Abstracts

Review of Progress in Quantitative NDE

Hilton Portland & Executive Tower
Portland,
July 30 – August 4, 2006

Organized by:

Center for Nondestructive Evaluation
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In cooperation with:

Air Force Research Laboratories

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Federal Aviation Administration

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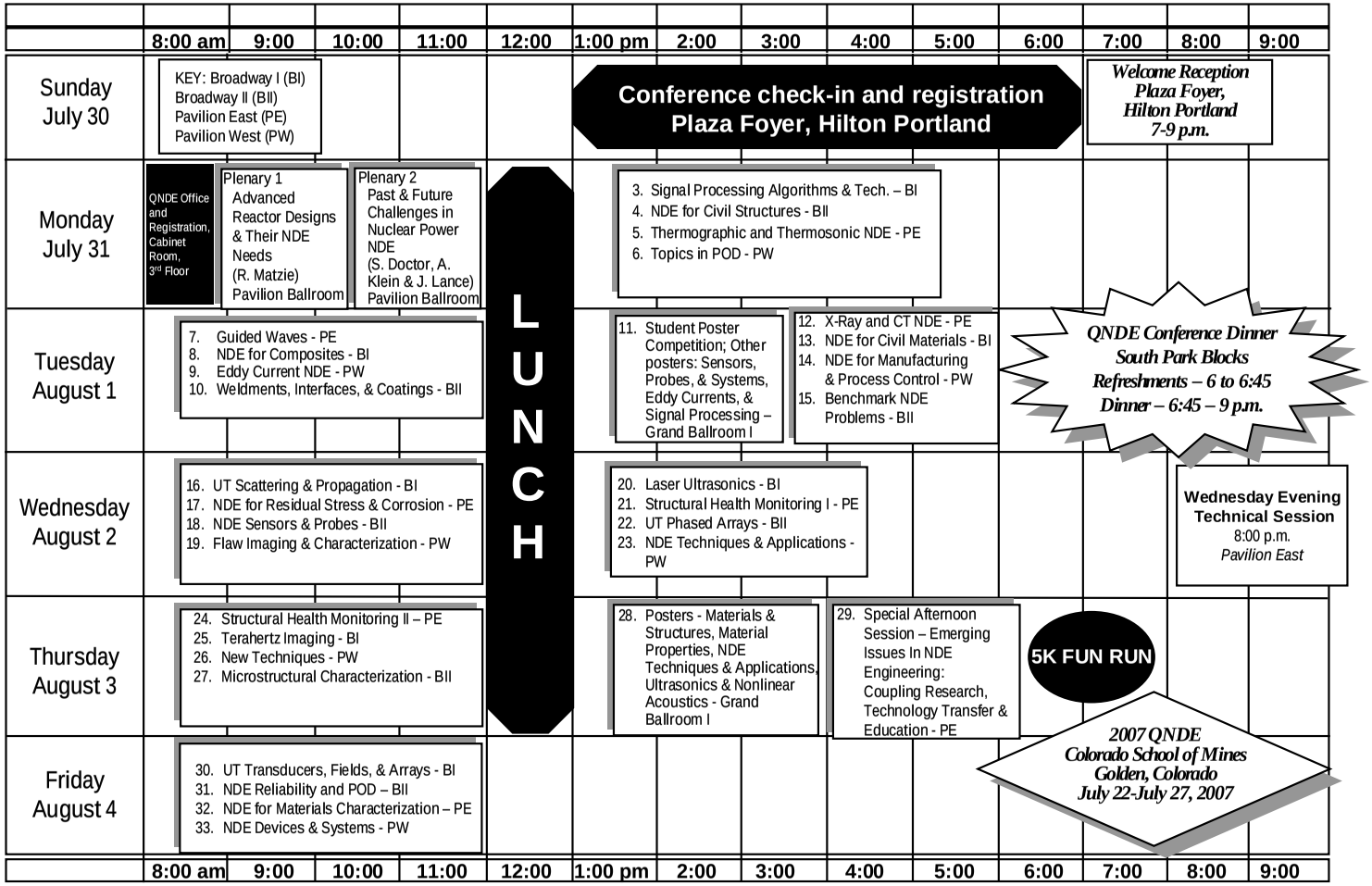
Industry/University Cooperative Research Centers

2006 Review of Progress in Quantitative NDE Program Summary



MONDAY

Plenary Sessions 1 and 2

REVIEW OF PROGRESS IN QUANTITATIVE NDE

Hilton Portland & Executive Tower
Portland, Oregon

July 30 – August 4, 2006

PROGRAM

Monday, July 31, 2006

PLENARY SESSION 1

ADVANCED REACTOR DESIGNS AND THEIR NDE NEEDS

R. B. Thompson, Chairperson
Pavilion Ballroom

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

9:15 AM **The Nuclear Renaissance – Implications on Quantitative Nondestructive Evaluations**
---**R. A. Matzie**, Westinghouse Electric Company, 20 International Drive, Windsor, CT 06095-0500

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

PLENARY SESSION 2

PAST AND FUTURE CHALLENGES IN NUCLEAR POWER NDE

D. E. Chimenti, Chairperson
Pavilion Ballroom

10:30 AM **Nuclear Power NDE Challenges – Past, Present, and Future**
---**S. R. Doctor**, Pacific Northwest National Laboratory, P. O. Box 999, Richland, WA 99352

11:20 AM **Future Directions, Challenges, and Opportunities in Nuclear Energy**
---**A. Klein**, Director of Education, Training and Research Partnerships and **J. Lance**, Director of Technology Partnerships, Idaho National Laboratory, P. O. Box 1625, Idaho Falls, ID 83415-3898

12:10 PM ***Lunch***

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

The Nuclear Renaissance – Implications on Quantitative Nondestructive Evaluations
---**Regis A. Matzie**, Westinghouse Electric Company, 20 International Drive, Windsor, CT 06095-0500

---The world demand for energy is growing rapidly, particularly in developing countries that are trying to raise the standard of living for billions of people, many of whom do not even have access to electricity. With this increased energy demand, and the high and volatile price of fossil fuels, nuclear energy is having a resurgence. This so called nuclear renaissance is broad based, reaching across Asia, the United States, Europe, as well as selected countries in Africa and South America. Some countries that have actually turned away from nuclear energy, such as Italy, are reconsidering the advisability of this decision. This renaissance provides the opportunity to deploy more advanced reactor designs than are operating today, with improved safety, economy, and operations. In this keynote address, I will briefly present three such advanced reactor designs in whose development Westinghouse is participating. These designs include the advanced passive PWR, AP1000, which recently received design certification for the US Nuclear Regulatory Commission; the Pebble Bed Modular Reactor (PBMR) which is being demonstrated in South Africa; and the International Reactor Innovative and Secure (IRIS), which was showcased in the US Department of Energy's recently announced Global Nuclear Energy Partnership (GNEP) program. The salient features of these designs that impact future requirements on quantitative nondestructive evaluations will be discussed. Such features as reactor vessel materials, operating temperature regimes, and new geometric configurations will be described, and mention will be made of the impact on NDE approaches.

Nuclear Power NDE Challenges – Past, Present and Future

---**Steven R. Doctor**, Pacific Northwest National Laboratory, Richland, WA 99352

---There has been a recent surge of interest in building new nuclear power plants in the United States to meet increasing domestic energy demand. Nuclear-generated power is attractive because it can provide cost-competitive energy, does not contribute atmospheric greenhouse gases and thus helps mitigate climate change. The operating fleet of U.S. nuclear power plants was built to fossil plant standards (of workmanship, not fitness for service) and with good engineering judgment. Because, nuclear power plants were designed using defense-in-depth concepts, with NDE being an important layer, nuclear power plants can tolerate the failure of almost any component and still continue to operate safely. This paper reviews these as well as other factors that influenced the NDE employed during plant construction and service. In the 30+ years of reactor operation, many material failures have occurred. Unfortunately, NDE has not provided the reliability to detect this degradation prior to initial failure (breaching the pressure boundary). There have been many improvements to NDE programs based on moving from prescriptive procedures to programs based on performance demonstrations that quantify inspection effectiveness for the probability of flaw detection and sizing accuracy. Other improvements include the use of risk-informed strategies to ensure that reactor components contributing the most risk receive the best and most frequent inspections. This paper looks back to see where NDE for nuclear power plants started and how it has evolved over the past 40 years, recounts the lessons learned, and describes the needs that remain as existing plants continue to operate and new construction is contemplated.

Future Directions, Challenges and Opportunities in Nuclear Energy

---**Andy Klein**, Director of Education, Training and Research Partnerships, **Jack Lance**, Director of Technology Partnerships, Idaho National Laboratory, P. O. Box 1625, Idaho Falls, ID 83415-3898

---The renaissance of nuclear energy for electricity and hydrogen production and process heat for other potential applications is moving ahead rapidly. Both near- and far-term roles are envisioned for this important energy technology, and each of these roles will have its own particular technical challenges and opportunities. Numerous power producers world-wide are actively considering the construction of new nuclear power plants for the production of electricity in the near-term. The U.S. Department of Energy has announced plans to develop both the next generation of nuclear power plants and the technology necessary to recycle used nuclear fuel. These exciting technologies will bring novel challenges to their developers and designers as they push the knowledge base in materials utilization, high temperatures and pressures, extended operating cycles, and extreme operating environments. Development of the techniques and methods to interrogate, understand, manage and control these devices will be crucial to enabling the full extension of these technologies.

Session 3

SESSION 3
SIGNAL PROCESSING ALGORITHMS AND TECHNIQUES
Broadway I

1:30 PM **An Algorithm for Screening Sonic IR Movies**
---C. Gao and **W. Meeker**, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

1:50 PM **Performance of Synthetic Aperture Focusing Technique for Cylindrical Geometries and Inhomogeneous Media**
---**M. Navalgund**, B. Ganesan, and S. Ramaswamy, GE Global Research, John F. Welch Technology Center, Bangalore 560 066, India; M. E. Keller, GE Aviation, QTC, 1 Neumann Way, Cincinnati, OH 45215-1988

2:10 PM **Synthetic Aperture Focusing for Curved Composite Laminates**
---**C. Engstrand** and R. A. Kline, San Diego Center for Materials Research, Department of Mechanical Engineering, San Diego State University, San Diego, CA 92065

2:30 PM **Discrimination Between Ultrasonic Echo Signals Within the Same Time Window**
---R. Cepel and **S. P. Neal**, University of Missouri-Columbia, Mechanical and Aerospace Engineering, E2412 Lafferre, Columbia, MO 65211

2:50 PM **Ultrasonic Signal Decomposition Via Matching Pursuit with an Adaptive and Interpolated Dictionary**
---**Y. Lu** and J. E. Michaels, Georgia Institute of Technology, School of Electrical and Computer Engineering, 777 Atlantic Drive NW, Atlanta, GA 30332-0250

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

3:30 PM **Signal Processing to Quantify the Reflection/Refraction of Guided Waves by a Defect in Viscoelastic Plates**
---**B. Hosten** and M. Castaings, Laboratoire de Mécanique Physique, Université Bordeaux 1, UMR CNRS 5469, 351 cours de la Libération, Talence 33405 Cedex, France

3:50 PM **Diffraction Coefficients of a Semi-Infinite Planar Crack Embedded in a Transversely-Isotropic Space**
---A. Gautesen, Iowa State University, Department of Mathematics, Ames, IA 50011; L. Fradkin and **V. Zernov**, London South Bank University, Engineering, Science and The Built Environment, 103 Borough Road, London SE1 0AA, United Kingdom

4:10 PM **Semi-Analytical Ultrasonic Modeling of Scatter from Cracks**
---**L. J. Fradkin**, London South Bank University, Department of Electrical, Electronic, and Communications Engineering, 103 Borough Road, London SE1 0AA, United Kingdom

4:30 PM **Parametric Studies and Optimization of Eddy Current Techniques Through Computer Modeling**
---**E. I. Todorov**, Edison Welding Institute (EWI), Engineering and NDE, 1250 Arthur E. Adams Drive, Columbus, OH 43221-3585

4:50 PM **Investigation of Frequency Mixing Techniques for Eddy Current Testing of Steam Generator Tubes in Nuclear Power Plants**
---**H. J. Jung**, Y. B. Kong, S.-J. Song, and C.-H. Kim, Sungkyunkwan University, School of Mechanical Engineering, Suwon, Kyonggi-do, Korea; Y.-H. Choi, S.-C. Kang, and M.-H. Song, Korea Institute of Nuclear Safety, Daejeon, Korea

An Algorithm for Screening Sonic IR Movies
---Chunwang Gao and **William Meeker**, Iowa State University, Center for Nondestructive Evaluation, Ames, IA 50011

---Sonic IR is a promising new method for detecting flaws in certain system components. A well-trained inspector can probably outperform a computer algorithm in correctly detecting or identifying flaws for any given inspection realization consisting of a time-sequence of IR camera images (i.e., a “movie”). When, however, an inspector must judge a large number of such movies where the proportion of units containing flaws is very small, inspector performance can be expected to deteriorate. Thus a useful strategy is to use the computer to categorize units into those that clearly have flaws, those that probably do not, and those that the inspector needs to scrutinize carefully. This paper describes such a detection algorithm, based on fitting a spatial-temporal regression model to the expected flaw signature. Principal components regression is then used to provide a simple low-dimensional detection criterion. We illustrate the method on inspection data from a controlled experiment using specimens containing fatigue cracks and compare the performance of the algorithm with that of an inspector.

Performance of Synthetic Aperture Focusing Technique for Cylindrical Geometries and Inhomogeneous Media
---**Megha Navalgund**, Baskaran Ganesan, and Sivaramanivas Ramaswamy, GE Global Research, John F Welch Technology Center, Bangalore 560 066, INDIA; Michael E. Keller, GE Aviation, QTC, 1 Neumann Way, Cincinnati, OH 45215-1988

---In this paper the studies on the development of the synthetic aperture focusing technique (SAFT) for inspection at curved interfaces, as in the case of billet inspections, is presented. Unlike planar interfaces, the coherent delay-summation of A-Scans, in a curved interface has to accommodate the circular and hyperbolic time-of-flight curves, for the circumferential and radial directions respectively, during reconstructions. The performance of 2D and 3D SAFT in curved interfaces is presented from experimental data from titanium billet and simulation results from CIVA. The effects of aperture weighting function and aperture size on the side lobes in the reconstruction are presented. The performance of SAFT in an inhomogeneous background grain noise is presented.

Synthetic Aperture Focusing for Curved Composite Laminates

---**Cody Engstrand** and Ronald A. Kline, San Diego Center for Materials Research, Department of Mechanical Engineering, San Diego State University, San Diego, CA 92065

---The synthetic aperture focusing technique (SAFT) was originally developed to improve signal to noise ratio and lateral resolution capability in radar applications. This approach was later found to be useful for the same purposes in ultrasonic signal processing. Recently, we have devoted our attention to extending the applicability of synthetic focusing from isotropic media to anisotropic media. In particular, we have developed a SAFT approach which can be used in layered, anisotropic media with arbitrary stacking sequences as might be encountered in high performance composite applications. To this point, only flat panels have been considered. However, there are many instances of practical importance, such as airfoils, where curved laminates are utilized. Here, a modified SAFT algorithm, suitable for curved composite laminates, is presented . Examples will be presented which demonstrate the utility of this approach in a series of samples where the specimen geometry has been systematically varied to introduce varying degrees of material curvature. We feel that this approach is useful in many practical composite applications.

Discrimination Between Ultrasonic Echo Signals Within the Same Time Window

---Raina Cepel and **Steven P. Neal**, University of Missouri-Columbia, Mechanical and Aerospace Engineering, E2412 Lafferre, Columbia, MO 65211

---In ultrasonic NDE problems, echo signals from component interfaces are used for various purposes including thickness estimation and defect detection due to signal loss. In certain applications, the echo signal from the interface of interest occurs in the same time window as confounding signals from other interfaces within the component. In many instances, the confounding signals are multiple reflection signals. For example, in a two-layered structure, a second reflection from the first interface may lie in the same time window as the first reflection from the second surface - making identification of the signal of interest (and ultimately thickness estimation) for the overall structure difficult even if wave speeds are well known. In composite/metal structures where the wave speed and thickness of the composite layers are not well controlled, identification of the signal of interest is particularly difficult. In this paper, a field perturbation approach is used to unambiguously identify the signal of interest - without precise prior knowledge of wave speeds. New measurements and calculations are implemented using existing equipment. Only single-sided access is required, with implementation possible using one single-element transducer or an array transducer in either immersion or contact mode. Experimental results are presented to demonstrate implementation of the field perturbation approach.

Ultrasonic Signal Decomposition Via Matching Pursuit with an Adaptive and Interpolated Dictionary

---**Yinghui Lu** and Jennifer E. Michaels, Georgia Institute of Technology, School of Electrical and Computer Engineering, 777 Atlantic Drive, NW, Atlanta, GA 30332-0250

---Matching pursuit is an iterative method whereby a signal is decomposed into a linear combination of wavelets that are selected from a redundant dictionary. In the original paper by Mallat and Zhang, a dictionary of Gabor wavelets is proposed. Each Gabor wavelet is the product of a Gaussian function with a complex sinusoid, and is specified by time, frequency and scale parameters. Since these wavelets are qualitatively and quantitatively very similar to ultrasonic echoes, it is appropriate to use the matching pursuit method to decompose ultrasonic signals to locate and identify discrete echoes embedded in complex signals. In this paper, a modified implementation of the matching pursuit algorithm is described where the algorithm is specifically designed for an efficient decomposition of ultrasonic signals. The size of the wavelet dictionary is adaptively determined by the spectrum of the ultrasonic signal and is further controlled by additional physically meaningful restrictions. In each iterative step, the pursuit of the matching wavelet begins with a coarse grid in the parameter space of the wavelet dictionary, and the highest energy matching wavelet is found by interpolation of this coarse grid in all parameters. The algorithm is tested with noise-free and noisy synthetic data, and is then applied to a variety of measured ultrasonic signals. Signals consisting of multiple echoes are successfully decomposed, and the individual wavelets are well-matched to the original echoes.

Signal Processing to Quantify the Reflection/Refraction of Guided Waves by a Defect in Viscoelastic Plates

---**Bernard Hosten** and Michel Castaings, Laboratoire de Mécanique Physique, Université Bordeaux 1, UMR C.N.R.S. 5469, 351 cours de la Libération, Talence 33405 Cedex, France

---Using the ultrasonic guided waves for the control of the integrity of materials and structures is very efficient in non-absorbing materials since these waves can travel along long distances. In modern materials, like composites, the absorption brings some drawbacks to this non destructive method. The purpose of this paper is to suggest a signal processing procedure adapted to the measurement of the reflection and transmission coefficients of guided waves propagating in plates made of viscoelastic materials in presence of a defect. This procedure is based on a double Fourier transformation from the temporal/spatial domains to the frequency/wave number domains, first introduced by Alleyne and Cawley. The viscoelasticity introduces a difficulty for evaluating the effects of a defect on the diffraction of the guided waves, since the results of the Fourier transforms strongly depends on the position and on the length of the monitoring zone and the shape of the corresponding spatial window. The procedure is checked by processing Finite Element (FE) results. In the particular case of a notch in a Perspex plate, it is shown that the coefficients remain unchanged whether the material is considered as elastic or viscoelastic. Its validity and precision is specified by an energy balance computation.

Diffraction Coefficients of a Semi-Infinite Planar Crack Embedded in a Transversely-Isotropic Space

--- Arthur Gautesen, Iowa State University, Department of Mathematics, Ames, IA 50011; Larissa Fradkin and **Victor Zernov**, London South Bank University, Engineering, Science and The Built Environment, 103 Borough Road, London SE1 0AA, United Kingdom

---The main aim of this project is to evaluate diffraction coefficients of a semi-infinite planar crack embedded into a transversely isotropic solid such as an austenitic steel. The diffraction coefficients relate the far field amplitudes of the corresponding waves diffracted by a straight crack edge to the amplitude of an incident plane wave. We consider two cases, in one the crack edge is perpendicular to the axis of symmetry and in another, it runs along it. We develop a semi-analytical procedure, because analytical models give explicit dependence on system parameters and elucidate the physics of the problem. This makes them useful in inspection design and interpretation. Also, the resulting codes are usually tens of thousands times faster than numerical ones and can be invaluable in inspection qualification. Finally, semi-analytic codes can be used to validate more general numerical codes based on direct numerical schemes.

Semi-Analytical Ultrasonic Modeling of Scatter from Cracks

---**Larissa Ju. Fradkin**, London South Bank University, Department of Electrical, Electronic and Communications Engineering, 103 Borough Road, London, United Kingdom

---Our group specializes in applying the modern mathematical theory of diffraction to ultrasonic modelling of scatter from large cracks, both embedded and surface-breaking. Our models lead to fast and accurate computer codes, elucidate the physics of the problem, provide explicit dependence on problem parameters and by the same token allow the design of powerful code tests. In this talk we report new results on our codes validation.---The work was carried out in collaboration with many international visitors, UK academics and researchers. Most of the work has been sponsored by EPSRC, some through RCNDE, some by London Mathematical Society and some by LSBU and IMC.

