual stress in fretting fatigued shot peened samples of Ti-6Al-4V. Results of residual stress measurements performed along a line perpendicular to the scar, covering both the sides as well as the interior of the fretted region will be presented. Possible reasons for the variation observed in residual stress in different regions will be discussed.---This research was sponsored by and performed on-site at the NDE Branch, AFRL/Material and Manufacturing Directorate, Wright-Patterson Air Force Base, Ohio under contract # F33615-98-C-5217.

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