Parametric Studies and Optimization of Eddy Current Techniques Through Computer Modeling

---**Evgueni I. Todorov**, Edison Welding Institute (EWI), Engineering and NDE, 1250 Arthur E. Adams Drive, Columbus, OH 43221-3585

---Current conditions in aerospace and other industries require that faster ways are devised to develop and validate the nondestructive inspection techniques. Advances in computer modeling allow faster NDT technique optimization and reduction or replacement of costly physical experimentation. The paper demonstrates the use of computer models for parametric studies and optimization of surface and subsurface eddy current techniques. Two typical inspection cases were modeled: shielded high-frequency probe with ferrite core above aluminum coated carbon steel substrate and sliding low-frequency probe with ferrite cup-cores above multilayer aluminum alloy structure with fasteners. The parametric optimization study with pencil-type high-frequency probe investigates the effect of eddy current frequency and probe shape on the detectability of flaws in the steel substrate. The low-frequency sliding probe simulation study addresses the effect of conductivity between the fastener and the hole, frequency and coil separation distance on detectability of flaws in the third layer. Advanced finite element modeling software was used to model the probe configurations and obtain the data. The agreement between the modeling data, actual data, physical considerations, and past experience is good. This allows significant reduction of cost and time for NDT technique and procedure development and optimization.

Investigation of Frequency Mixing Techniques for Eddy Current Testing of Steam Generator Tubes in Nuclear Power Plants

---**Hee Jun Jung**, Young Bae Kong, Sung-Jin Song, and Chang-Hwan Kim, Sungkyunkwan University, School of Mechanical Engineering, Suwon, Kyonggi-do, Korea; Young-Hwan Choi, Suk-Chull Kang, and Myung-Ho Song, Korea Institute of Nuclear Safety, Daejeon, Korea

---In eddy current testing (ECT) of steam generator tubes in nuclear power plants, it is very important to extract the flaw signal from the signals compound by flaws and supporting structures. To perform such an important task, the multifrequency ECT methods are widely adopted since they have a well-known capability of extracting the flaw signal from the compound signals. Therefore, various frequency mixing algorithms have been proposed up to now. In the present work, two different frequency mixing algorithms a time-domain optimization method and a discrete cosine transform (DCT) optimization method are investigated using the experimental signals captured from steam generator tube samples made of Inconel. In this presentation, we will discuss the basic principles and the performances of these two frequency mixing techniques.

Session 4

SESSION 4
NDE FOR CIVIL STRUCTURES
Broadway II

1:30 PM **Guided Wave Approach for Concrete Pavement Thickness Estimation**
---**J. S. Popovics**, A. Gibson, and M. Haas, Department of Civil & Environmental Engineering, The University of Illinois, Urbana, IL 61801; N. Ryden, Department of Engineering Geology, Lund Institute of Technology, Sweden

1:50 PM **Ultrasonic Attenuation Changes with Damage Level in Concrete**
---**C. B. Woodward, Jr.** and S. E. Roe, Civil Engineering Department, New Mexico State University, Las Cruces, NM 88003; M. J. Cramer, Chavez-Grieves Consulting Engineers, Albuquerque, NM 87109

2:10 PM **An Impact Echo Array Technique for Concrete Structure NDT: Simulation Studies**
---**S. Chandrasekaran**, A. Muralidharan, K. Balasubramaniam, C. V. Krishnamurthy, Centre for Nondestructive Testing (CNDE), Department of Mechanical Engineering, Indian Institute of Technology, IIT, Chennai 600036 India

2:30 PM **Evaluation of a Concrete Continuous Beam Bridge Using Load Test**
---**X. Zhang**, H. Li, H. Su, and X. Yan, Wuhan University of Technology, School of Transportation, Wuhan, Hubei, P.R. China ; X. Li, Illinois Institute of Technology, Department of Applied Mathematics, Chicago, IL 60616

2:50 PM **Damage Identification of Highway Bridge Based on Modal Analysis and Neural Networks**
---**X. Zhang**, Z. Zhang, and H. Zhan, Wuhan University of Technology, School of Transportation, Wuhan, Hubei, P.R. China; X. Li, Illinois Institute of Technology, Department of Applied Mathematics, Chicago, IL 60616

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

3:30 PM **Complementary Ultrasonic Testing in Pipelines Deformation Study Experiencing Differential Underground Stretching**
---**R. Munoz Ledo C.**, M. A. González-Núnez, and E. Neri-Barrio, Instituto de Investigaciones Eléctricas, Reforma #113, Palmira, Cuernavaca, Morelos; Mexico; E. Rodríguez-Betancourt, M. Sánchez-Romero, PEMEX Gas y Petroquímica Básica, Subdirección de Ductos, Subgerencia de Tecnología, Gerencia de Mantenimiento; Av. Marina Nacional No. 329, Torre ejecutiva, piso 24, Col. Huasteca en la Ciudad de México, D. F., CP 11311

3:50 PM **Characterization of Strain in Damaged Pipelines Utilizing Ultrasonic Measurements**
---**P. D. Panetta**, S. Gosselin, and M. Morra, Pacific Northwest National Laboratory, 902 Battelle Boulevard, MS K5-26, Richland, WA 99352

4:10 PM **Detection of Critical Defects in Rails Using Ultrasonic Surface Waves**
---**D. Hesse** and P. Cawley, Imperial College, 682 Mechanical Engineering, Exhibition Road, London SW7 2AZ, United Kingdom

4:30 PM **High Speed Detection and Characterization of Defects in the Railhead**
---**R. S. Edwards**, Y. Fan, and S. Dixon, Department of Physics, University of Warwick, Coventry, United Kingdom

Guided Wave Approach for Concrete Pavement Thickness Estimation

---**John S. Popovics**, Alexander Gibson, and Michael Haas, Department of Civil & Environmental Engineering, The University of Illinois, Urbana, IL 61801; Nils Ryden, Department of Engineering Geology, Lund Institute of Technology, Sweden

---Work on accurate in-place concrete pavement thickness determination is described in this paper. The new non-destructive method is based on a hybrid approach that combines frequency domain (impact-echo) and time domain (seismic) data. The data are interpreted in terms of guided plate wave (Lamb wave) theory: the dynamic response is assumed to propagate as the S1 Lamb mode in the slab. This approach provides enhanced accuracy since the effects of material property gradients, for example those due to aggregate segregation and moisture variation, through the slab thickness are compensated for. In this paper, a field testing set up is described and experimentally verified. Verification tests, carried out on full-scale concrete slabs cast atop granular base, show that the new method provides more accurate thickness estimates than obtained by the standard impact-echo procedure. On average the error between predicted thickness and actual thickness determined by cores is less than 6mm, although some individual estimates exceed this error value. However this hybrid method does not work well on concrete overlying and well bonded to asphalt concrete base, or on full-depth asphalt concrete pavements.

Ultrasonic Attenuation Changes With Damage Level in Concrete

---**Clinton B. Woodward, Jr.** and Shannon E. Roe, Civil Engineering Dept., New Mexico State University, Las Cruces, NM 88003; Matthew J. Cramer, Chavez-Grieves Consulting Engineers, Albuquerque, NM 87109

---This paper will present data and discuss ultrasonic attenuation changes in concrete with changes in damage level and input power which were observed during a nonlinear ultrasonic test of concrete. A toneburst ultrasonic pulser was used to isonify concrete specimens in the through transmission mode. Output levels were monitored as the specimen was progressively damaged. Damage was induced by loading the specimen in increments of twenty percent of its ultimate strength. The change in attenuation from the undamaged to the damaged states was found to increase significantly as the damage level and the input ultrasonic power level was increased. Although some of the energy lost by the fundamental wave was due to harmonic generation, this represents a small percentage of the total energy lost with the majority being lost by other attenuation mechanisms.

An Impact Echo Array Technique for Concrete Structure NDT: Simulation Studies

---**Sridharan Chandrasekaran**, Ajith Muralidharan, Krishnan Balasubramaniam, C. V. Krishnamoorthy, Centre for Non - Destructive Testing, (CNDE) , Department of Mechanical Engineering, Indian Institute of Technology, IIT, Chennai - 600036

---This paper simulates an impact-echo array technique for the two-dimensional imaging of defects in thick structures such as concrete. A Finite Difference Time Difference Model was employed for the forward model of the impact-echo method. The absorbing boundary conditions were employed for the efficient modeling of the technique. The signals predicted using the FDTD models from a linear array of impact-echo transmitter-receiver system in a multiplexed configuration was used for 2-D image reconstruction of the cross-sectional region of the structure. The reconstruction algorithm uses time shifting (migration) of the signals based on point-source assumption for the impact sources. The images are represented in a typical “B-scan” representation. Several types of defects were simulated and parametric studies on the different parameters that influence the image quality during imaging of defects in concrete structures were examined. The simulated results were validated with the experiments.

Evaluation of a Concrete Continuous Beam Bridge Using Load Test

---**Xiedong Zhang**, Hong Li, Hang Su, and Xiaoyun Yan, Wuhan University of Technology, School of Transportation, Wuhan, Hubei, P. R. China; Xiaofan Li, Illinois Institute of Technology, Department of Applied Mathematics, Chicago, IL 60616

---Interests in safety assessment of bridge structures have been increasing recently. Load test is an efficient non-destructive way to evaluate the condition of highway bridges. This paper presents a static and dynamic load test on a long-span prestressed concrete continuous beam bridge. In order to determine the distribution of truck loads and the location of measured section, we obtained the internal force influence line of the bridge from FEM analysis. We also calculated the vibration frequencies and modal shapes from dynamic analysis of the bridge structure. We used internal and external strain sensors, and diagnostic strain gages to measure the stress of the beam. The deformation of the bridge under the truck loads was measured by both Precision Levels and Total Station. Accelerating sensors and the Random Signal and Vibration Analysis System were introduced to get the vibration characteristics of the bridge under the dynamic truck loads. We found that the results from the experimentally measured data are consistent with those from the theoretical calculation, indicating good condition of the bridge. Further, it was showed that the load test is effective to evaluate the highway bridge.

Damage Identification of Highway Bridge Based on Modal Analysis and Neural Networks

---**Xiedong Zhang**, Zhiguo Zhang, and Hao Zhan, Wuhan University of Technology, School of Transportation, Wuhan, Hubei, P. R. China; Xiaofan Li, Illinois Institute of Technology, Department of Applied Mathematics, 10 West 32nd Street, E1 Building, Suite 208, Chicago, IL 60616

---Damage identification of large-scale structure based on vibration data has received considerable attention in recent years. The dynamic characteristic parameters consist of modal frequency, modal vibration shape, curvature modal shape, flexibility curvature and so on. Signatures of damage identification obtained from modal parameters always involve solving complex mathematical iteration problem. Neural networks have anti-linear mapping ability, which can change an inverse problem into a forward problem. In this work, vibration modal analysis is integrated with neural networks. Damage signatures derived from the vibration modal parameters are the input to the neural networks as parameters for structural health monitoring. Furthermore, a damage-detection-oriented finite element model of a long-span highway cable-stayed bridge is established and the modal analysis is then carried out. The focus of the research is placed on three instances, including one, two, or three damaged components of the bridge respectively. The modal frequency, the displacement and curvature modal shapes are used as the BP neural network input vector; sample data of each damaged state are collected; nine BP neural network models are established for detection the damage in stay cables of a cable-stayed bridge. The result indicates that the method based on vibration modal analysis theory and BP neural networks can detect quantificationally both the position and degree of the damage.

Complementary Ultrasonic Testing in Pipelines Deformation Study Experiencing Differential Underground Stretching

---**R. Muñoz Ledo C.,** M. A. González-Núñez, and E. Neri-Barrio, Instituto de Investigaciones Eléctricas; Reforma #113, Palmira, Cuernavaca, Morelos; Mexico ; E. Rodríguez-Betancourt, M. Sánchez-Romero, PEMEX Gas y Petroquímica Básica, Subdirección de Ductos, Subgerencia de Tecnología, Gerencia de Mantenimiento; Av. Marina Nacional No. 329, Torre ejecutiva, piso 24, Col. Huasteca en la Ciudad de México, D. F., CP 11311

---At some gas and oil pumping station facilities in Mexico, it has been appearing some stretching problems in the pipelines because of the water extraction from the underground, this has caused cave-in at some supports in the plates on which the pipelines come out from the soil. This effect has caused stretching of the pipelines and in some times it produced plastic deformation in the pipes. As the stresses are cyclic (load - unload) the pipeline wall has suffering stress hardening; in order to make a tracking of the pipeline integrity it has been monitored with ultrasonic testing 170 welded joints of these pipelines, in which the flaws found have not changed either from position or size due to the stresses. In this work we will present the testing carried out on different pipelines' welds which are potential sites of flaws, the results, and the information obtained from the analysis of the results.

Characterization of Strain in Damaged Pipelines Utilizing Ultrasonic Measurements

---**Paul D. Panetta**, Steve Gosselin, and Marino Morra, Pacific Northwest National Laboratory, 902 Battelle Boulevard, MS K5-26, Richland, WA 99352

---Maintaining the integrity of the nation's aging infrastructure is of primary importance. Specifically there is a desire to characterize degradation to the civil infrastructure to monitor its integrity. Of particular importance is the accurate prediction of the lifetime of natural gas pipelines that have been damaged by impact or earth movement. In order to accurately predict the remaining life it is essential to accurately determine the degree of plastic strain in damaged regions 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 variations in the alloys and the difficulty in separating these effects. We will report ultrasonic measurements on plastically deformed natural gas pipelines to elucidate the state of damage in bent and bulged regions. Predictions of the maximum operating pressure of the damaged pipe will be based on strain estimates from ultrasonic measurements. Ultrasonic results will be compared with finite element modeling calculations of the stress and strain distributions and analytic theories of the effects of stress and strain on the ultrasonic measurements.

Detection of Critical Defects in Rails Using Ultrasonic Surface Waves

---**Daniel Hesse** and Peter Cawley, Imperial College, 682 Mechanical Engineering, Exhibition Road, London SW7 2AZ, United Kingdom

---Defects in rails caused by rolling contact fatigue (RCF) are of growing concern to the railway industry. Conventional ultrasonic inspection methods are often not reliable in detecting critical RCF defects which means that maintenance staff have to rely on visual inspection. Under- or overestimation of crack severity can lead to unnecessary and expensive track removal as well as increased risk of train accidents. The aim of this work was therefore to develop a reliable screening tool that discriminates between critical and tolerable defects and therefore complements the existing inspection methods. The method presented here employs ultrasonic surface waves which propagate several meters along the railhead. They are excited by a local immersion probe which is operated in pulse-echo mode and scanned along the rail; in practice this would be done using a wheel probe. The excitation frequency was chosen to be around 200 kHz at which there exists a suitable surface wave mode with a sufficient penetration depth. A spatial averag-ing technique is applied to suppress unwanted guided wave modes and reduce signal complexity. The method has been tested successfully on a number of specimens containing real defects including a rail from the source of the Hatfield (UK) rail crash in 2000. The results are very promising, even in cases where the rail surface is heavily spalled.

High Speed Detection and Characterization of Defects in the Railhead

---**Rachel S. Edwards,** Yichao Fan, and Steve Dixon, Department of Physics, University of Warwick, Coventry, United Kingdom

---In the UK, changing usage patterns for the rail network mean that head checking in the railhead is an increasingly urgent problem. Current ultrasonic testing techniques have limitations in terms of testing speed and ability to reliably detect such defects. A different approach to the problem is to use ultrasonic surface waves generated and detected in a pitch-catch manner, thus simplifying the probe to detect surface defects such as head checking and to ignore deeper bulk defects. By using a pitch-catch configuration several of the speed limitations are removed; the probes are free to move as soon as each signal has been generated, without the need to wait for detection of the signal, and separation of the probes can be increased to allow for limited pulse repetition rates. Better reliability of detection for such defects is also found, with the transmitted signal being dominated by the deepest defect present between the probes. We present details of a new high speed system, consisting of a series of electro-magnetic acoustic transducers (EMATs) to generate and detect the signals, plus a high speed A-D system which has the ability to detect, window and FFT signals within 1 ms, giving a depth for any defects present between the probes.

Session 5

Monday, July 31, 2006

SESSION 5

THERMOGRAPHIC AND THERMOSONIC NDE

X. Han, Chairperson
Pavilion East

1:30 PM **Synchronization of Infrared Imaging with Acoustic Emission for Depth Measurement of Discrete Failure Events in Composites**
---B. Knight, J. Li, **H. I. Ringermacher**, G. Aksel, D. R. Howard, M. J. Osterlitz, Y. A. Plotnikov, and J. L. Thompson, GE Global Research Center, 1 Research Circle, Niskayuna, NY 12309

1:50 PM **Thermographic Determination of Flaw Depth in Multilayer Materials**
---**W. P. Winfree**, P. A. Howell, J. N. Zalameda, and K. E. Cramer, Nondestructive Evaluation Sciences Branch, NASA Langley Research Center, Hampton, VA 23681

2:10 PM **Detection of Cracks at the Root of Dampers in Fan Blades Using SONIC IR Inspection: A Feasibility Demonstration**
---**W. Hassan**, Honeywell Aerospace, 111 S. 34th Street, Phoenix, AZ 85034; C. Homma, Siemens AG, Otto-Hahn-Ring 6, D-81730, Munich, Germany; F. Vensel, Honeywell Aerospace, 111 S. 34th Street, Phoenix, AZ 85034

2:30 PM **Sonic Infrared (IR) Imaging and Fluorescent Penetrant Inspection Probability of Detection (POD) Comparison**
---**J. DiMambro**, M. Ashbaugh, C. L. Nelson, and F. W. Spencer, NDI Validation Center (AANC), Sandia National Laboratories, 3260 University Boulevard, Spirit Drive, Albuquerque, NM 87106

2:50 PM **Further Development of the Simulation of Sonic IR Imaging of Cracks in Metals with Finite-Element Models**
---**X. Han** and M. S. Islam, Department of Electrical and Computer Eng., Wayne State University, Detroit, MI 48202; G. Newaz, Department of Mechanical Eng., Wayne State University, Detroit, MI 48202; L. D. Favro, Institute for Mfg. Research, Wayne State University, Detroit, MI 48202; R. L. Thomas, Department of Physics and Astronomy, Wayne State University, Detroit, MI 48202

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

3:30 PM **Development of a Broadband Vibrothermography Measurement System**
---**S. D. Holland**, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

3:50 PM **Low Power PZT Exciter for Thermosonics**
---**B. Kang** and P. Cawley, Imperial College, Mechanical Engineering, Exhibition Road, London, SW7 2AZ, United Kingdom

4:10 PM **The Relationship Between Crack Damping, Vibration Amplitude and Temperature Rise in Thermosonics NDT**
---**M. Morbidini**, P. Cawley, P. Duffour, T. Barden, and D. Almond, Research Centre in Nondestructive Evaluation, Mechanical Engineering, Imperial College, Exhibition Road, London, SW7 2AZ United Kingdom

4:30 PM **Crack Detection by Laser Spot Imaging Thermography**
---A. Rashed and **D. P. Almond**, University of Bath, Department of Mechanical Eng., Bath, United Kingdom; S. Burrows and S. Dixon, Univ. of Warwick, Dept. of Physics, Coventry, United Kingdom

4:50 PM **Fracture Mechanics of Crack Growth During Sonic-IR Inspection**
---**J. C. Chen[1],** W. Riddell[2], K. Lick[1], C.-H. Wong[1], [1]Rowan University, Department of Mechanical Engineering, 201 Mullica Hill Road, Glassboro, NJ 08028-1701; [2]Rowan University, Department of Civil and Environmental Engineering, Glassboro, NJ 08028

5:10 PM **Determination of the Minimum Energy Required for Sonic-IR Detection**
---**K. Lick**, C.-H. Wong, and J. C. Chen, Rowan University, Department of Mechanical Engineering, 201 Mullica Hill Road, Glassboro, NJ 08028

Synchronization of Infrared Imaging with Acoustic Emission for Depth Measurement of Discrete Failure Events in Composites

--- Bryon Knight, Jian Li, **H.I. Ringermacher**, Gulperi Aksel, D.R. Howard, M.J. Osterlitz, Y.A. Plotnikov and J.L. Thompson, GE Global Research Center, 1 Research Circle, Niskayuna, NY 12309

---We employ multi-modal monitoring including infrared imaging, acoustic emission sensing and digital radiography to follow the progression to failure of CFRP test panels under loading. Acoustic emission generated by fiber breaks and matrix cracks define the “zero” time for surface observation by an IR camera of the deep heat source from that event. The AE clock and IR clock must be synchronized. The timing of the surface event relative to “zero” permits the calculation of its depth. Digital high resolution X-rays of the crack propagation were also made as the loading to failure progressed. The position and depth of the IR events can then be related to crack evolution and modeling for failure prediction.

Thermographic Determination of Flaw Depth in Multilayer Materials

---**William P. Winfree**, Patricia A. Howell, Joseph N. Zalameda, and K. Elliott Cramer, Nondestructive Evaluation Sciences Branch, NASA Langley Research Center, Hampton, VA 23681

---Thermographic detection of flaws in materials and structures is maturing into a viable technique for rapid inspection of critical hardware. As this technique continues to mature, there is an increasing need to examine complex configurations where the thermal response is not simply defined. For these cases the determination of the depth of a flaw is not as straightforward as depth estimation for a homogeneous layer. A method of accurately determining the depth of flaws in the substrate of a layered system with a thin protective surface layer is presented. The method uses a multilayer thermal model to accurately predict the thermal response of the material. Depth determinations based on the multilayer model are shown to be more accurate than conventional thermal analysis techniques for depth determination. Results are presented on different materials with manufactured flaws.

Detection of Cracks at the Root of Dampers in Fan Blades Using SONIC IR Inspection: A Feasibility Demonstration

---**Waled Hassan**, Honeywell Aerospace, 111 S. 34th Street, Phoenix, AZ 85034; Christian Homma, Siemens AG, Otto-Hahn-Ring 6, D-81730, Munich, Germany; Fred Vensel, Honeywell Aerospace, 111 S. 34th Street, Phoenix, AZ 85034

---Recent work demonstrating the beneficial effects of combining mechanical excitation with thermal detection to improve signal response from cracks has been reported. The developed technique is often referred to as SONIC Infra Red (IR), Acoustic Thermography, Thermal Acoustics, or Vibro-Thermography inspection. The basic premise of the method is to use an external energy source like an ultrasonic horn originally intended for use in ultrasonic welding to excite the component. The differential vibration of the crack faces causes an increase in local heating which is detectable with infrared cameras typically used in thermographic inspection. While preliminary results are promising, additional knowledge is needed prior to application to critical components such as engine disks. In this work we present the results of a feasibility demonstration for the detection of tight cracks at the root of dampers in fan blades. The primary purpose of these dampers is to reduce undesired vibrations of the fan blades during operation. Unfortunately cracks can develop at the root of these dampers in a very tight radius which renders their detection using other NDE techniques like FPI and eddy current rather unreliable and sometimes not possible. SONIC IR is proposed as an alternate effective detection technique in such situations. An optimized SONIC IR inspection technique using the SIEMAT system that was developed by Siemens AG in Munich, Germany will be presented. An empirical study was conducted to determine the optimal excitation position for the ultrasonic horn that results in the highest crack detectability. FEM modeling was then used to further understand the actual vibrational modes that are needed to ensure detectability of such cracks and to validate the empirical results. Preliminary results from the Smart SIEMAT system that is based on a swept frequency approach will also be presented.

Sonic Infrared (IR) Imaging and Fluorescent Penetrant Inspection Probability of Detection (POD) Comparison

---**Joseph DiMambro**, Michael Ashbaugh, Ciji L. Nelson, and Floyd W. Spencer, NDI Validation Center (AANC), Sandia National Laboratories, 3260 University Boulevard, Spirit Drive, Albuquerque, NM 87106

---Sonic IR imaging is an emerging inspection technique that uses high-power ultrasonic excitation as a heat source and infrared technology to detect defects in a variety of materials. There is interest in replacing some fluorescent penetrant inspections (FPI) currently performed in the aviation field with Sonic IR. Benefits include reduced part preparation requirements (i.e. no paint stripping, no specialized cleaning), inspector dependency, processing and evaluation time, floor space requirements, and environmental issues (i.e. elimination of chemicals). However, several questions must be answered before the technology can be successfully transferred into the field such as: How reliably can the technology detect defects? Is the technology truly nondestructive? This effort attempts to explore these questions. Sandia National Laboratories Airworthiness Assurance Nondestructive Inspection Validation Center (AANC) implemented two crack POD experiments to compare in a quantitative manner the ability of Sonic IR and FPI to reliably find cracks. Sonic IR and FPI inspections were performed on titanium and Inconel® specimens having statistically relevant flaw profiles, and POD curves for each technique were generated. Wayne State University participated in the Sonic IR inspections, and Honeywell participated in the FPI inspections. In addition, AANC optically measured the crack lengths of a number of titanium and Inconel® specimens used as Sonic IR reference standards before and after repeated Sonic IR inspections to determine if crack growth occurred.

Further Development of the Simulation of Sonic IR Imaging of Cracks in Metals with Finite-Element Models

---**Xiaoyan Han** and Md. Sarwar Islam, Department of Electrical and Computer Engineering, Wayne State University, Detroit, MI 48202; G. Newaz, Department of Mechanical Engineering, Wayne State University, Detroit, MI 48202; L. D. Favro, Institute for Manufacturing Research, Wayne State University, Detroit, MI 48202; R. L. Thomas, Department of Physics and Astronomy, Wayne State University, Detroit, MI 48202

---Sonic IR imaging, which combines infrared imaging and ultrasound excitation, as a relative new member of the NDE family, has been drawing wider and wider attention due to its fast, wide area inspection capability. In our previous presentations and publications, we have described the application of acoustic chaos to Sonic IR imaging and have provided experimental illustrations as well. In addition, we have described realistic finite-element models that simulate the heating of cracks in metals by both chaotic and non-chaotic sound. These models allow for both friction and plastic deformation as sources of heating. In this paper, we present our further study on the physical mechanisms that are responsible for the advantages of chaotic sound for Sonic IR crack detection. Using finite-element analysis, here we will present theoretical explanations, both for the origin of the chaos, and for the mechanisms responsible for the chaotic enhancement of crack detection. The relative roles of crack-face friction and plastic deformation as sources of the heating, as well as the practical questions of possible damage from the sonic excitation will be discussed.---
This material is based upon work supported by the Air Force Research Laboratory under Contract # FA8650-04-C-5228 placed with Iowa State University's Center for NDE. This project was performed at Wayne State University. This material is also based upon work supported by the Federal Aviation Administration under Contract #DTFA03-98-D-00008 with Iowa State University as Delivery Order #0018 performed at Wayne State University as part of the Center for Aviation Systems Reliability program.

Development of a Broadband Vibrothermography Measurement System

---**Stephen D. Holland**, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

---We report on the construction and development of a broad-spectrum vibrothermography (Sonic IR) measurement system at the Center for NDE. The new system uses a broadband actuator instead of an ultrasonic welder to generate vibration and induce heating of cracks. A high-resolution infrared camera captures the IR signature of a crack, and a reconfigurable data acquisition software system acquires and processes the IR images and vibrometry waveforms in real time. We will present and discuss results from initial experiments with this system.---This material is based upon work supported by the Air Force Research Laboratory under Contract #FA8650-04-C-5228 at Iowa State University's Center for NDE.

Low Power PZT Exciter for Thermosonics

---**Bubyoung Kang** and Peter Cawley, Imperial College, Mechanical Engineering, Exhibition Road, London, SW7 2AZ, United Kingdom

---An acoustic ultrasonic horn originally designed for welding has generally been used for thermosonic testing. However, it is difficult to obtain reproducible and controllable excitation with the existing horn system because of nonlinearity in the coupling; surface damage can also be produced by hammering caused by loss of contact between the tip of the horn and the structure. In some applications, for example the detection of impact damage in composites, it has been shown that relatively low vibration strain levels are required (typically less than 10 με). Therefore, a simple piezo-exciter might provide adequate excitation and this is investigated here. The exciters developed were bolt-clamped Langevin-type transducers, in which piezoelectric elements were sandwiched by two metal blocks and clamped with a bolt. Single frequency excitation leads to the possibility of vibrational nodes at the positions of any defects that may be present in the sample. Therefore, it is necessary to excite several modes at different frequencies to cover the whole area of the structure. Most structures of interest have a large number of resonances around the exciter resonance frequency (chosen to be above 20 kHz) and it is possible to excite similar amplitudes in each of them. It was shown that wax or adhesive tape could be used satisfactorily to couple the exciter to the structure without causing hammering. 70 με was obtained at an input voltage of 250Vpp in tests on a steel plate with 4mm thickness and 300mm side length. 12 με was obtained in tests on a 7mm thick composite plate; this lower value was due to the higher damping in composites but was above the required level. The results therefore suggest that a simple, small exciter may provide a convenient, reliable thermosonic test system in applications where relatively low strain levels are required for damage detection.

The Relationship Between Crack Damping, Vibration Amplitude and Temperature Rise in Thermosonics NDT

---**Marco Morbidini**, Peter Cawley, Philippe Duffour, Tim Barden, and Darryl Almond, RCNDE (Research Centre in Nondestructive Evaluation), Mechanical Engineering, Imperial College, Exhibition Road, London, SW7 2AZ United Kingdom

---Thermosonics (also known as Sonic-IR) is attracting increasing interest as an NDT method for the detection of small fatigue cracks in metals. A high power acoustic horn excites a high amplitude cyclic strain in the test piece which causes the defect interfaces to rub, thus generating heat. The resulting local increase in temperature can be detected by an IR camera. In this study a set of steel beams with fatigue cracks of different size was tested. Each beam was instrumented with strain gages for the measurement of the vibration strain. The heat dissipated by the crack was predicted from the measured strain and an experimental estimate of the additional damping introduced in the specimens by each crack. Simple thermal models of the cracks and of the beams were then used to calculate the surface temperature rise as a function of time during the excitation. Finally the predictions were compared with the infrared camera measurements. The results showed a good linear correlation between predictions and measurements, hence validating the prediction algorithm. An analysis of the sensitivity of the method to crack size was also carried out. The findings of this study will be used in future to determine the minimum detectable crack size for a given strain amplitude using an IR camera of known performance.

Crack Detection by Laser Spot Imaging Thermography

---Atef Rashed and **Darryl P Almond**, Department of Mechanical Engineering, University of Bath, Bath, United Kingdom; Sue Burrows and Steve Dixon, Department of Physics, University of Warwick, Coventry, United Kingdom

---The thermal image of the surface of a sample heated at a point by a laser pulse takes the form of a circular hot patch that spreads radially with time. A surface crack, close to the heated point, impedes lateral heat flow and produces alterations in the shape of the laser spot image that can be monitored by thermography. The technique has been found to be successful for determining the location of fatigue cracks in steel samples. Such cracks produce noticeable changes in laser spot images at distances up to 5mm from the point of illumination. Results will be presented that have been obtained using two different potential inspection modes: raster scanning of the test piece and flying spot scanning of the laser beam. Results have also been obtained using two different laser types: a pulsed laser and a CW laser applied in a long pulse mode. Experimental results have been found to be in good agreement with modeling predictions. Modeling results indicate the technique to be sensitive to cracks in metals having openings as small as ~ 1 micron.

Fracture Mechanics of Crack Growth During Sonic-IR Inspection

---**John C. Chen**[1], William Riddell[2], Kyle Lick[1], Chang-Hwa Wong[1], [1]Rowan University, Department of Mechanical Engineering, 201 Mullica Hill Road, Glassboro, NJ 08028-1701, [2]Rowan University, Department of Civil and Environmental Engineering, Glassboro, NJ 08028

---In past studies, we showed that cracks synthesized under carefully controlled conditions will propagate when subsequently subjected to sonic IR testing. The extent or severity of the propagation observed depended on several parameters including the stress-intensity factor (which corresponds to crack growth rate) under which the crack was synthesized, the tightness of the crack closure, and the initial crack length. Furthermore, we showed that crack propagation during sonic IR testing occurs for 2024 aluminum, titanium and 304 stainless steel specimens. In this study, we extend the range of experimental conditions for synthesizing cracks to further elucidate their effect on the crack propagation, and we focus more specifically on the stress intensity factor. The stress intensity factor not only determines the rate of crack growth, but it has two profound effects on crack characteristics: the establishment of plastic zones around the crack and the variation of the topography of the mating crack surfaces. These two parameters appear to strongly affect crack propagation.

Determination of the Minimum Energy Required for Sonic-IR Detection

---**Kyle Lick**, Chang-Hwa Wong, and John C. Chen, Rowan University, Department of Mechanical Engineering, 201 Mullica Hill Road, Glassboro, NJ 08028

---Sonic IR inspection is typically conducted using a commercial, off-the-shelf, ultrasonic welding gun driven by a matching, high-powered supply, regardless of the shape, size, mass or material under inspection. Often times, the power delivered to the sample is orders of magnitude higher than is required for detection of the defects present. Such 'over-driving' of the samples may result in rendering sonic IR a destructive inspection method, which is obviously undesirable. In this study, our goal is to determine the minimum energy required for detecting cracks using sonic IR. We are designing and constructing an experimental apparatus to simulate crack detection using sonic IR, which we then plan to use to calibrate our instruments. With this task completed, we will then conduct conventional sonic IR experiments with controlled power delivery to the samples in order to achieve our goal. This presentation will discuss our approach to this experiment, its design, and some preliminary data.

Session 6

SESSION 6
TOPICS IN POD
J. Knopp, Chairperson
Pavilion West

1:30 PM **Assessing the POD of Hard-Alpha Inclusions from Field Data**
---**R. B. Thompson**, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50010

1:50 PM **Comparing the Effectiveness of a90/95 Calculations**
---**C. Annis**, Statistical Engineering, Palm Beach Gardens, FL 33418-7161; J. Knopp, Materials and Manufacturing Directorate, Wright Patterson AFB, OH 45433-7817

2:10 PM **The Major Role of Human Factors in Nondestructive Materials Evaluation**
---**M. J. Golis**, P. O. Box 141388, Columbus, OH 43214

2:30 PM **Model Assisted Probability of Detection Validation for Immersion Ultrasonic Application**
---**K. D. Smith**, Pratt & Whitney, M/S 114-37, 400 Main Street, E. Hartford, CT 06108; R. B. Thompson, T. A. Gray, and L. Brasche, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011; W. Q. Meeker, Iowa State University, Department of Statistics, Ames, IA 50011; J. A. Umbach, Pratt & Whitney, West Palm Beach, FL 33410-9600

2:50 PM **Investigation of a Model-Assisted Approach to Probability of Detection Evaluation**
---**J. S. Knopp**[1], J. C. Aldrin[2], E. A. Lindgren[1], and C. Annis[3], [1]Materials and Manufacturing Directorate, Air Force Research Laboratory, 2230 Tenth Street, STE 1, Wright Patterson, AFB OH 45433; [2]Computational Tools; [3]Statistical Engineering

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

3:30 PM **Sensitivity Analysis to Assess the Effects of Misses in the Estimation of POD from Field Inspection Data**
---**W. Meeker** and R. B. Thompson, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

3:50 PM **Assessment of Components of Variance in NDE Data**
---Y. Wang and **W. Q. Meeker**, Iowa State University, Department of Statistics and Center for NDE, 304C Snedecor Hall, Ames, IA 50011; W. Hassan, Honeywell Engines, Systems, and Services, Phoenix, AZ 85034

4:10 PM **The Calculation and Use of Confidence Bounds in POD Models**
---**F. W. Spencer**, Sandia National Laboratories, Independent Surveillance Assessment and Statistics, 1515 Eubank SE, P. O. Box 5800-MS 0829, Albuquerque, NM 87185-0829

4:30 PM **Growing NDE Reliability Needs in the Aerospace Industry**
---**J. C. Malas**[1] and J. P. Gallagher[2], [1]Air Force Research Laboratory, Materials & Manufacturing Directorate, [2]Aeronautical Systems Center, Engineering Directorate, Wright Patterson AFB, OH 45433

4:50 PM **Results from a New Prototype Embedded Defect Specimen Proposed for POD Analysis of Ultrasonic Systems**
---**D. A. Stubbs**, V. A. Kramb, W. C. Hoppe, D. S. Erdahl, and D. L. Petricola, University of Dayton Research Institute, 300 College Park, Dayton, OH 45469

5:10 PM **Surprising Results from a Probability of Detection Assessment of a Standard Bubble Leak Test Procedure Gaps Between NDE Research, NDE Engineering, and NDE Applications**
---**W. D. Rummel**, D&W Enterprises, LTD, Littleton, CO; G. Garcia, Transportation Technology Center, Inc., Pueblo, CO 81001

Assessing the POD of Hard-Alpha Inclusions From Field Data

---**R. Bruce Thompson** and William Q. Meeker, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---Detection of hard-alpha inclusions is a key step is assuring the safety of titanium rotating components in aircraft engines. Since these are melt-related defects, ultrasonic techniques provide the primary inspection, both in billet and forging material. The success of these inspections is quantified by the Probability of Detection (POD). FAA Advisory Circular AC.33.14-1, "Damage Tolerance for High Energy Turbine Engine Rotors" contains a set of Default POD Curves that provide estimates of the ability of ultrasonic techniques to detect hard-alpha inclusions, based on data and analysis techniques that existed in 1995. Since that time, new inspection techniques have been deployed, new data regarding the detection of hard-alpha inclusions during manufacturing have become available, and new statistical tools to analyze the data have become available. The current paper discusses the update of the Default POD curves based on this new information, an activity that involved the efforts many individuals participating in the Engine Titanium Consortium. Included will be a discussion of the data available, the analysis techniques used, and the results obtained. Although the final results obtained are specific to the hard-alpha detection process, a number of the issues encountered have generic interest. Included are the challenges associated with the estimation of POD from finds information (i.e. without full knowledge of misses), the assessment of POD when accept/reject decisions are based on multiple criteria, and treating situations in which a single regression line does not fit plots of log a-hat versus log a.

Comparing the Effectiveness of a90/95 Calculations

---**Charles Annis**, Statistical Engineering, Palm Beach Gardens, FL 33418-7161; Jeremy Knopp, Materials and Manufacturing Directorate, Wright Patterson AFB, OH 45433-7817

---Most practitioners see a90/95 as a static, single-point summary of an entire inspection's capability. It purports to be the size of the target having at least 90% probability of detection in 95 of 100 POD experiments under nominally identical conditions. But in some situations the actual coverage is closer to 80%, rather than 95%, with 50% coverage being the median POD(a) curve itself. For POD(a) models based on log(â) vs log(a) data, all POD calculations are with respect to the log(â) vs log(a) regression, not the POD(a) space. The parameters of the POD model are used only for plotting. Thus the lower bounds constructed for the POD curve - including the calculation for a90/95 - are not significantly different based on their method of construction, either the Wald or loglikelihood ratio method. With hit/miss data things are very different, and the effectiveness of lower bound calculations depends on the sample size, the balance of the target sizes (how many are on either side of the POD inflection), the sensitivity of the inspection (as indicated by the steepness of the POD(a) relationship) and how all these are influenced by the method for constructing lower bounds. This paper discusses the two philosophies for constructing lower bounds on POD(a) curves (and therefore determining a90/95) and compares the effectiveness of each as functions of other experimental realities such as sample size and balance.

The Major Role of Human Factors in Nondestructive Materials Evaluation

---**Matthew J. Golis**, P. O. Box 141388, Columbus, OH 43214

---In that most Nondestructive Inspections of engineered structures, components and systems involve human intervention, it is not surprising that the reliability of such inspections is heavily dependent on the situational conditions within which inspectors must perform their duties. What is less known, however, is the degree to which personal aptitudes and attitudes, environmental and physical conditions, training and technical instructions, and interpersonal relations can degrade the results of an inspection. Fortunately, several notable studies have been conducted that shed some light on the subject, but little has been done to assure that the findings of such studies are incorporated into the daily practices of NDT operations. This presentation will review several of the most significant attempts at defining the key human factors that have been found to affect NDT performance. It will also summarize current actions that are aimed at assuring existing cadres of NDT inspectors are better prepared to achieve and maintain an elevated state of inspection reliability through novel approaches related to their operational readiness and on-going vigilance. We will try to address the ongoing dilemma of what constitutes the ideal NDT inspector.

Model Assisted Probability of Detection Validation for Immersion Ultrasonic Application

---**Kevin D. Smith**, Pratt & Whitney, M/S 114-37, 400 Main Street, East Hartford, CT 06108; R. Bruce Thompson, Timothy A. Gray, and Lisa J. Brasche, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011; William Q. Meeker, Iowa State University, Department of Statistics, Ames, IA 50011; Jeffrey A. Umbach, Pratt & Whitney, West Palm Beach, FL 33410

---Model assisted probability of detection (MAPOD) is a method of calculating probability of detection versus flaws size curves which utilizes physics-based models to reduce the time, cost, and complexity of POD studies compared to purely empirical approaches. An approach to utilizing models combined with empirical data in calculating POD curves utilizing immersion ultrasonics as the example case is described. Before MAPOD calculations can be performed, the applicable physics-based model must be validated to accuracy consistent with the desired accuracy of the resulting POD curve. In this case, the Thompson-Gray model was used. For the purposes of validating the MAPOD approach, a specimen was configured that would allow empirical data to be collected that would not only be input to the MAPOD calculation but also provide input to empirical POD calculations (MIL-HDBK-1823). Validation of the MAPOD approach consisted of directly comparing the results of conventional empirical calculation of POD curves with MAPOD POD curves for the same inspection problem. The results of the two calculation approaches agreed very well.

Investigation of a Model-Assisted Approach to Probability of Detection Evaluation

---**Jeremy S. Knopp**[1], John C. Aldrin[2], Eric A. Lindgren[1], and Charles Annis[3], [1]Materials and Manufacturing Directorate, Air Force Research Laboratory, 2230 Tenth Street, STE 1, WPAFB, OH 45433; [2]Computational Tools; [3]Statistical Engineering

---Probability of detection (POD) is a metric used to quantify the reliability of inspection systems. POD provides engineers with the minimum flaw size that can be reliably detected and can also be used as an input to probabilistic risk assessment analysis. Traditional POD evaluation methodologies are entirely empirical. In most cases, the cost of manufacturing the number of samples required for a traditional POD study is prohibitive and may delay or prevent a new inspection procedure or new technology from being implemented. Alternative methodologies have been proposed that incorporate modeling to reduce the number of samples required. Statistical analysis methods have also evolved since the standard method for conducting POD studies was codified in MIL-STD-1823. This study investigates a class of aerospace structural inspection problems and considers the use of models and new statistical analysis methods in the POD evaluation. Eddy current measurements for varying crack length around fastener holes in a two-layer aluminum structure were studied using both experimental and simulated data. Probability of detection results are presented contrasting several feature extraction algorithms and various methods for confidence bound calculation. The problem of fully addressing uncertainty in model-assisted POD evaluations will also be discussed.

Sensitivity Analysis to Assess the Effects of Misses in the Estimation of POD from Field Inspection Data

---**William Meeker** and R. Bruce Thompson, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

---It has been suggested that field data cannot be used for estimation of POD because of the bias caused by ignoring the fact that some flaws are missed in inspections. The use of a regression model that allows for truncated data can, however, provide estimates that do not have serious bias. In this paper we use Monte Carlo simulation to assess the effects of misses in the estimation of POD and to study the properties of estimates that one obtains by using the truncated data regression model. FAA ETC Phase II - "This material is based upon work supported by the Federal Aviation Administration under Contract #DTFA03-98-D-00008, Delivery Order #0034 and performed at Iowa State University's Center for NDE as part of the Engine Titanium Consortium Phase II program.

Assessment of Components of Variance in NDE Data

---Yurong Wang and **William Q. Meeker**, Department of Statistics, 304C Snedecor Hall and Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Iowa State University, Ames, Iowa, 50011; Waled Hassan, Honeywell Engines, Systems, and Services, Phoenix, AZ

---Nondestructive evaluation (NDE) methods are used widely in industries to assure the integrity of critical system components. There is an important need to quantify and improve the probability of detection (POD) for NDE inspection. In programs to improve POD, It is important to identify and quantify sources of variability. A standard NDE inspection assessment method uses a manufactured "block" of material containing seeded defects of known size and character. This block is then inspected according to an experimental design that will capture the important sources of variability. The commonly used NDE data analysis/modeling method, known as ahat versus a, uses a linear regression to relate the NDE signal response to the flaw or defect size. The model behind this method contains only one component of variance for the response. There are, however, many random factors causing variability in NDE inspection. In this paper, we use a Bayesian hierarchial model to identify and quantify the inspection variance components in the presence of data censoring. We use Markov Chain Monte Carlo simulation to estimate the model parameters, including the variance components. We demonstrate the effectiveness of the approach with simulated data and the experimental data from an ultrasonic inspection round-robin experiment.---FAA ETC Phase II - "This material is based upon work supported by the Federal Aviation Administration under Contract #DTFA03-98-D-00008, Delivery Order #0034 and performed at Iowa State University's Center for NDE as part of the Engine Titanium Consortium Phase II program.

The Calculation and Use of Confidence Bounds in POD Models

---**Floyd W. Spencer**, Sandia National Laboratories, Independent Surveillance Assessment and Statistics, 1515 Eubank SE, P. O. Box 5800- MS0829, Albuquerque, NM 87185-0829

---At a qualitative level the calculation of a statistical confidence interval for a quantity X is an attempt to answer the question: "How variable could X have been and still be consistent with the data that have been observed?" The models used in POD estimation fit an entire curve to the data in hand. However, the quantity X(p) is often a single point on the curve, such as the flaw size for which the probability of detection is equal to p. In order to make a confidence statement about X(p) the uncertainty about the parameter estimates are translated to the uncertainty about X(p). The methodologies often used for regression based models either make the calculation for each p or characterize how variable POD may be for each flaw size and then display the results as a curve. Curves derived in such a manner are not themselves POD-curves, although often interpreted as such. In this paper we will present the most often used methods for constructing confidence bound curves and discuss the implications of the structure of those curves concerning the underlying state of nature. We will also discuss the impact of sample size with regards to flaw size distributions.

Growing NDE Reliability Needs in the Aerospace Industry

---**James C. Malas**[1] and Joseph P. Gallagher[2], [1]Air Force Research Laboratory, Materials and Manufacturing Directorate, [2]Aeronautical Systems Center, Engineering Directorate, Wright Patterson AFB, OH 45433

---Reliable, affordable, nondestructive evaluation methods and processes are needed for detecting aircraft structural integrity problems that impact fleet readiness and maintenance costs. This is important to the United States Air Force because many of its aircraft either experience more time in service or more damaging operations than were anticipated in design. Longer service times means that it becomes difficult to anticipate fatigue cracking and corrosion problems that were not experienced and analyzed during the design period. Because our aircraft are being used beyond design full-scale test data and failure analysis predictions, reliable NDE will be essential to ensure safety. The USAF needs more reliable nondestructive inspection capabilities in the field and depot maintenance shops to prevent structural failures that could lead to loss of availability, increased cost and increase risk to ensuring safety. New approaches for assuring NDE reliability are needed to meet the coming wave of inspection requirements and for qualifying the growing number of new NDE technologies. This presentation will emphasize the importance of NDE reliability and a multi-faceted approach for addressing it.

Results from a New Prototype Embedded Defect Specimen Proposed for POD Analysis of Ultrasonic Systems

---**David A. Stubbs**, Victoria A. Kramb, Wally C. Hoppe, Dathan S. Erdahl, David L. Petricola, University of Dayton Research Institute, 300 College Park, Dayton, OH 45469

---Tests to evaluate ultrasonic inspection systems sometimes use flat-bottom holes (FBHs) in test objects representing the actual component. FBHs are useful because the holes are relatively easy to create and the reflected response is predictable experimentally and analytically. However, problems can arise during specimen design and testing due to difficulties specific to FBHs, such as drilling a statistically significant number of holes, specific hole orientation for longitudinal or shear wave tests, holes often cut through other inspection surfaces, small diameter holes require counterbores which produce unwanted reflections, and hole orientation accuracy affects results. These and other problems combine to produce cumbersome tests producing large numbers of unwanted or inaccurate indications. The Turbine Engine Sustainment Initiative (TESI) program produced an ultrasonic probability of detection (POD) specimen that overcomes the FBH disadvantages described above. The specimen contains 78 spheres, of different materials and diameters, embedded at different depths in a titanium ring. The spheres selected create a wide range of reflected responses ranging from < #1 FBH to approximately a #3 FBH. The specimen can be inspected using longitudinal or shear modes, from the top, bottom, inner and outer diameters, providing the equivalent of >250 FBHs. Experimental results will be presented and compared to predicted results.

Surprising Results From a Probability of Detection Assessment of a Standard Bubble Leak Test Procedure Gaps Between NDE Research, NDE Engineering and NDE Applications

---**Ward D. Rummel,** D&W Enterprises, LTD., Littleton, CO; Greg Garcia, Transportation Technology Center, Inc., Pueblo, CO 81001

---Assessment of the detection capabilities of nondestructive evaluation (NDE) procedures has produced surprising results since it was first implemented. Use of the method for the assessment of standard bubble leak test procedures also produced surprising results. This presentation discusses the design of experiment, fabrication and characterization of a variety of leak rates, and their use in assessment of standard bubble leak test procedures. Tests were completed at varying static pressures and results were detected and analyzed in the manner that is use in field applications. The results were analyzed in plotted in the standard, “HIT / MISS” mode. Additional analysis of results and reporting are in progress.

TUESDAY

Session 7

Tuesday, August 1, 2006

SESSION 7
GUIDED WAVES
P. Cawley, Chairperson
Pavilion East

8:30 AM **Long Range Ultrasonic Guided Wave Focusing in Pipe for Large Defect Circumferential Length Analysis**
---**J. Mu** and J. L. Rose, The Pennsylvania State University, Department of Engineering Science and Mechanics, 212 Earth and Engineering Science Building, University Park, PA 16802; L. Zhang, FBS, 2134 Sandy Drive, Suite 14, State College, PA 16803; J. Spanner, EPRI NDE Center, 1300 W. T. Harris Boulevard, Charlotte, NC 28262

8:50 AM **The Application of Synthetically Focused Imaging Techniques for High Resolution Guided Wave Pipe Inspection**
---**J. Davies** and P. Cawley, Imperial College, 682 Mechanical Engineering, Exhibition Road, London SW7 2AZ United Kingdom

9:10 AM **Phased Array Focusing Potential in Pipe with Viscoelastic Coating**
---**J. K. Van Velsor** and J. L. Rose, The Pennsylvania State University, Department of Engineering Science and Mechanics, University Park, PA 16802; L. Zhang and M. J. Avioli, Feature Based Systems, Inc., State College, PA 16802

9:30 AM **Scattering of the Fundamental Shear Horizontal Guided Wave Mode Incident at an Arbitrary Angle on a Slit in an Isotropic Plate**
---**P. Rajagopal** and M. J. S. Lowe, Imperial College, Exhibition Road, 682 Mechanical Engineering, London SW7 2AZ United Kingdom

9:50 AM **Defect Detection and Imaging Using Focused Ultrasonic Guided Waves**
---**R. Sicard** and H. Serhan, TecScan Systems Inc., Boucherville, Quebec, Canada

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

10:30 AM **Imaging Flexural Inhomogeneities Using Plate-Wave Diffraction Tomography**
---A. H. Rohde and **M. Veidt,** School of Engineering, The University of Queensland, Brisbane, Qld 4072, Australia; L. R. F. Rose, Platform Sciences Laboratory, Defence Science and Technology Organisation, Melbourne, Vic 3001, Australia; J. Homer, School of Information Technology and Electrical Engineering, The University of Queensland, Brisbane, Qld 4072, Australia

10:50 AM **Strategies for Guided Wave Structural Health Monitoring**
---**P. D. Wilcox**, G. Konstantinidis, A. Croxford, and B. W. Drinkwater, Department of Mechanical Engineering, University of Bristol, Bristol, United Kingdom

11:10 AM **A Computational Tool for the Design of Built-In Piezoelectric-Based SHM**
---Y. Kim and **F.-K. Chang**, Department of Aeronautics and Astronautics, Stanford University, Stanford, CA 94305

11:30 AM **Guided Wave Inspection for Bottom Edge of Rails**
---**T. Hayashi** and Y. Miyazaki, Nagoya Institute of Technology, Nagoya, Japan; M. Murase, Ultrasonic Materials Diagnosis Lab, Tsukasa Abe, JR East

11:50 AM **Lamb Wave Techniques for the Detection of Damage-Induced Material Nonlinearlity**
---**C. Bermes**, K. Luangvilai, and L. J. Jacobs, Georgia Institute of Technology, School of Civil and Environmental Engineering, Atlanta, GA 30332; J.-Y. Kim, L. J. Jacobs, and J. Qu, G. W. Woodruff School of Mechanical Engineering, Georgia Institute of Technology, Atlanta, GA 30332

12:10 PM ***Lunch***

Long Range Ultrasonic Guided Wave Focusing in Pipe for Large Defect Circumferential Length Analysis

---**Jing Mu** and Joseph L. Rose, The Penn State University, Department of Engineering Science and Mechanics, 212 Earth and Engineering Science Building, University Park, PA 16802; Li Zhang, FBS, 2134 Sandy Dr. Suite 14, State College, PA 16803; Jack Spanner, ERRI NDE Center, 1300 W. T. Harris Blvd., Charlotte, NC 28262

---Planar saw cuts and volumetric elliptical corrosion with different circumferential lengths are studied using ultrasonic guided wave focusing techniques in steel pipe. A circumferential scan is achieved by focusing at 44 circumferential positions around the pipe at a specific distance. The maximum amplitude of the defect echo is recorded with respect to each circumferential focal position in producing an experimental angular profile of the reflected wave. The maximum amplitude of the angular profiles occurs at the angle of the defect circumferential location. The energy reflected from the defects with different cross sectional areas (CSA) for each focusing position can be calculated from the focused angular profile. Comparison between the experimental angular profiles and the theoretical ones provides us with a good estimate of the defect circumferential length.

The Application of Synthetically focused Imaging Techniques for High Resolution Guided Wave Pipe Inspection

---**Jacob Davies** and Peter Cawley, Imperial College, 682 Mechanical Engineering, Exhibition Road, London SW7 2AZ, United Kingdom

---Synthetically focused imaging guided wave imaging techniques have previously been employed for plate like structures. Much work has been has been done using algorithms such as the Synthetic Aperture Focusing Technique (SAFT), the Total Focusing Method (TFM) and Common Source Method (CSM) using both linear and circular arrays. The resolutions for such algorithms for the plate case are well known. We have attempted to use these algorithms for imaging defects in pipes using an array of piezoelectric shear transducers clamped around the pipe circumference. We show that the SAFT and the TFM methods both suffer from coherent noise in the image caused by circumferentially propagating wave modes. We find that a better method is to not attempt to focus in transmission (this is equivalent to firing all transducers at the same time and thus avoiding the generation of circumferentially propagating modes). We then synthetically focus on reception to build the image (CSM). Results from the different imaging algorithms are presented for an 8 inch pipe using 50 kHz excitation, both from finite element simulations and laboratory experiments. The resolution obtained as a function of the aperture of the array, the wavelength and the distance from the array is defined.

Phased Array Focusing Potential in Pipe with Viscoelastic Coating

---**Jason K. Van Velsor** and Joseph L. Rose, The Pennsylvania State University, Department of Engineering Science & Mechanics, University Park, PA 16802; Li Zhang and Michael J. Avioli, Feature Based Systems, Inc., State College, PA

---The concept and usefulness of guided wave phased array focusing has been proven for the case of an elastic uncoated pipe. Many field applications require that a protective coating be applied to the pipeline prior to being put in service. Though there are a large number of protective coating types, almost all are viscoelastic in nature and require special attention when considering wave propagation. This work investigates the potential of traditional focusing techniques to obtain focus in piping with viscoelastic coating. Focusing results for an uncoated pipe are compared to that of pipe with single and dual-layer fusion bonded epoxy coatings, a coal tar mastic coating, a coal-tar epoxy coating, a bitumen tape coating, a wax coating, and an enamel coating. Experimental results are compared to computationally derived models. Results show that, for most coating types, focusing can be achieved without special consideration of the coating. This is significant in that it demonstrates the immediate applicability of traditional focusing techniques to coated pipeline.

Scattering of the Fundamental Shear Horizontal Guided Wave Mode Incident at an Arbitrary Angle on a Slit in an Isotropic Plate

---P. Rajagopal and M. J. S. Lowe, Imperial College, Exhibition Road, 682 Mechanical Engineering, London, SW7 2AZ, United Kingdom

---Guided ultrasonic waves are well established in the rapid inspection of pipelines, and developments for using them also to inspect plate structures are now advanced. The approach taken so far has been to develop screening tools to maximize coverage. However there is much interest in improving the resolution of guided wave NDE towards defect sizing for applications where direct access is difficult. One possible way of achieving this, presently being studied by the group at Imperial College, is to use fundamental modes in conjunction with array imaging methods. The fundamental shear horizontal guided wave mode (SH0) is attractive for such studies because it is non-dispersive and is unaffected by fluid in contact with the structure. Further, it can be exploited either as the SH0 mode in a plate or as the torsional mode T(0,1) in a pipe. The project behind this presentation is aiming to understand the nature of the scattering of SH0 waves from defects so as to inform the development of the imaging procedures. Here we present a study of the interaction of the SH0 mode with a slit in an isotropic plate. Circular wavefronts from a point source are considered, with arbitrary angle of incidence on the slit, and the scattered fields are studied. The problem is complex, involving a number of parameters, including the angles of incidence and observation, the wavelength, the length of the slit, and the distances of the source and receiver. Therefore the simple case of normal incidence will first be used to gain insights about the minimum number of independent parameters required and the physics of the scattering. These will then be incorporated in analyzing the scattering dependence on the other parameters at arbitrary angles of incidence. The presentation will include results from Finite Element simulations, together with analytical and experimental confirmation.

Defect Detection and Imaging Using Focused Ultrasonic Guided Waves

---**René Sicard** and Hussam Serhan, TecScan Systems Inc., Boucherville, Québec, Canada

---The use of numerical and phased focusing to perform guided wave inspection of plates and pipes has not been widely used; it represents an interesting solution for defect detection and localization. In addition, imaging of ultrasonic guided wave results using color coded B-Scans is also considered a highly valuable tool for data interpretation. The present paper presents an experimental study for the implementation of focal law algorithms applied to the inspection of plate structures using ultrasonic Lamb waves generated by the angle beam wedge method. The wedge properties and the considerations for the image representation are outlined in this work. A comparison between spike and toneburst excitation is also performed, demonstrating the feasibility for current phased array systems as well as the potential advantages of a toneburst based phased array system to perform imaging using Lamb waves.

Imaging Flexural Inhomogeneities Using Plate-Wave Diffraction Tomography

---Andrew H. Rohde and **Martin Veidt,** School of Engineering, The University of Queensland, Brisbane, Qld 4072, Australia; L. R. Francis Rose, Platform Sciences Laboratory, Defence Science and Technology Organisation, Melbourne, Vic 3001, Australia; John Homer, School of Information Technology and Electrical Engineering, The University of Queensland, Brisbane, Qld 4072, Australia

---This paper investigates the implementation and application of plate-wave diffraction tomography for the reconstruction of flexural inhomogeneities in plates. All aspects of the numerical implementation of the fundamental reconstruction algorithm are investigated, viz. diffraction limited sensitivity, influence of source-receiver configurations and weak scatterer assumption, damage location and scatter field data processing in time and Fourier space. The feasibility of the imaging technique is investigated for cylindrical inhomogeneities of various severities and relative position within the interrogation space and a normal incident interrogation configuration. The results show that plate-wave diffraction tomography enables the quantitative reconstruction of location, size and severity of plate damage with excellent sensitivity and offers the potential for detecting corrosion thinning, disbonds and delamination damage in structural integrity management applications.

Strategies for Guided Wave Structural Health Monitoring

---**Paul D. Wilcox**, George Konstantinidis, Anthony Croxford, and Bruce W. Drinkwater, Department of Mechanical Engineering, University of Bristol, Bristol, United Kingdom

---Guided acoustic waves are arguably the only viable mechanism for a Structural Health Monitoring (SHM) system capable of detecting damage at any location in a large structure. This is because guided waves provide a reasonable compromise between the required number of sensors and sensitivity to defects. The challenge for guided wave SHM even in a simple structure is signal to coherent noise ratio where the coherent noise is due both to unwanted modes and reflections from benign features such as edges and corners. Reference or baseline signal subtraction potentially resolves this, but in practice the authors have shown previously that small changes in the environment (e.g. temperature) cause changes in signals that are of comparable amplitude to those from defects. In this paper, two different defect detection strategies are compared for the generic case of defects in a flat rectangular plate. In the first, presented by the authors at last year's QNDE meeting, the detection mechanism is by reflection and defects anywhere in the structure can theoretically be detected by any transducers. In the second, detection is by modification of the direct transmission signal between a pair of transducers and is detection is therefore restricted to zones between transducer pairs. The techniques are considered in terms of defect sensitivity, structural coverage, signal to noise requirements and robustness.

A Computational Tool for the Design of Built-In Piezoelectric-Based SHM

---Yujun Kim and **Fu-Kuo Chang,** Department of Aeronautics and Astronautics, Stanford University, Stanford, CA 94305

---A computational tool is developed to analyze structures with built-in piezoelectric-based sensor networks. The tool serves two purposes: to understand fundamentally the interaction between sensors/actuators and the host structure in high frequency domains; and to optimize the design of sensor networks for maximizing sensor sensitivity and energy efficiency. A spectral element approach is adopted in this study. The software includes an equation solver and an interface program to link with pre/post-processing software. The elastodynamic equation solver is developed based on the spectral element method, which provides an excellent solution in wave propagation problems. Furthermore, the solver includes an algorithm to solve the coupled electro-mechanical field in piezoelectric materials. The interface program links to commercial finite element pre/post-processing software such as ABAQUS/CAE to grant access to the geometrical complexity of host structures and to facilitate understanding of the physical phenomena. This paper reports the efficiency and accuracy of the code using comparisons to FEM. The code is verified by matching the spectral-element solutions with experimental results. Sensor size, shape and location are also examined using the code to optimize sensitivity to damage.

Guided Wave Inspection for Bottom Edge of Rails

---**Takahiro Hayashi** and Yusuke Miyazaki, Nagoya Institute of Technology, Nagoya, Japan; Morimasa Murase, Ultrasonic Materials Diagnosis Lab., Tsukasa Abe, JR East

---Defects in a railhead and web can be detected with a rail inspection train and rail inspection tools equipped with special transducers such as tire transducers. A bottom edge of rails, an easily damaged part due to contact to soil and rail fastening, is, however, a blind zone for the conventional ultrasonic technique where signals are input from a head of rails. In this study, inspection technique for defects in a bottom edge of rails were developed using guided waves. Dispersion curves for a rail obtained by a semi analytical finite element calculation show that a lot of propagating modes exist in a frequency region used for guided wave inspection, eg. 10kHz - 200kHz. Guided wave modes mainly vibrating a bottom edge of a rail were selected among the many modes in dispersion curves, and then the selected modes vibrating at the bottom edge were excited and received. A sharp defect echo was obtained with a vertically vibrating mode. A highly dispersive longitudinally vibrating mode also provided a defect echo, but a lot of unwanted signals were detected as well as the fastest longitudinally vibrating mode.

Lamb Wave Techniques for the Detection of Damage-Induced Material Nonlinearity

---**Christian Bermes**, Kritsakorn Luangvilai, and Laurence J. Jacobs, School of Civil and Environmental Engineering, Georgia Institute of Technology, Atlanta, GA 30332; Jin-Yeon Kim, Laurence J. Jacobs, and Jianmin Qu, G. W. Woodruff School of Mechanical Engineering, Georgia Institute of Technology, Atlanta, GA 30332

---An understanding of the generation of higher harmonics in Lamb waves is of critical importance for applications such as remaining life prediction of plate-like structural components. The aim of this work is to use nonlinear Lamb waves to experimentally investigate damage in aluminum plates. This damage results in a nonlinear stress-strain relationship which causes higher harmonics (at certain frequencies) to form in propagating Lamb waves. The amplitudes of these higher harmonics increase with increasing propagation distance due to the accumulation of nonlinearity while the Lamb wave travels along its path. Damage causes nonlinearity (in addition to the inherent material nonlinearity) which can occur after plastic deformation. This increase in nonlinearity is experimentally observed, and a comparison is made between the higher harmonics occurring in undamaged and damaged specimens. The experimental setup uses an ultrasonic transducer and a wedge for the Lamb wave generation, and a laser interferometer for detection. The experimentally measured Lamb wave signals are processed with a fast Fourier transformation (FFT) which yields the amplitudes at different frequencies, allowing the observation of the nonlinear behavior of the material. It is important to distinguish between the inherent instrumentation nonlinearity and the material nonlinearity being investigated. Finally, undamaged and damaged specimens are compared using the ratio of the amplitude of the second harmonic and the squared amplitude of the fundamental frequency expressed as a function of propagation distance.

Session 8

Tuesday, August 1, 2006

SESSION 8
NDE FOR COMPOSITES
Broadway I

8:30 AM **Ultrasonic Inspection of Thin High Performance Composite Structures**
---**J. K. Na**, Wyle Laboratories, Inc., 2700 Indian Ripple Road, Dayton, OH 45440

8:50 AM **Nondestructive Evaluation of Elastic Constants of Laminated Composite Sandwich Plates Using Vibration Data**
---**T. Y. Kam** and C. R. Lee, Mechanical Engineering Department, National Chiao Tung University, 1001 Ta Hsueh Road, Hsin Chu 300, Taiwan, China

9:10 AM **Combined Application of NDE Techniques for Characterization of Shortfiber-Reinforced Thermoplastics in Intact and Damaged State**
---**S. Predak**, I. Solodov, H. Gerhard, N. Schneider, and G. Busse, Institute of Polymer Testing and Polymer Science, Department of Non-Destructive Testing (ZfP), University of Stuttgart, Stuttgart, Germany

9:30 AM **Internal Damage Detection in a Laminated Composite Plate Using Ultrasonic Guided Waves**
---**C. J. Lissenden**, F. Yan, E. T. Hauck, D. M. Noga, and J. L. Rose, Engineering Science and Mechanics, Penn State, University Park, PA 16802

9:50 AM **NDE of Damage in Aircraft Flight Control Surfaces**
---**D. K. Hsu**, D. J. Barnard, and V. Dayal, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

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

10:30 AM **Active Thermography for Defect Detection in Carbon Fiber Reinforced Composite Materials**
---**H. Gerhard**, A. Gleiter, G. Riegert, and G. Busse, Institute of Polymer Testing and Polymer Science, Department of Non-Destructive Testing (ZfP), University of Stuttgart, Stuttgart, Germany

10:50 AM **Thermo-Elastic Nondestructive Evaluation of Thermally Induced Damage in Polymer Matrix Composites**
---**J. T. Welter** and E. Lindgren, AFRL/MLLP, Wright Patterson AFB, OH 45469; S. Sathish, 300 College Park, University of Dayton Research Institute, Dayton, OH; E. Ripberger, AFRL/MLSA, Wright Patterson AFB, OH 45469

11:10 AM **Application of Acoustic Emission for Characterization of Impact Damage in Composites**
---**R. Y. Kim**, G. P. Tandon, and J. H. Kang, Nonmetallic Materials Division, University of Dayton Research Institute, Dayton, OH 45469-0168

11:30 AM **NDI Assessment of Composite Structural Elements**
---**R. M. Aoki**, Institute of Structures and Design, German Aerospace Center DLR, Stuttgart, Germany

11:50 AM **Boundary Value Problems for Anisotropic Elastic Waves**
---**E. L. Roetman**, Henry Cogswell College, Engineering and Science, 3002 Colby Avenue, Everett, WA 98201

12:10 PM ***Lunch***

Ultrasonic Inspection of Thin High Performance Composite Structures

---**Jeong K. Na**, Wyle Laboratories, Inc., 2700 Indian Ripple Road, Dayton, OH 45440

---As more and more composite materials are used for air and surface crafts, reliable and accurate nondestructive inspection techniques are required not only for the manufacturing process but also for the maintenance of high performance crafts. Voids (porosity) and delaminations are commonly found problems for composite structures. In an extreme environment, such as near jet engine exhausts, materials experience heat and vibration close to the design limits. Immersion ultrasonic technique is not a viable method for a craft as big as a jumbo jet. An ultrasonic probe and inspection technique that can be carried out with a portable system have been developed for inspection of thin and multilayered (<50 mils) composite structural materials. Laboratory and field test results show that the individual layers, less than 10 mils, can be inspected reliably and accurately.

Nondestructive Evaluation of Elastic Constants of Laminated Composite Sandwich Plates Using Vibration Data

---**Tai Yan Kam** and Ching Rong Lee, Mechanical Engineering Department, National Chiao Tung University, 1001 Ta Hsueh Road, Hsin Chu 300, Taiwan, China (ROC)

---This paper presents a method for the elastic constants evaluation of laminated composite sandwich plates using measured natural frequencies. In the plate vibration analysis, the Rayleigh-Ritz method constructed on the basis of the layer-wise linear displacement theory is used to predict the theoretical natural frequencies of the laminated composite sandwich plate using trial elastic constants. Impulsive vibrating testing of the composite sandwich plate is performed to measure the lower natural frequencies of the plate. A frequency discrepancy function is established to measure the sum of the squared differences between the experimental and theoretical natural frequencies of the sandwich plate. The identification of the elastic constants of the sandwich plate is then formulated as a constrained minimization problem in which the four elastic constants of the laminated composite face sheets together with the two elastic constants of the core material are determined by making the frequency discrepancy function a global minimum. The elastic constants identification of a number of laminated composite sandwich plates with different core materials, laminated composite face sheets, and boundary conditions is performed to demonstrate the capability and efficiency of the proposed method. The study has shown that the use of merely six to eight measured natural frequencies can determine the elastic constants of the composite sandwich plates. The excellent results of the identified elastic constants with small errors obtained in this study have validated the applicability of the proposed technique. A discussion on the causes of the errors induced in the elastic constants evaluation is also given.

Combined Application of NDE Techniques for Characterization of Shortfiber-Reinforced Thermoplastics in Intact and Damaged State

---**Sabine Predak**, Igor Solodov, Henry Gerhard, Nadine Schneider, and Gerd Busse, Institute of Polymer Testing and Polymer Science, Department of Non-Destructive Testing (ZfP), University of Stuttgart, Stuttgart, Germany

---NDE methods differ in the way they display the specimen under test. This is caused by the specific interaction with the material and its physical properties. Combining electromagnetic, optical, thermal, and elastic wave techniques, surface or integral information is achieved. The methods used for this work show a broad range of lateral resolution. For some of them it is possible to perform investigations in-situ during a tensile test and monitor the damage behavior of the material. Fiber orientation and fiber content of injection molded shortfiber reinforced thermoplastics can be measured. Both determine the mechanical and thermomechanical features of these materials. While the integral orientation informs on the main direction of reinforcement, local variations may influence the occurring damage and its development in these materials. It will be shown how these techniques can reveal the different types of damages and document the damage processes.

Internal Damage Detection in a Laminated Composite Plate Using Ultrasonic Guided Waves

---**Cliff J. Lissenden**, Fei Yan, Eric T. Hauck, Dawn M. Noga, and Joseph L. Rose, Engineering Science and Mechanics, Penn State, University Park, PA 16802

---Composite materials are susceptible to hidden internal damage in the form of matrix microcracking, fiber/matrix debonding, fiber fracture, and delamination. The particular damage mode that occurs depends on the composite itself and the type of loading. Damage may have different effects on the overall stiffness of the laminate; bulk velocity; phase and group velocities, and the wave structure of the guided waves. Sixteen-ply quasi-isotropic laminated graphite/epoxy panels were fabricated and then instrumented with permanently bonded piezoelectric wafer sensors. The instrumented panel was loaded cyclically with a stress ratio R = 0.1 using a 3-point fixture on a servohydraulic load frame. Cycling was interrupted intermittently to monitor the material state with ultrasonic waves in the frequency range 100-800 kHz. The experiment is automated using Labview control programs for both mechanical loading and monitoring. The objective of this monitoring is to detect the early stages of material damage, especially matrix cracking or the growth of a small delamination. Damage is detected by searching for signal differences from the initial state using frequency sweeps. Guided waves are transmitted and received using four different combinations of sensors to enable triangulation of the damage location.

NDE of Damage in Aircraft Flight Control Surfaces

---**David K. Hsu**, Daniel J. Barnard, and Vinay Dayal, Center for NDE, Iowa State University, Ames, IA 50011

---Flight control surfaces on an aircraft, such as ailerons, flaps, spoilers and rudders, are typically constructed of adhesively bonded composite or aluminum honeycomb sandwiches. These components can suffer from damage caused by hail, runway debris, or dropped tools during maintenance. On composite honeycomb sandwiches, low velocity impact damages can damage the core but often escape visual inspection, whereas on aluminum, buckling failure of the honeycomb core may or may not be accompanied by a more harmful disbond. This paper reports a study of the damage morphology in such structures and the NDE methods for detecting and characterizing them. Impact damages or overload failures in composite sandwiches with Nomex or fiberglass core tend to be a fracture or crinkling of the honeycomb cell wall located some distance below the facesheet-to-core bondline. The damage in aluminum honeycomb is usually an accordion-like buckling failure from the top skin down. The NDE methods used in this study for mapping out these damages were air-coupled ultrasonic scan and imaging by a computer aided tap tester. Representative results will be shown. In addition, damaged honeycomb sandwiches were found to exhibit pronounced hysteresis in the mechanical load-displacement curves, with the area of the hysteresis loop dependent on the severity of the damage.---This material was based upon work supported by the NSF IUCRC for NDE at Iowa State University, and partially by the FAA under Contract #DTFA03-98-D00008 (technical monitor Paul Swindell), and by NASA under award NAG-1-02098.

Active Thermography for Defect Detection in Carbon Fiber Reinforced Composite Materials

---**H. Gerhard,** A. Gleiter, G. Riegert, and G. Busse, Institute of Polymer Testing and Polymer Science, Department of Non-Destructive Testing (IKP-ZFP), University of Stuttgart, Pfaffenwaldring 32, D-70569 Stuttgart, Germany

---Recent developments in infrared technology allow for thermography methods which are well suited for robust applications in nondestructive evaluation. As compared to scanning methods, a significant advantage is the short measurement duration of several seconds. In active thermography methods a thermal wave is induced in the inspected specimen by modulation of heat deposition. Thermal wave reflections due to subsurface defects (like delamination) in the sample affect amplitude and phase of the temperature modulation at the surface. After a Fourier transformation of a recorded sequence of about 1000 thermal images one obtains phase and amplitude image containing the relevant information on the thermal structure and hidden defects. Especially carbon fiber reinforced plastics (CFRP) are well suited to these thermal methods since their surface efficiently converts light into heat. The depth of inspection ranges up to 6 mm. Measurement results of various CFRP samples containing industrially relevant hidden defects are presented.

Thermo-Elastic Nondestructive Evaluation of Thermally Induced Damage in Polymer Matrix Composites

---**John T. Welter** and Eric Lindgren, AFRL/MLLP, Wright-Patterson, AFB, OH 45469; Shamachary Sathish, 300 College Park, University of Dayton Research Institute, Dayton, OH; Erik Ripberger, AFRL/MLSA, Wright Patterson AFB, OH

---Thermal damage of polymer matrix composites (PMCs) caused by heat exposure that exceeds design specifications can dramatically degrade the performance of these materials. This type of damage can result from lightning strikes, fires, exhaust wash, maintenance and repair mishaps, etc.. Destructive measurements of overheated PMCs demonstrate mechanical strength can be reduced by as much as 20-30 percent before there is any visible damage. Many traditional nondestructive evaluation (NDE) techniques have been investigated during the last two decades and have been only successful in detecting severely damaged regions such as ply delaminations and matrix cracking. A large majority of the NDE techniques cannot detect incipient damage in PMCs and typically measure only changes to a single material property. This paper presents an NDE method that measures the thermo-elastic parameter of the material. Results from this technique demonstrate the feasibility of detecting incipient thermal damage in PMCs by comparing the thermo-elastic parameter measured in pristine samples and samples damaged by controlled thermal exposure. Thermo-elastic measurements are compared with ultrasonic C-scan and thermography results obtained from the same set of specimens. These measurements confirm that these traditional measurement techniques cannot detect thermal damage that can be detected by the thermo-elastic parameter measurements. In addition, experimental details of the thermo-elastic parameter measurements and possible mechanisms responsible for the change in this parameter due to thermal damage are discussed. A gradual decrease in the thermo-elastic parameter was determined as a function of increasing temperature and time of exposure. The results of these measurements indicate that this technique may be a viable tool for detecting heat damage in composite structures.

Application of Acoustic Emission for Characterization of Impact Damage in Composites

---**Ran Y. Kim**, Gyaneshwar P. Tandon, and Ji Ho Kang, Nonmetallic Materials Division, University of Dayton Research Institute, Dayton, OH 45469-0168

---Composite structures in an aircraft are susceptible to impact damage, which can occur during manufacture, service or maintenance. The results of such damage can have detrimental effects on the overall structural performance and safety. The main objective of this paper is to develop a methodology to identify impact damage location and to estimate its severity using acoustic emission (AE) in conjunction with acousto-ultrasonic technique. In this work, these approaches have been used to study various aspects of nondestructive testing in quasi-isotropic and braided carbon/epoxy composite laminates subjected to low velocity impact. In order to characterize the acoustic wave propagation, four resonant type AE sensors are mounted on the specimen. The specimen is then tapped lightly with a hand-held acoustic impact hammer at several different chosen locations. We investigate both the velocity distribution and the damping characteristics of the laminates, since both of these properties will be dependent on a number of parameters, such as material anisotropy, geometry, ply stacking arrangement and boundary conditions. After this initial test, the impact force is increased a number of times until visual damage is inflicted, while the AE signals are monitored. Preliminary results indicate that source location technique used in this work closely predicts the actual impact location in most cases. Besides the source location, discussion will also be presented on measured signal parameters such as amplitude, energy, frequency, number of events related with impact force, and damage size in detail.

NDI Assessment of Composite Structural Elements

---**Rodolfo M. Aoki,** Institute of Structures and Design, German Aerospace Center DLR, Stuttgart, Germany

---Lightweight, high-strength and high stiffness fiber reinforced structural elements are being used in a variety of larger structures. Often the fabrication process control is not sufficient to eliminate the possibility that the composite material structure might contain imperfections that would influence their load carrying capability. Furthermore, during service such structure might suffer severe damages. In such situations non-destructive inspection (NDI) and evaluation is necessary in order to ascertain the presence and nature of any imperfection and determine their significance. NDE results of experimental investigations which show the steps towards a more complete and synergetic evaluation of the damage development in static and fatigue loaded composite structural elements like GFRP tubes (torsion), CFRP spars (bending) and non crimp impacted flat panels (compression) will be presented. Results obtained with help of NDI methods like acoustic emission (AE), ultrasound A- and C-scans (US), thermography, lockin thermography, X-ray and in some cases computer tomography (CT) are correlated to photogrammetric strain measurements to demonstrate a better damage development understanding in composite structural elements under mechanical loading.

Boundary Value Problems for Anisotropic Elastic Waves

---**Ernest L. Roetman**, Henry Cogswell College, Engineering and Science, 3002 Colby Avenue, Everett, WA 98201

---The formulation of the elastodynamics problem as a system of first-order partial differential equations has shown promise for improved analysis for anisotropic composite materials. The system development is quickly reviewed and preliminary results are presented for isotropic and anisotropic materials that illustrate the promise of the approach. The propagating fields are expressed as a sum of characteristic propagation modes of an expanded acoustic matrix, which include the stress terms as well as the displacements. The analysis of the boundary behavior leads to unusual systems, but provides new results for the isotropic as well as anisotropic materials. Boundary projection operators for the reflection and refraction coefficients are determined and the classic Fresnel coefficients are recovered for the one transverse mode where they apply. The method establishes the mechanism for the mode coupling between longitudinal and shear waves in the isotropic case, and mode coupling coefficients for all angles for some special cases are obtained using MATLAB® and displayed as illustration. An anisotropic composite case is also displayed to illustrate the ease of extending the approach.

Session 9

SESSION 9
EDDY CURRENT NDE
J. Bowler, Chairperson
Pavilion West

8:30 AM **Eddy Current Induction Calculations for 3D Coil Configurations in Boltholes and Tubes**
---**T. Theodoulidis**[1] and J. Bowler[2], [1]University of West Macedonia, Greece; [2]Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

8:50 AM **Recent Advances in Simulation of Eddy Current Testing of Tubes and Experimental Validations**
---**C. Reboud**, D. Prémel, and G. Pichenot, SYSSC, CEA LIST, Saclay, France; D. Lesselier, Laboratoire des Signaux et Systèmes (L2S), Supélec, Gif-sur-Yvette, France; B. Bisiaux, SETVAL, Centre de Recherche VALLOUREC, Aulnoye-Aymeries, France

9:10 AM **Case Study for New Feature Extraction and Automated Data Classification Methods and Model-Assisted Probability of Detection Evaluation**
---**J. C. Aldrin**, Computational Tools, Gurnee, IL; J. S. Knopp, NDE Branch, Materials and Manufacturing Directorate, U. S. Air Force Research Laboratory, Wright Patterson AFB, OH

9:30 AM **A 3D Model for Eddy Current Inspection in Aeronautic: Application to Riveted Structures**
---**S. Paillard** and G. Pichenot, CEA/LIST, CEA Saclay, 91191 Gif-sur-Yvette, France; M. Lambert, DRE/L2S, 3 rue Joliot Curie, 91192 Gif-sur-Yvette, France; H. Voillaume, EADS CCR, DCR/SP/PN, 92152 Suresne, France

9:50 AM **Eddy Current Differential Transducer for Deep Flaws Evaluation**
---**T. Chady** and P. Frankowski, Department of Electrical Engineering, Szczecin University of Technology, Szczecin, Poland

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

10:30 AM **An Element-Free Boundary Integral Equation Method for Modeling Eddy Current Nondestructive Evaluation Problems**
---**Z. Chen** and N. Nakagawa, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

10:50 AM **Iterative Inversion Method for Eddy Current Evaluation of Near-Surface Residual Stress Profile in Surface-Treated Metals**
---**B. Abu-Nabah** and P. B. Nagy, Department of Aerospace Engineering and Engineering Mechanics, University of Cincinnati, Cincinnati, OH 45221

11:10 AM **Electromagnetic Enhancement of Pulsed Eddy Current Signals**
---**C. V. Mandache**, Institute for Aerospace Research, National Research Council of Canada, Ottawa, Ontario, Canada; J. H. Vivier Lefebvre, Air Vehicles Research Section, Defence R&D Canada, Ottawa, Ontario, Canada

11:30 AM **Interface Removal Techniques for Planar Geometries: The Vector Case**
---**N. V. Nair**, L. Udpa, and S. S. Udpa, Michigan State University, Department of Electrical and Computer Engineering, East Lansing, MI 48824; A. Tamburrino, Ingegneria dell'Informazione e Matematica Industriale, Universita degli Studi di Cassino, Cassino, Italy

11:50 AM **Transient Eddy Current Response Due to a Conductive Cylinder**
---**F. Fu** and J. R. Bowler, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

12:10 PM ***Lunch***

Eddy Current Induction Calculations for 3D Coil Configurations in Boltholes and Tubes

---**Theodoros Theodoulidis**[1] and John Bowler[2], [1]University of West Macedonia, Greece; [2]Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

---In both aircraft bolthole inspections and steam generator tube inspections miniature coils are utilized to scan the inner surface of the cylindrical structure for defects. There is a need therefore for a fast model simulating these inspections and the use of the Volume Integral Method seems to be an appropriate solution method. In this case, however, apart from knowledge of the relevant Green's dyad there is a need for a fast computation of the incident electromagnetic field (field in the absence of the flaw). In this paper we propose the modification of such an existing model by truncating the solution domain. As a result, both the field and impedance change expressions have the form of a double series instead of an integral and a series. Apart from the fact that this modification is necessary if the solution to the end effect problem is sought, further benefits include better accuracy control and considerable speed-up of computations. Closed form expressions have been derived for the cases of the classical bobbin type coil in an offset position or the horizontal coil (pancake type coil with its axis perpendicular to the inner cylindrical conductor surface). A semi-numerical approach involving Fourier transforms is followed in the case of an arbitrary coil orientation. The theoretical results have been verified experimentally for the bolthole case.---This material is based in part upon work supported by the Air Force Research Laboratory under Contract # FA8650-04-C-5228 at Iowa State University's Center for NDE.

Recent Advances in Simulation of Eddy Current Testing of Tubes and Experimental Validations

---**C. Reboud**, D. Prémel, and G. Pichenot, SYSSC, CEA LIST, Saclay, France; D. Lesselier, Laboratoire des Signaux et Systèmes (L2S), Supélec, Gif-sur-Yvette, France ; B. Bisiaux, SETVAL, Centre de Recherche VALLOUREC, Aulnoye-Aymeries, France

---CEA and Vallourec Research Centre are aiming at developing a 3D electromagnetic model dedicated to the simulation of eddy current testing (ECT) configurations which involve isotropic, non-magnetic tubes and external probes. This model achieves accurate and fast calculations using the Volume Integral Equations (VIE) approach. Three configurations of probe are addressed: encircling coils that are centered about the tube axis, encircling coils that are off-centered and tilted with respect to the tube axis and finally sectorial coils dedicated to ECT of welding seams. The following 3D flaws shapes are considered: first a flaw that is defined in the cylindrical coordinates of the tube, then a borehole with flat bottom and finally a longitudinal or transversal notch with flat bottom. All these defects may be through-wall. Simulation results have been compared to experimental data in order to validate the model. ECT configurations with centered and off-centered encircling coils are available in version 8 of CIVA platform. Volume integrals are discretized using the Method of Moments (MOM). A study of basis and projection functions has been performed and leads to the proposal of a new discretization scheme based on B-splines functions, the performance of which is discussed.

Case Study for New Feature Extraction and Automated Data Classification Methods and Model-Assisted Probability of Detection Evaluation

---**John C. Aldrin**, Computational Tools, Gurnee, IL; Jeremy S. Knopp, NDE Branch, Materials and Manufacturing Directorate, U.S. Air Force Research Laboratory, Wright-Patterson AFB, OH

---Research in eddy current nondestructive evaluation (NDE) continues to improve the reliability to detect, locate and size cracks around fastener sites in multi-layer structures. As new techniques are developed, due to the high cost of probability of detection (POD) studies, model-assisted methodologies are being investigated for validation. Since the influence of human factors on conventional NDE is difficult to model, automated techniques provide the best opportunity for demonstrating model-assisted POD evaluation methodologies. The objectives of this work are to present new feature extraction and classification algorithms for crack characterization at fastener sites and to discuss the influence on model-assisted POD evaluation. First, a novel feature extraction method fitting approximate models to data associated with geometric part features such as adjacent fastener sites and panel edges was developed. Second, data analysis methods in the circumferential direction around the fastener hole were developed to better characterize fatigue cracks with improved noise invariance. Model-assisted probability of detection results are also presented highlighting the benefit of the automated signal classification algorithms. Lastly, the success of automated classification algorithms and model-assisted POD evaluation is explored in terms of the particular controlling factors in a measurement including variation in part geometry and surface condition, flaw location and characteristics, and model quality.

A 3D Model for Eddy Current Inspection in Aeronautic: Application to Riveted Structures

---**Séverine Paillard** and Grégoire Pichenot, CEA/LIST, CEA Saclay, 91191 Gif-sur-Yvette, France ; Marc Lambert, DRE/L2S, 3 rue Joliot Curie, 91192 Gif-sur-Yvette, France ; Hubert Voillaume, EADS CCR, DCR/SP/PN, 92152 Suresne, France

---Eddy current technique is currently the operational tool used for fastener inspection which is an important issue for the maintenance of aircraft structures. The industry calls for faster, more sensitive and reliable NDT techniques for the detection and characterization of potential flaws nearby rivet. In order to reduce the development time and to optimize the design and the performances assessment of an inspection procedure, the CEA and EADS have started a collaborative work aiming to extending the modeling features of the CIVA non destructive simulation plate-form in order to handle the configuration of a layered planar structure with a rivet and a flaw deeply buried nearby. Therefore, an approach based on the Volume Integral Method using the Green dyadic formalism which greatly increases computation efficiently has been developed. The first step -modeling the rivet without flaw as a hole in a multi-stratified structure- has been reached and validated in several configurations with experimental data.

Eddy Current Differential Transducer for Deep Flaws Evaluation

---**Tomasz Chady** and Pawel Frankowski, Department of Electrical Engineering, Szczecin University of Technology, Szczecin, Poland

---In certain applications it is necessary to measure precisely a depth of flaws in thick plates. This paper presents a new differential eddy current transducer, which can be utilized to solve this problem. The transducer consists of a set of excitation coils and pick-up coils connected and arranged in such way that the output signal is close to zero if the tested material is uniform. The output signal is additionally adjusted using phase and amplitude of the exciting signals. A nearly linear dependence of the output signal amplitude on the flaw depth can be achieved by precise selection of exciting frequency. In order to calibrate and prove usability of the newly developed transducer a set of experiments were carried out. The experiments were done with a thick aluminum plates with artificial defects having depth from 0.5mm to 20mm. The obtained results confirmed that, the linear relation between amplitude and flaw depth is obtained for a wide range of flaws' depths. It can be retained even in case of very deep flaws. Details of transducer construction, results of preliminary numerical analysis of the transducer model and all results of experiments will be presented in a full version of the paper.

An Element-Free Boundary Integral Equation Method for Modeling Eddy-Current Nondestructive Evaluation Problems

---**Zhigang Chen** and Norio Nakagawa, Center for NDE, Iowa State University, Ames, IA 50011

---We present an element-free boundary integral equation method for modeling eddy-current nondestructive evaluation problems. Using the moving least squares algorithm, the proposed method effectively discretizes the boundary integral equations for electromagnetic fields entirely in terms of distributed nodes without imposing the element structure that requires node connectivity. The method retains the dimensionality advantage of the conventional boundary element method while adding the element-free attribute of the moving least squares algorithm. By solving three-dimensional eddy current problems for various prototypical geometries, we explicitly demonstrate that the method has the potential to achieve higher accuracy than the conventional boundary element method for similar numbers of nodes while alleviating meshing tasks and retaining the dimensionality advantage of the boundary element method. It is anticipated that similar computational advantages, flexibilities and accuracies will manifest themselves for electromagnetic problems involving complex geometry components and deformations, often encountered in eddy-current nondestructive evaluation. These are highly desirable features for advanced eddy-current nondestructive evaluation model applications such as model-assisted probability of detection studies where faster and more flexible modeling tools are required.---This material is based upon work supported by the Air Force Research Laboratory under Contract # FA8650-04-C-5228 at Iowa State University's Center for NDE.

Iterative Inversion Method for Eddy Current Evaluation of Near-Surface Residual Stress Profile in Surface-Treated Metals

---**Bassam Abu-Nabah** and Peter B. Nagy, Department of Aerospace Engineering and Engineering Mechanics, University of Cincinnati, Cincinnati, OH 45221

---Because of their frequency-dependent penetration depth, eddy current measurements are capable of mapping the near-surface depth profile of the electric conductivity. This technique can be used to nondestructively characterize the subsurface residual stress distribution in certain types of shot-peened metals, e.g., in nickel-base superalloys. To predict the frequency-independent intrinsic electric conductivity from the frequency-dependent apparent eddy current conductivity (AECC), a highly convergent iterative inversion procedure is presented. The proposed technique exploits three specific features of the subsurface electric conductivity variation caused by near-surface residual stresses in shot-peened metals. First, compressive residual stresses are limited to a shallow surface region of depth, much less than typical probe coil diameters. Second, the change in electric conductivity due to residual stresses is always very small, typically less than 1%. Third, the electric conductivity profile is fairly smooth and continuous. The accuracy of the proposed iterative inversion procedure is one order of magnitude better than that of the previously developed simpler method.---This material is based upon work supported by the Air Force Research Laboratory under Contract # FA8650-04-C-5228 placed with Iowa State University's Center for NDE. This project was performed at The University of Cincinnati.

Electromagnetic Enhancement of Pulsed Eddy Current Signals

---**Catalin V. Mandache**, Institute for Aerospace Research, National Research Council of Canada, Ottawa, Ontario, Canada; J. H. Vivier Lefebvre, Air Vehicles Research Section, Defence R&D Canada, Ottawa, Ontario, Canada

---In general, eddy current testing suffers from the limited depth of penetration of electromagnetic fields into the conductive material to be characterized. Pulsed input partially solves this problem by using a broadband excitation equivalent to a simultaneous injection multi-frequency testing. Nevertheless, increasing the pulsed eddy currents response amplitude and improving the signal-to-noise ratio represent advantages that cannot be overlooked. Backing the test piece with a thin layer of soft magnetic material, such as mu-metal, has the role of amplifying the eddy current response. The mu-metal reflects and amplifies a small amplitude magnetic field reaching the backside of the test piece. In this study, the method is demonstrated for metal-loss defects as a technique of increasing sensitivity and depth resolution of pulsed eddy current testing. Moreover, this procedure ensures preservation of the lift-off point of intersection (LOI) feature. The LOI is a point in the time domain for which the amplitude of transient signals does not change with varying lift-off. The presented method could find applications in non-destructive inspections for corrosion thinning, thickness of conductive coatings on ferrous substrates, and integrity of thermally insulated pipes.

Interface Removal Techniques for Planar Geometries: The Vector Case

---**Naveen V. Nair**, Lalita Udpa, and Satish S. Udpa, Michigan State University, Department of Electrical and Computer Eng., East Lansing, MI, 48824; Antonello Tamburrino, Ingegneria dell'Informazione e Matematica Industriale, Universita degli Studi di Cassino, Cassino, Italy

---The Q transform has been shown to be useful in extracting the Time of Flight (TOF) from diffusion domain data, such as is obtained from eddy current testing. The extraction technique makes use of the freedom available in the choice of the excitation waveform to relate the TOF to an easily measurable quantity in the received signal. However, in the presence of material interfaces, the design of excitation waveform becomes an extremely complicated exercise due to multiple reflections from the material boundary. Nevertheless, most practical geometries involve material interfaces of some kind and consequently there is considerable interest in the development of a technique for removing the effect of the interfaces. Initial work in this direction was previously presented by the authors for cylindrical and planar geometries for scalar fields. This work extends the development of such an "Interface Removal" transformation to the case of planar geometries for vector fields. The basic technique used in the derivation is the expression of the field in basis functions suited to the geometry. In particular, for the planar case, the plane wave representation is used. Theoretical results as well as numerical simulation results validating the proposed approach will be presented.

Transient Eddy Current Response Due a Conductive Cylinder

---**Fangwei Fu** and J. R. Bowler, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

---Transient eddy current test systems have been developed both for aircraft inspection and for pipeline testing and although theoretical developments have been made for planar geometries to simulate field interactions with flaws in aircraft skins, there has been relatively little attention paid to the corresponding problems in cylindrical geometries. In order to begin to rectify this deficiency, we have examined theoretically the transient probe signal response due to a cylindrical conductive rod excited by an encircling coil. The transient fields can be calculated from a Fourier transform of the frequency domain solutions for infinite rods or tubes but, as with planar structures, we have found that it is better to use series solutions in the time domain. Apart from the basic requirement for accuracy and flexibility, the series forms provide a firmer foundation for formulating flaw signal calculations. Two types of series are used; one which converges faster at short times and one which converges faster at longer times. Calculations using these series are in mutual agreement and agree with results computed using the fast Fourier transform.---This work was supported by NASA, grant number NAG-1-01040.

Session 10

SESSION 10
WELDMENTS, INTERFACES, AND COATINGS
Broadway II

8:30 AM **The Guiding of Ultrasound by a Welded Joint in a Plate**
---**N. Juluri**, M. Lowe, and P. Cawley, Imperial College, Mechanical Engineering, Exhibition Road, London SW7 2AZ, United Kingdom

8:50 AM **Characterization of Microstructural Features and Imaging of Ferritic and Austenitic Stainless Steel Weldment Profiles Using NDE Techniques**
---A. Kumar, B. P. C. Rao, S. Vaidyanathan, **T. Jayakumar**, and B. Raj, Indira Gandhi Centre for Atomic Research, Nondestructive Evaluation Division, Kalpakkam, Tamil Nadu, India

9:10 AM **Measuring Weld Transmissivity with an Ultrasonic Phased Array**
---**W. B. Davis**, Engineering Department, Lawrence Berkeley National Laboratory, One Cyclotron Road, Berkeley, CA 94720

9:30 AM **Detection of Skin Disbond in Honeycombs and Coating Detachment by a Laser Acoustic Technique**
---**A. Blouin,** B. Campagne, C Néron, and J.-P. Monchalin, Industrial Materials Institute, National Research Council Canada, Boucherville, Quebec, Canada

9:50 AM **Local Elastic Properties and Residual Stress Variation in a Friction Stir Welded Aluminum Alloy**
---**R. W. Martin**, S. Sathish, and R. Reibel, Structural Integrity Division, University of Dayton Research Institute, Dayton, OH 45469; K. V. Jata, Air Force Research Laboratory, Materials and Manufacturing Directorate, Wright Patterson AFB, OH 45433-7816

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

10:30 AM **Finite Element Modelling of the Propagation of Ultrasound Across a Solid-Solid Interface**
---R. Thomas and **B. W. Drinkwater**, Department of Mechanical Engineering, University of Bristol, Bristol, United Kingdom

10:50 AM **Nondestructive Evaluation of Thermal Spray Coating Interface Quality by Eddy Current Method**
---**B. Mi** and X. Zhao, Intelligent Automation, Inc., Rockville, MD 20855; R. Bayles, Center for Corrosion Science and Engineering, Naval Research Laboratory, Washington, DC 20375

11:10 AM **Measurement of Anisotropic Properties of Thin Films with Picosecond Sound Pulses**
---**M. Perton**, C. Rossignol, N. Chigarev, and B. Audoin, Laboratoire de Mécanique Physique, CNRS UMR 5469, Université Bordeaux 1, Talence, France

11:30 AM **Characterization of the CR203 Coatings Irradiated by HIPIB Based on Ultrasonic Reflection Coefficient Analysis**
---**L. Lin**, X. M. Li, and J. C. Li, Dalian University of Technology, School of Materials Science and Engineering, Nondestructing Testing & Evaluation Laboratory, Dalian 116024, China; M. K. Lei, Dalian University of Technology, School of Materials Science and Engineering, Surface Engineering Laboratory, Dalian 116024, China

11:50 AM **Investigation of Thermal Barrier Coating Degradation Using Local Residual Stress Measurements**
---S. A. Martinez, Materials and Manufacturing Directorate, Wright Patterson AFB, OH 45469; **S. Sathish**, 300 College Park, University of Dayton Research Institute, Dayton, OH 45469

12:10 PM ***Lunch***

The Guiding of Ultrasound by a Welded Joint in a Plate

---**Naresh Juluri**, Michael Lowe, and Peter Cawley, Imperial College, Mechanical Engineering, Exhibition Road, London, SW7 2AZ, United Kingdom

---Experimental observation has shown that a compression wave (similar to the Lamb wave S0) traveling along a weld between two plates is strongly guided by the weld and so does not decay as quickly as it would in a plane plate. This phenomenon is attractive for NDE because it may offer the potential to inspect long lengths of weld using a wave which travels along the weld and is guided by it. In order to understand the guiding phenomenon, studies have been carried out on an idealized structure consisting of a plate with thickened region of rectangular cross section. Finite element simulations and experimental measurements of waves propagating along this structure have revealed the physics of the guiding effect. The guiding occurs principally because of the geometry: the thickened region is slower than the plate. The paper will discuss the nature of the guiding effect, illustrate the effects, and propose its potential for practical NDE of welds and other geometric features.

Characterization of Microstructural Features and Imaging of Ferritic and Austenitic Stainless Steel Weldment Profiles Using NDE Technques

---Anish Kumar, Bhagi Purna Chandra Rao, Subramanian Vaidyanathan, **Tammana Jayakumar**, and Baldev Raj, Indira Gandhi Centre for Atomic Research, Non Destructive Evaluation Division, Kalpakkam, Tamil Nadu, India

---Determination of exact weld profile is important for fixing the required beam angles and scan ranges for ultrasonic testing of weldments with high reliability and unambiguous interpretation of the results. This becomes further more important in the case of automated weld inspection using robotics. It is also required to nondestructively assess the presence of desired microstructure after the post weld heat treatment (PWHT) in ferritic steel weldments. The present study brings out the possibility of using ultrasonic velocity and magnetic Barkhausen emission (MBE) measurements for imaging of various microstructural regions such as parent metal, heat affected zone (HAZ) and weld metal in ferritic steel weldments. Further, the study also indicates that these measurements be used effectively for the assessment of adequacy of the PWHT in ferritic steel weldments. Ultrasonic and eddy current testing carried out on stainless steel weldments exhibits that the weld profile can be imaged nondestructively by using ultrasonic velocity and eddy current impedance, suitable for automated weld inspection. The relative merits and limitations of different nondestructive testing parameters for microstructural characterization in ferritic and austenitic stainless steel weldments have been clearly brought out.

Measuring Weld Transmissivity with an Ultrasonic Phased Array

---**W. Bart Davis**, Engineering, Lawrence Berkeley National Laboratory, One Cyclotron Road, Berkeley, CA 94720

---A series of experiments is being performed at Lawrence Berkeley National Laboratory to develop software for an ultrasonic phased array, to inspect the quality of spot welds in auto bodies. Because welded metal transmits acoustic signals, while an unwelded interface reflects them, measures of acoustic transmissivity are expected to be strong indicators of weld quality. Therefore signal processing software to convert the electrical signals from the phased array into measures of acoustic transmissivity has been developed. This paper details a time-domain signal processing model used to estimate the acoustic transmissivity across the weld interface, and compares and contrasts it with two other measures: the relative energy in the first interface echo; and, a ratio of signal energies in the frequency windows that correspond to interface and backwall echoes. High resolution pixel maps of these three measures are compared with buttons pulled during destructive teardown. Image processing on these pixel maps provides weld nugget dimensions that correlate well with the size of the pulled button.

Detection of Skin Disbond in Honeycombs and Coating Detachment by a Laser Acoustic Technique

---**A. Blouin**, B. Campagne, C. Néron, and J.-P. Monchalin, Industrial Materials Institute, National Research Council Canada, Boucherville, Quebec, Canada

---Many engineering structures are composite and include for example a protective coating or a bonded layer. We have developed a novel technique, closed to laser-ultrasonics but significantly different, that allows the detection of disbonds between the coating or the bonded layer and the substrate. It is also applicable to the detection of unbonds in honeycomb structures. The technique is based on the thermoelastic excitation by a pulsed laser of the top layer or top skin which is driven into vibration if it is detached from the substrate underneath. This vibration is then detected by a second laser coupled to a photorefractive interferometer. The technique can be made very flexible by using optical fiber coupling. One foresees its application to the in-service inspection of aerospace structures for the detection of core unbonds in honeycombs or near surface delaminations. Examples of application to honeycombs and to a variety of coatings will be presented.

Local Elastic Properties and Residual Stress Variation in a Friction Stir Welded Aluminum Alloy

---**Richard W. Martin**, Shamachary Sathish, and Richard Reibel, Structural Integrity Division, University of Dayton Research Institute, Dayton, OH 45469; Kumar V. Jata, Air Force Research Laboratory, Materials and Manufacturing Directorate, Wright-Patterson AFB, Dayton, OH

---Friction Stir Welding (FSW) is a solid state joining technique that is being used to assemble aluminum aerospace structures. The FSW technique uses a non consumable rotating tool. During the joining process the rotating tool raises the temperature high enough to plasticize the material and makes joining possible. The FSW zone comprises of a heat affected zone (HAZ) a thermo-mechanically affected zone (TMAZ) and a dynamically recrystallized zone. The grain shape and size in all these three zones significantly differ from each other and influence the overall mechanical properties of the welded material. In an attempt to further understand the mechanical properties of the weld, elastic properties at various locations and along different directions in the weld were obtained using a High Precision Scanning Acoustic Microscope (HIPSAM). Longitudinal, Rayleigh, and Surface Skimming Longitudinal Wave velocities were measured. Residual stresses in the weld were also measured using X-ray diffraction. It is observed that the variation of acoustic velocities is caused by local variations in the microstructure and residual stresses across as well as thru the thickness of the weld.

Finite Element Modelling of the Propagation of Ultrasound Across a Solid-Solid Interface

---Ruth Thomas and **Bruce W. Drinkwater,** Department of Mechanical Engineering, University of Bristol, Bristol, United Kingdom

---A solid-solid interface consists of a plane of contacts and gaps of various sizes, surrounded by a solid. In practice such an interface could occur, for example, in a partially closed fatigue crack. This represents a very difficult scattering problem, not easily tackled analytically. This paper presents a finite element approach to modelling such interfaces. The modelling proceeds by first computing the interfacial geometry via a contact model. This then forms the input geometry to a large finite element model which predicts the interaction of ultrasound with the interface. Because the problem is non-symmetric in the general case of oblique incidence, and the single scattering approximation has been shown to be inaccurate, so the whole interface is modelled. From this the detail of the direct and mode converted reflection and transmission behaviors can be observed. This finite element approach is used to model a number of real interfaces and fatigue cracks. The results are shown to be in good agreement with a range of experimental data across a wide frequency range. For the cases when the wavelength is significantly larger than the scatterers the quasi-static spring model is shown to be an accurate model.

Nondestructive Evaluation of Thermal Spray Coating Interface Quality by Eddy Current Method

---**Bao Mi** and Xiaoliang Zhao, Intelligent Automation, Inc., Rockville, MD 20855; Robert Bayles, Center for Corrosion Science and Engineering, Naval Research Laboratory, Washington DC 20375

---Thermal spray coating is usually applied through directing molten or softened particles at very high velocities onto a substrate. An eddy current nondestructive inspection technique is presented here for thermal spray coating interface quality characterization. Several high-velocity-oxy-fuel (HVOF) coated steel plates were produced with different surface preparation conditions before applying the coating, e.g., grit-blasted surface, wire-brush cleaned surface, and a dirty surface. A quad-frequency eddy current probe was used to manually scan over the coating surface to evaluate the bonding quality. Experimental results show that the three surface preparation conditions can be successfully differentiated by looking into the impedance difference observed from the eddy current probe. The measurement is fairly robust and consistent. More specimens are also prepared with variations of process parameters, such as spray angle, stand-off distance, and application of corrosion protective sealant, etc. They are blindly tested to evaluate the reliability of the eddy current system. Quantitative relations between the coating bond strength and the eddy current response are also established with the support of destructive testing. This non-contact, non-destructive, easy to use technique has the potential for evaluating the coating quality immediately after its application so that any defects can be corrected immediately.

Measurement of Anisotropic Properties of Thin Films With Picosecond Sound Pulses

---**Mathieu Perton**, Clément Rossignol, Nikolay Chigarev, and Bertrand Audoin, Laboratoire de Mécanique Physique - CNRS UMR 5469, Université Bordeaux 1, Talence, France

---Properties of thin metallic films have been studied extensively by means of picosecond ultrasonics. Generation of longitudinal and shear waves via thermoelastic mechanism and large source has been demonstrated. Meanwhile, such measurements cannot provide complete information about properties of films. Like it has been already shown for nanosecond ultrasonics, the knowledge of group velocities in several directions for thin source allows determining the stiffness tensor coefficients of a film. To achieve this goal we have prepared experimental set-up to have the thinnest size for the source and adapted the calculation of group velocities for relatively large source. The typical features of propagation with diffraction and shear waves mode conversion were observed in the acoustic signal for thin film. First propositions about stiffness tensor coefficients for thin metallic film have been done.

Characterization of the CR2O3 Coatings Irradiated by HIPIB Based on Ultrasonic Reflection Coefficient Analysis

---**L. Lin**, X. M. Li, and J. C. Li, Dalian University of Technology, School of Materials Science and Engineering, Nondestructive Testing & Evaluation Laboratory, Dalian 116024, China; M. K. Lei, Dalian University of Technology, School of Materials Science and Engineering, Surface Engineering Laboratory, Dalian 116024, China

---Ultrasonic reflection coefficient as a function of frequency for the plasma sprayed Cr2O3 coatings on heat-resistant steel irradiated by High-intensity pulsed ion beam (HIPIB) was investigated using ultrasonic immersion focusing method. HIPIB irradiation produced a melting and ablating of coatings and formed layers with varied compactness, porosity and microcrack arrays. It was observed that there were alternate two minima among three maxima in the ultrasonic reflection coefficient spectra, which could be explained by the overlap of ultrasonic echoes from the interfaces between water/coating and coating/substrate, respectively. The relation of the reflection coefficient with the frequency was dependent on the density, ultrasonic velocity, and attenuation coefficient of the coatings. The increase of density and decrease of the attenuation coefficient increased the minimum of the reflection coefficient, wherever the increase of ultrasonic velocity not only increased the minimum value of the reflection coefficient, but also enlarged the frequency interval between the minima. The SEM images of irradiated Cr2O3 coatings were associated with the results from the ultrasonic reflection coefficient spectra. It is found that the ultrasonic reflection coefficient analysis method could be used to characterize the modified Cr2O3 coatings.

Investigation of Thermal Barrier Coating Degradation using Local Residual Stress Measurements

---Sonia A. Martinez, Materials and Manufacturing Directorate, Wright-Patterson AFB, OH 45469; **Shamachary Sathish**, 300 College Park, University of Dayton Research Institute, Dayton, OH

---Thermal Barrier Coatings (TBCs) are an integral part of high performance aircraft engines blade. TBCs are used in the high temperature section of the engine. Typically, TBCs are ceramic materials, plasma sprayed over a bond coat of NiCoCrAlY deposited on a substrate. During engine operation, the coatings degrade due to excess temperature and mechanical stresses. This leads to debonding and finally peeling off of the TBCs from the substrate and exposure of the bare metallic substrate, to higher temperatures, possibly causing catastrophic failures of engines. Currently many NDE techniques are in use for inspection of the coating. Most often these techniques detect delaminations or missing portions TBC. Although these techniques are important for detecting the defective portion of TBCs, there is a great need for NDE techniques that can provide information about rate of degradation of TBC coatings that may provide an opportunity, to possibly detect and predict the failure of the coatings. This paper presents local surface residual stress measurement and analysis for possible evaluation of the degradation of TBCs. To test the feasibility of the methodology, local residual stress measurements were performed using x-ray diffraction, on a TBC coated nickel base superalloy blade that was removed from service. Measurements were performed in many different regions including the leading edge, trailing edge as well as in the root section of the blade. The compressive residual stress in the intact regions (no discoloration) were observed to be at least 70% higher than the discolored regions that appear to be showing signs of degradation. The results of experimental measurements are presented and possible mechanisms for reduction of residual stress in the coating are discussed in light of application of the methodology for evaluation of degradation of TBC.

Session 11

SESSION 11
STUDENT POSTER COMPETITION
Grand Ballroom I

NOTE: Student posters are to be mounted Monday, July 31st from 3:00 to 6:00 PM for Monday evening judging only-*not public display*. During this period, no identification (author names, institutional names etc.) will be shown on the posters in order to preserve anonymity during judging. They will be open for public viewing with author and institutional titles during the regular Poster Session 11 on Tuesday, August 1st from 1:30-3:00 PM

- *Long Range Ultrasonic Guided Wave Focusing in Pipe Using a Phased-Array System*
- *Microwave Quantitative NDE Technique for Dielectric Slab Thickness Estimation Using the Music Algorithm*
- *Nonlinear Ultrasonic Testing on a Laboratory Concrete Bridge Deck*
- *Practical Considerations of Sludge and Blockage Detection inside Pipes Using Guided Ultrasonic Waves*
- *Dispersive Wave Analysis Using the Adaptive Chirplet Transform*
- *Eddy Current Testing for Detecting Small Defects in Thin Films*
- *High-Frequency Eddy Current Profiling of Near-Surface Residual Stress in Surface-Treated Nickel-Base Superalloys*
- *Development of Subharmonic Imaging Apparatus for Closed Cracks*
- *The Analysis and Assessment of Environmental Aspects Influence on Power Equipment Thermography Inspection*
- *Characterization of Adhesive Bond Properties Using Guided Waves in Multi-Layered Plates*
- *Incident Wave Removal for Enhancement of Defects in Acoustic Wavefield Images*

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

Long Range Ultrasonic Guided Wave Focusing in Pipe Using a Phased-Array System

---Guided waves can propagate long distances and are excellent in long range defect inspection and screening from a single probe position. The guided wave focusing techniques in pipe is used to provide us with more wave penetration power and, therefore, to improve defect detection probability and sizing potential. An ultrasonic multi-channel phased-array system with different amplitude and time-delay inputs is employed to achieve guided wave focusing at a pre-determined position in a pipe. The amplitude and time-delay inputs for focusing are calculated by the Normal Mode Expansion (NME) technique and a deconvolution algorithm. When these amplitudes and time-delays are applied to different channels of the phased array system, a constructive phase can be realized at the pre-determined focal spot. Experiments have shown that the phased array focusing substantially increased defect echoes compared to defect detection using axisymmetric waves. The phased-array system can focus on 44 positions around the circumferential direction of the pipe. This is called a circumferential scan. By doing circumferential scans at defect distances, defect circumferential locations can be very accurately determined.

Microwave Quantitative NDE Technique for Dielectric Slab Thickness Estimation Using the Music Algorithm

---Non-invasive monitoring of dielectric slab thickness is of great interest in various industrial applications. Examples of these applications include monitoring the thickness variations in ceramic and synthetic rubber coatings, concrete pavements, and refractory walls. This paper is focused on estimating the thickness of dielectric slabs, and consequently monitoring their variations, utilizing wideband microwave signals and the MUtiple SIgnal Characterization (MUSIC) algorithm. Basically, an antenna is used to illuminate the slab with a wideband microwave signal and intercept the reflected signal. Microwave signals are very sensitive to the boundaries instituted by the dielectric slab interfaces. Therefore, the interrogating microwaves are reflected toward the transmitter upon incidence on these interfaces. The reflected microwave signals are coherently detected and, subsequently, processed using the MUSIC algorithm to determine the location of the slab interfaces, and hence the slab thickness. The resolution in estimating the thickness is proportional to the bandwidth of the transmitted signal (the higher the bandwidth, the higher the resolution). With a given bandwidth, the MUSIC algorithm has shown to offer higher thickness resolution compared to the conventional techniques which are based on the Fast Fourier Transform (FFT) algorithm. This is particularly appealing since the practical systems are typically limited by their bandwidth. Herein, the performance of the proposed approach is assessed via simulations and laboratory experiments as well. It will be shown that the proposed approach is potentially suitable for the aforementioned applications.

Nonlinear Ultrasonic Testing on a Laboratory Concrete Bridge Deck

---Nonlinear ultrasonic testing (NLUT) has been shown to be extremely sensitive to distributed damage in concrete. It has the capability of detecting small defects that are not visible to the human eye. Nonlinear nondestructive ultrasonic tests were performed on a laboratory bridge to detect distributed damage in the bridge deck after it had been overloaded. The bridge deck had visible cracks where the bending moment was the highest and had no visible damage at the supports where the bending moment was assumed to be zero. Numerous locations along the span of the bridge were tested using NLUT. These locations included points where the moment was highest and had visible cracks, to points where the moment was zero and showed no visible damage. The NLUT detected damage throughout the deck, and of particular interest in locations where damage was not visible. These results were compared to results obtained using pulse velocity tests at the same locations. The nonlinear ultrasonic tests were several orders of magnitude more sensitive to damage than the results obtained from pulse velocity.

Practical Considerations of Sludge and Blockage Detection Inside Pipes Using Guided Ultrasonic Waves

---It has been reported that in principle sludge and blockages in pipes can be detected and characterized by using ultrasonic guided waves. The model idealized the sludge to be an asymmetrically uniform layer that is well bonded to the internal surface of the pipe wall. However, in practice, sludge layers normally have a very irregular shape and an asymmetrical circumferential profile. Also, the bonding state of sludge to pipe wall may be poor, or even be a sliding contact. These practical issues complicate the testing and perhaps bring some different new features to the guided wave modes. We investigated the different effects of each of these issues on the characteristics of guided wave modes to find out the most critical factors that influence the detection capability of guided waves. Investigation is further performed by combining these practical issues to give a general assessment of the potential of using guided ultrasonic waves to detect and characterize sludge blockage in practice. The investigations are carried out through finite element modeling and validated by experimental measurements.

Dispersive Wave Analysis Using the Adaptive Chirplet Transform

---Different time-frequency analysis techniques can be used to characterize dispersive wave signals. As a consequence of the uncertainty principle, however, the resolution in both time and frequency is limited for all these existing methods. Thus, the allocation of energy to individual modes is adversely affected, especially when these modes are close together, or intersect in the time-frequency plane. The chirplet transform offers additional degrees of freedom to adjust time-frequency atoms, and thus allocate energy more accurately to the respective modes. This work uses an adaptive chirplet algorithm to estimate the energy distribution of individual propagation modes for multimode dispersive wave signals with a known dispersion relation. As a first application, an aluminum plate coupled to a water half-space is considered. Experimental data is analyzed with the chirplet algorithm to determine attenuation of Lamb waves propagating in this system. These results are validated by comparison with the attenuation results of a theoretical dispersion model. The second application is the characterization of bond properties in a bonded plate specimen. These results are compared to numerical predications, and are used to demonstrate the robustness and accuracy of the proposed analysis technique.

Eddy Current Testing for Detecting Small Defects in Thin Films

---Presented here is a technique of using Eddy Current based Giant Magneto-Resistance sensor (GMR) to detect surface and sub-layered minute defects in thin films. For surface crack detection, a measurement was performed on a copper metallization of 5-10 microns thick. It was done by scanning the GMR sensor on the surface of the wafer that had two scratches of 0.2 mm, and 2.5 mm in length respectively. In another experiment, metal coatings were deposited over the layers containing five defects with known lengths such that the defects were invisible from the surface. The limit of detection (resolution), in terms of defect size, of the GMR high-resolution Eddy Current probe was studied using this sample. Applications of Eddy Current testing include detecting defects in thin film metallic layers, and quality control of metallization layers on silicon wafers for integrated circuits manufacturing.

High-Frequency Eddy Current Profiling of Near-Surface Residual Stress in Surface-Treated Nickel-Base Superalloys

---Mechanical surface enhancement methods significantly improve the fatigue resistance and foreign-object damage tolerance of metallic components by introducing beneficial near-surface compressive residual stresses and hardening the surface. However, the fatigue life improvement gained via surface enhancement is not explicitly accounted for in current engine component life prediction models because of the lack of accurate and reliable nondestructive methods that could verify the presence of compressive near-surface residual stresses in shot-peened hardware. In light of its frequency-dependent penetration depth, the measurement of eddy current conductivity has been suggested as a possible means to allow the nondestructive evaluation of subsurface residual stresses in surface-treated components. This technique is based on the so-called piezoresistive effect, i.e., the stress-dependence of electric conductivity. Previous experimental studies were conducted on excessively peened (Almen 10-16A) nickel-base superalloy specimens that exhibited harmful cold work in excess of 30% plastic strain. Such high level of cold work causes thermo-mechanical relaxation at relatively modest operational temperatures; therefore the obtained results were not directly relevant to engine manufacturers and end users. The main reason for choosing peening intensities in excess of recommended normal levels was that the eddy current penetration depth could not be decreased below 0.2 mm without conducting accurate measurements above 10 MHz, i.e., beyond the operational range of most commercially available eddy current instruments. In this presentation we will report the development of a new high-frequency eddy current conductivity measuring system that offers an extended inspection frequency range up to 80 MHz with a single spiral coil. In addition, the new system offers better reproducibility, accuracy, and measurement speed than the previously used conventional system.---This material is based upon work supported by the Air Force Research Laboratory under Contract # FA8650-04-C-5228 placed with Iowa State University's Center for NDE. This project was performed at The University of Cincinnati.

Development of Subharmonic Imaging Apparatus for Closed Cracks

---Although closed cracks can propagate under applied stress resulting in catastrophic accidents e.g. in aged atomic power plants, it is difficult to detect them since the intensity of scattering waves is much lower than that from open cracks. Recently, nonlinear ultrasound is expected to be capable of detecting and evaluating them, and subharmonic wave with half-frequency of input signal is particularly useful because of its selectivity and sensitivity for closed cracks. For a practical application, we constructed a novel closed crack imaging apparatus by a combination of digital filters for subharmonic wave and a phased array algorithm. In this study, we examined the change of closed crack images with varying crack closure stress, where the material (SUS316L) and thickness of the specimen are almost the same as those of recirculation pipe used in nuclear power plant. As a consequence, we found that the crack had an extraordinarily strong residual stress which was only partly relieved by applying the nominal maximum bending stress of more than 100 MPa. Nevertheless, it must be noted that we successfully imaged the change of crack state with varying closure stress and that the subharmonic images always gave the accurate crack length which was underestimated in the fundamental images.

The Analysis and Assessment of Environmental Aspects Influence on Power Equipment Thermography Inspection

---Thermographic inspection is a viable technique for diagnostic power equipment on power stations. A significant advantage of thermography is the potential for rapid, non-contacting, full field imaging of objects which allow opportunely develop defects and failure of it's operation. This paper presents an investigation of environmental aspects influence on power equipment thermography inspection for the purpose of increasing accuracy and reliability results of diagnostic and determination the most favorable conditions for it's conduction. The thermal process on surface of an object during it's normal operation was modeled to determine the most significant factors of environment (such as temperature, humidity, wind speed, daily variation of temperature, and solar radiation) which influence on thermography inspection. The optimum conditions based on obtained results were determined for conducting the thermography diagnostic. Modeling results were confirmed by experimental data.

Characterization of Adhesive Bond Properties Using Guided Waves in Multi-Layered Plates

---This research focuses on the application of guided waves techniques to nondestructively characterize the structural integrity of bonded engineering components. Analytical and computational models are used to examine the properties of multi-layered, adhesive bonded plates. This study quantifies the effect of the adhesive bond, including its low stiffness (relative to the adherents) and viscoelastic behavior, on the dispersion curves. A commercial finite element code (ABAQUS) is used for the numerical model and a variety of methods are employed to back-out the resulting dispersion relationships. These methods include the two-dimensional Fourier transform (2D-FFT), the reassigned spectrogram, and the waveguide-FE method. Note that the 2D-FFT and reassigned spectrogram operate on the transient output signals of the FE results, while the waveguide-FE method uses mass-, damping- and stiffness-matrices to generate the dispersion relation between frequency and wavenumber. Specific features examined include damping along the transition zones, which bond modes can be measured on the adherent, and which bond properties can be measured in-situ.

Incident Wave Removal for Enhancement of Defects in Acoustic Wavefield Images

---The method of Acoustic Wavefield Imaging (AWI) offers many advantages over conventional ultrasonic techniques for nondestructive evaluation, and also provides a means of incorporating fixed ultrasonic sensors used for structural health monitoring into subsequent inspections. AWI utilizes these fixed sensors as wave sources and an externally scanned ultrasonic transducer (or laser interferometer) as a receiver to acquire complete waveform data over the surface. When displayed as time-dependent images, these signals show the propagation of acoustic waves through a structure and subsequent interactions of these waves with both defects and structural geometry. Defect areas appear as stationary scattering sources on these images, but such scattered wave energy is often obscured by the stronger incident acoustic wavefield. Several methods are investigated for removing these incident wavefield components to better visualize waves interacting with and scattering from defects. The overall objective is to develop robust multidimensional signal processing algorithms to enhance the appearance of structural defects on wavefield images as a first step in automated processing of AWI data for defect detection and quantification. Results are presented for analysis of images from aluminum plate and solid laminate composite specimens.

SESSION 11 – POSTERS

SENSORS, PROBES, AND SYSTEMS, EDDY CURRENTS, AND SIGNAL PROCESSING

Grand Ballroom I

1:30 PM

Sensors, Probes, and Systems

On-Line Measurement of Moisture Content of Powered Food Using Microwave Free-Space Transmission at Dual Frequencies
---**K. B. Kim** and S. Park, Korea Research Institute of Standards and Science, Safety Metrology Group, 1 Doroyong-dong Yuseong-gu, Daejeon 305-340, Korea; J. Y. Kim and J. H. Kim, Kwangun University, Department of Radio Science and Engineering; C. J. Lee, Shinheung College, Department of Electric Communication Associate

In-Plane Ultrasound Propagation in an Elastic Silicon Tube as a Function of Tension
---A. Akujarvi, **A. Salmi**, J. Haapalainen, and E. Haeggstrom, Department of Physical Sciences, University of Helsinki PB 64, FIN-00014 Helsinki, Finland

Thickness Gauging of Thin Coatings Using Ultrasonics
---**S. Dixon**, B. Lanyon, and G. Rowlands, University of Warwick, Department of Physics, Gibbet Hill Road, Coventry, CV4 7AL, United Kingdom

Leaky Lamb Waves of Piezoelectric Plate Immersed in a Fluid: Analysis and Measurements
---**Y.-C. Lee** and S. H. Kuo, Dept. of Mech. Eng., National Cheng Kung University, Tainan, Taiwan

NDE Probe with Piezoceramic Interface and its Interrogating Electric Field Modeling
---**A. A. Bezusenko** and Y. I. Bulbik, Krasnoyarsk State Technical University, 26 Kirenski Str. Krasnoyarsk, 660074, Russia

Water Level Detection in Silty Materials Using Ground Penetrating Radar
---**U. B. Halabe and H. J. Siriwardane**, S. Pyakurel, and R. Kiriakidis, West Virginia University, Constructed Facilities Center, Department of Civil and Environmental Engineering, P. O. Box 6103, Morgantown, WV 26506-6103

Subsurface Defect Detection in FRP Bridge Decks Using Ground Penetrating Radar
---**U. B. Halabe** and C. L. Hing, West Virginia University, Constructed Facilities Center, Dept. of Civil and Environmental Eng., Morgantown, WV 26506-6103; P. Klinkhachorn, West Virginia University, Lane Department of Computer Science and Electrical Engineering, Morgantown, WV 26506-6109; H. V. S. GangaRao, West Virginia University, Constructed Facilities Center, Dept. of Civil and Environmental Eng., Morgantown, WV 26506-6103

Performance of Spherically Focused Air-Coupled Ultrasonic Transducers
---D. E. Chimenti and **J. Song**[1], Iowa State University, Center for NDE and Department of Aerospace Engineering, Ames, IA 50011; [1]Harvard Medical School, Boston, MA 01217

Fabrication and Evaluation of PMN-PT Single Crystal Ultrasonic Transducers for NDE Applications
---B. Ahn, **K. B. Kim**, and Y.-G. Kim, Korea Research Institute of Standards and Science, Safety Metrology Group, 1 Doroyng-dong Yuseong-gu, Daejeon 305-340, Korea; S. K. Park and J. S. Ha, Korea Electric Power Research Institute, Daejeon, Korea

Detection of Cracks Through Thick Composite Skins Using Arrays of Magnetoresistive Sensors
---R. Rempt, The Boeing Company, P. O. Box 3999, Seattle, WA 98124-2499

In-Situ Damage Detection in Plate Structures Using PWAS and Noncontact Laser Doppler Velocimeter
---P. P. Kumar, B. V. Somasekhar, C. V. Krishnamurthy, and **K. Balasubramaniam**, Indian Institute of Technology, Madras, Chennai 600036 India

Eddy Currents

Electric Potential Gradient Drives Eddy Current Away from Discontinuities
---**H. Hoshikawa** and K. Koyama, Nihon University, Izumicho Narashino Chiba 275-8575, Japan

Hidden Crack Detection with GMR Sensing of Magnetic Fields from Eddy Currents
---R. T. Ko, **S. Sathish**, J. S. Knopp, and M. P. Blodgett, University of Dayton Research Institute, Structural Integrity Division, 300 College Park Drive, Dayton, OH 45469-0120

A Fast Multipole Boundary Integral Equation Method for Two-Dimensional Diffusion Problems
---**M. Yang**, Z. Chen, and N. Nakagawa, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011; J. Song, Iowa State University, Department of Electrical and Computer Engineering, Ames, IA 50011

Multi-Resolution Eddy Current Measurements
---**T. Chady** and P. Lopato, Department of Electrical Engineering, Szczecin University of Technology, Szczecin, Poland

Comparison of Selected Multifrequency Eddy Current Systems
---**R. Sikora**, T. Chady, and P. Baniukiewicz, Szczecin University of Technology, Department of Electrical Engineering, ul. Sikorskiego 37, 70-313 Szczecin, Poland

Development of a Pulsed Eddy Current System and its Characterization
---**C. Lee** and N. Nakagawa, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011; M. J. Johnson, Optomec Design Company, Inc., St. Paul, MN 55114

Signal Processing

Optimization of Neural Network Pattern Recognition Systems for Guided Wave Damage Identification in Beams
---C. K. Liew and **M. Veidt**, School of Engineering, The University of Queensland, Brisbane, Qld 4072, Australia

Estimation of the Tool Condition by Applying the Wavelet Transform to Acoustic Emission Signals
---M. P. Gómez, Departmento de Ingenieria Electrónica, FRBA, Universidad Tecnológica Nacional, Buenos Aires, Argentina; R. Piotrkowski, Universidad Nacional de Gral. San Martin, San Martin, Buenos Aires, Argentina; J. E. Ruzzante, UA ENDE, Centro Atómico Constituyentes, Comisión Nacional de Energia Atómica, San Martin, Buenos Aires, Argentina; C. E. D'Attellis, Universidad Favaloro, Buenos Aires, Argentina (Poster presented by: **Pablo Katchadjian**)

Fusion of Microwave and Eddy Current Data for a Multi-Modal Approach in Evaluating Corrosion under Paint and in Lap Joints
---M. T. A. Ghasr, S. Kharkovsky, and R. Zoughi, University of Missouri-Rolla, Applied Microwave Nondestructive Testing Laboratory, Rolla, MO 65409; **K. Gupta** and R. J. Stanley, University of Missouri-Rolla, Electrical and Computer Engineering Department, Rolla, MO 65409; A. Padwal and M. O'Keefe, University of Missouri-Rolla, Department of Material Science and Engineering, Rolla, MO 65409; D. Palmer and N. Wood, The Boeing Company, Boeing Phantom Works, St. Louis, MO 63166; J. Blackshire and G. Steffes, Air Force Research Laboratory, Wright Patterson AFB, OH 45433

Ultrasonic Detection Using Correlation Images
---**R. Cepel** and S. P. Neal, Mechanical and Aerospace Engineering, University of Missouri-Columbia, Columbia, MO 65211; K. C. Ho, Electrical and Computer Engineering, University of Missouri-Columbia, Columbia, MO 65211; L. Thombs, Department of Statistics, University of Missouri-Columbia, Columbia, MO 65211; B. A. Rinker, Honeywell Federal Manufacturing and Technology, Kansas City, MO; D. D. Palmer, Jr., The Boeing Company, Boeing Phantom Works, St. Louis, MO 63166

Information Theory Based Registration of Industrial Radiographs
---**K. Sanghamithra** and R. Sivaramanivas, NDE Imaging Lab, GE Global Research, GE India Technology Centre, JFWTC, EPIP, Whitefield Road, Bangalore 560066, India

FPI Techniques

Comparison of Dry and Wet Developer Processes for FPI
---**L. Brasche**, B. Meeker, R. Lopez, and D. Eisenmann, Iowa State University, Center for NDE, Ames, IA 50011

Summary of Emulsification Processes for FPI
---**L. Brasche**, B. Meeker, R. Lopez, and D. Eisenmann, Iowa State University, Center for NDE, Ames, IA 50011

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

On-Line Measurement of Moisture Content of Powered Food Using Microwave Free-Space Transmission at Dual Frequencies

---**K. B. Kim** and S. Park, Korea Research Institute of Standards and Science, Safety Metrology Group, 1 Doroyong-dong Yuseong-gu, Daejeon 305-340, Korea; J. Y. Kim and J. H. Kim, Kwangun University, Department of Radio Science and Engineering; C. J. Lee, Shinheung College, Department of Electric Communication Associate

---The moisture content of food is not only the most important quality factor but also one of the essential parameters affecting their physical and chemical properties related to storage, capability of processing and quality control. As on-line machinery is now being used in storage and processing of food, demand for on-line moisture meters is increasing rapidly. The moisture measurement technique using microwave is very attractive because that method has merits of rapid and accurate measurement in the wider range of moisture content, simple implementation and inexpensive compared with other methods. In this study, microwave free-space transmission technique was applied to measure the moisture content of powdered food. The microwave measurement system with 2.5 GHz and 10.5 GHz frequencies consisted of oscillators, isolators, transmitting and receiving patch antennas, detectors, power amplifiers and signal processing units. The on-line measurement system consisting of microwave system, conveying device to move the food samples, inlet and outlet of the food samples, guide plate to control the thickness of the food samples, temperature sensing unit, taco-meter and central processing unit having analog to digital convert and microprocessor was constructed. As powdered food samples, wheat flour, coffee powder and milk powder were used and their ranges of moisture content were 7 to 15 %, 1 to 8 %, and 1 to 16 %, respectively. The output voltages of microwave measurement system due to the moisture content, sample temperature and sample moving speed were measured and analyzed. The multiple linear regression calibration equation for moisture content of powdered food samples was developed and its performance was evaluated. The developed calibration equation provided the coefficient of determination and standard error of prediction for all unknown samples 0.953 and 0.916 % moisture content, respectively, regardless of moving speed of food samples.

In-Plane Ultrasound Propagation in an Elastic Silicon Tube as a Function of Tension

---Altti Akujärvi, **Ari Salmi,** Jonne Haapalainen, and Edward Hæggström, Department of Physical Sciences, University of Helsinki, PB 64, FIN-00014 Helsinki, Finland; Edward Hæggström, Helsinki Institute of Physics, PB 64 FIN-00014, Helsinki, Finland

---The propagation of in-plane ultrasound in silicon tube wall subjected to different applied static tension (mfr. Kavan) (inner diameter 1,5 0,05 mm, wall thickness 1.5 0,05 mm) was studied. A 23 kHz, 1-cycle square signal (27,7 nm amplitude) was excited into the tube wall with a piezoceramic pickup (Ronette ST105/Tonar) and received with an inductive pickup (Shure M92E). The wave phase velocities in the tube wall were determined by measuring the time-of-flight from different inter-transducer distances. The longitudinal mode sound velocity was 86,64 0,13 m/s and 55,0 0,3 m/s for the shear mode, respectively with 202 1 g tension. This compares with the FEM (Abaqus 6.5-1) estimation. With a laser-doppler vibrometer it was shown that the waveforms were purely in-plane. A negative control test detected no out-of-plane modes while exciting longitudinal and shear waves, and a later positive control test saw the out-of-plane modes excited with an ultrasonic shaker (Wilcoxon F7-1). A 2DFFT graph revealed the waveforms present in the tube. No dispersive modes were seen. Artificially induced local stiff patches on the tube wall were also measured.

Thickness Gauging of Thin Coatings Using Ultrasonics

---**Steve Dixon**, Ben Lanyon, and George Rowlands, University of Warwick, Department of Physics, Gibbet Hill Road, Coventry, CV4 7AL, United Kingdom

---A homogeneous plate is able to support through thickness ultrasonic 'resonant' modes and measurement of these modes can be achieved via a Fast Fourier Transform of an A-scan. We describe an extension of this principle to two layer systems, particularly for the case of a thin coating on a substrate of known properties. The model predicts the resonant behaviour of these systems and we explain how this approach is used to measure thickness or elastic modulus of the coating. Non-contact Electromagnetic Acoustic Transducers are used for ultrasonic generation and detection as they do not significantly modify the resonant response of the system, when compared to other transducers. The effect of loading a sample with a contact transducer is shown to significantly affect the resonant mode of the system being measured.

Leaky Lamb Waves of Piezoelectric Plate Immersed in a Fluid: Analysis and Measurements

---**Yung-Chun Lee** and Shi Huoa Kuo, Department of Mechanical Engineering, National Cheng Kung University, Tainan, Taiwan

---For waves propagating in a piezoelectric plate immersed in a fluid (dielectric or conductive), that is, leaky Lamb waves, both mechanical and electrical loading effects will induce phase velocity variation and wave attenuation. To quantitatively characterize these loading effects play an important role in various applications of these plate waves for sensing purposes in liquid phase. In this work, we will analyze the fluid's mechanical, dielectric, and conductive loading effects on an XZ-cut LiNbO3 plate. Both phase velocity variation and wave attenuation as a function of the fluid's permittivity and conductivity are numerically determined. Furthermore, a new differential type measurement system is developed to accurately and sensitively measure the loading effects on the leaky Lamb waves, including both the velocity variation and wave attenuation. The dielectric and conductive loading effects on the wave velocity as well as the wave attenuation have been quantitatively and experimentally determined. The experimental data in general agree well with the numerical results predicted by partial wave theory, which verify the analytic model of the leaky Lamb wave. However, some discrepancies are also observed. Possible reasons for these discrepancies will be discussed. The information obtained in this work is very useful for further development of dielectric or conductivity sensors based on leaky Lamb waves.

NDE probe with Piezoceramic Interface and Its Interrogating Electric Field Modeling

---**Alexander A. Bezusenko** and Yanis I. Bulbik, Krasnoyarsk State Technical University, 26 Kirenski Str. Krasnoyarsk – 660074, Russia

---Probes having ring-shaped coaxial electrodes placed between coplanar central and peripheral ones are available for surface and subsurface property's nondestructive evaluation (NDE) of nonmetallic composite structures under test. In consequence of this design, the probe's interrogating field is an electric field fringe using in the pulse-excited mode. The ring sensory electrode's system sectioning ensures a possibility to reconstruct the transient or quasi-stationary field fringe discrete pattern in an inspection zone by partial electric charges subsequent reduction to the probe's output. The required sensitivity can be attained by raising the excitation voltage pulse level, especially at the probe's contacting area reduced value. Transient or quasi-stationary field states are inevitably accompanied by the charge carrier's injection into subsurface layers of nonmetallic composite. This effect reduction can be reached by a piezoceramic interface permanently linked with the central high-potential electrode. Owing to this design, the injection current stabilization is attained. The paper concerns with a hybrid approach to the computational model that based on the secondary field source method and electric charge image one. The model is available to the integral boundary equation system as well as to the fictitious electric charge linear equation system forming and solving for a numerical modeling of the probe's transfer functions. Some results are discussed.

Water Level Detection in Silty Materials Using Ground Penetrating Radar

---**Udaya B. Halabe, Hema J. Siriwardane**, Sandeep Pyakurel, and Ricardo Kiriakidis West Virginia University, Constructed Facilities Center, Department of Civil and Environmental Engineering, P. O. Box 6103, Morgantown, WV 26506-6103

---Detection of water level in silty soils can be complicated because of capillary action. In this study, the water level in a silty soil sample was detected using Ground Penetrating Radar (GPR) technique in the laboratory. The soil sample has dimensions of 62 cm x 46 cm x 36 cm and was kept in a clear Plexiglas container which facilitated water level measurements. Two ground-coupled antennas with frequencies of 900 MHz and 1,500 MHz were used in this study. The soil sample was dry at the beginning of the experiment. The water level in the soil sample was raised to a pre-determined level and radar readings were taken at different times over 24 hours. The moisture content in the soil sample above the water level increased with time due to capillary action. At the end of the experiment, the variation of moisture content with depth of the sample was experimentally determined. The GPR observations were compared with measured water depth in the soil sample. The paper presents the comparison of water level as determined by GPR with the variation of experimentally determined moisture content of the sample. This study includes an investigation on the effects of capillary action on GPR measurements.

Subsurface Defect Detection in FRP Bridge Decks Using Ground Penetrating Radar

---**Udaya B. Halabe** and Cheng L. Hing, West Virginia University, Constructed Facilities Center, Department of Civil and Environmental Engineering, Morgantown, WV 26506-6103; Powsiri Klinkhachorn, West Virginia University, Lane Department of Computer Science and Electrical Engineering, Morgantown, WV 26506-6109; Hota V. S. GangaRao, West Virginia University, Constructed Facilities Center, Department of Civil and Environmental Engineering, Morgantown, WV 26506-6103

---While Ground Penetrating Radar (GPR) has been widely used for defect detection in concrete bridge decks and pavements, its use has not been explored for Fiber Reinforced Polymer (FRP) bridge decks. This paper presents the results from an experimental study that investigated the use of GPR for subsurface defect detection in FRP bridge decks. Several FRP bridge deck specimens were cast with embedded subsurface defects (air- and water-filled) of varying planar sizes and thicknesses. These decks were then tested using a GPR system with 2.0 GHz air-launched and 1.5 GHz ground-coupled antennas. Results from both antennas have been compared. Both antennas had problems in detecting air-filled defects but could detect water-filled defects. Moreover, it was found that because of its closer proximity (ground-coupling) and higher energy input into the bridge deck, the ground-coupled antenna could detect smaller defect sizes (water-filled) much better compared to the air-launched antenna.

Performance of Spherically Focused Air-Coupled Ultrasonic Transducers

---D. E. Chimenti and **Junho Song**[1], Iowa State University, Center for Nondestructive Evaluation and Department of Aerospace Engineering, Ames, IA 50011; [1]Current Address: Harvard Medical School, Boston, MA

---This paper reports the development, testing, and performance evaluation of spherically focused capacitive air-coupled ultrasonic transducers 1 and 5 cm in diameter. A flexible micro-machined copper/polyimide backplate permits a conformal fit to a spherically shaped fixture, forming the rear capacitor plate. A spherically deformed 6-μm aluminized Mylar foil forms the front capacitor plate, completing the transducer. The device's frequency spectrum is centered near 800 kHz with -6dB points at about 400 and 1200 kHz. The device's focal-plane behavior is successfully modeled theoretically as a focused piston radiator. The imaging and defect detection capabilities of the new transducer are demonstrated in a series of critical tests: a 250-μm wire is easily imaged in a confocal geometry with a second device. Composite, honeycomb, and wood samples are imaged in through-transmission C-scans, showing internal defects. A printed circuit board is imaged, showing features as small as 200-μm.---This work is supported by NASA under grant award NAG-1-029098.

Fabrication and Evaluation of PMN-PT Single Crystal Ultrasonic Transducers for NDE Applications

---B. Ahn, **Ki-Bok Kim**, and Young-Gil Kim, Korea Research Institute of Standards and Science, Safety Metrology Group, 1 Doroyng-dong Yuseong-gu, Daejeon 305-340, Korea; S. K. Park and J. S. Ha, Korea Electric Power Research Institute, Daejeon, Korea

---Generally, piezo-ceramic materials such as lead zirconate titanate (PZT) ceramics have been widely used to make ultrasonic transducers as it has high performance and allows for ease of manufacture due to its robustness. Recently, a new class of single-crystal piezoelectric materials such as lead metaniobate doped with lead titanate (PMN-PT) has been synthesized and were found to further enhance the electromechanical coupling factor compared to piezo-ceramic materials. These materials can offer significantly improved the performance of ultrasonic transducers through enhanced bandwidth and sensitivity, both in transmission and transmit-receive configurations. However, in the field of non-destructive evaluation, there are not enough researches on development of ultrasonic transducer based on PMN-PT single crystal. This paper describes fabrication and evaluation of PMN-PT single crystal ultrasonic transducers for contact measurement of stainless steel that is one of the high attenuative materials. The design conditions of components of ultrasonic transducer such as front matching layer between test material and piezo-material and backing materials were investigated based on the simulation results by KLM model. The PMN-PT single crystal ultrasonic transducers with centre frequencies at 1, 2.25 and 5 MHz were fabricated and their performances were evaluated.

Detection of Cracks Through Thick Composite Skins Using Arrays of Magnetoresistive Sensors

---**Ray Rempt**, The Boeing Company, P. O. Box 3999, Seattle, WA 98124-2499

---We have been developing Magnetoresistive (MR) sensor arrays for rapid large area scanning of aircraft surfaces for most of the past decade. I present results of scanning of metallic skeletal structure beneath thick (0.2” to 0.9”) composite skins. The superior performance of the sensors, coupled with the fact that they can be operated in a deeper penetrating scheme, make them highly successful for this particular application. I discuss the operational issues associated with the arrays for various applications, as well as describing several of the arrays that we have developed and operated. I also give some suggestions for where the MR sensor technology can go from here, as applications in NDE open up. Our immediate goal is for an array that can scan along a line of fasteners at speeds upwards of one inch per second, while imaging subsurface conditions/features/flaws in real time.

In-Situ Damage Detection in Plate Structures Using PWAS and Non-Contact Laser Doppler Velocimeter

---**P. Padma Kumar**, B. V. Somasekhar, C. V. Krishnamurthy, and Krishnan Balasubramaniam, Centre for Nondestructive Evaluation, Department of Mechanical Engineering, Indian Institute of Technology Madras, Chennai India 600 036

---The capability of embedded piezoelectric wafer active sensors (PWAS) to perform in-situ nondestructive evaluation (NDE) for structural health monitoring (SHM) of fiber reinforced polymer (FRP) composite plate like structures is explored. The basic principles of Lamb wave transmission and reception with PWAS transducers were verified with simple laboratory experiments, performed on both isotropic and anisotropic plates. In the second case, non-contact measurements for Lamb wave sensing using Laser Doppler Velocimeter were explored. The damage detection using pulse-echo and through transmission techniques on anisotropic plates for delaminations and disbond detection were performed.

Electric Potential Gradient Drives Eddy Current Away from Discontinuities

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

---This presentation gives the answer to the mysterious phenomena such as why axi-symmetric circulation of eddy current causes no electric potential difference in the material and why a discontinuity drives eddy current away. The authors indicate that eddy current induced by alternating magnetic flux from the exciting coil develops electric potential difference around a discontinuity and the potential gradient drives eddy current away from it in eddy current testing. The eddy current conveys electric charges in conductive material. Based on the conservation law of electric charges, eddy current has to circulate continuously. When eddy current circulates continuously without any hindrance, there is no accumulation of electric charges and no electric potential difference in the material. If a discontinuity hinders and changes the circulation of eddy current, electric charges accumulate in the area where the eddy current varies because of the conservation law of electric charges. The accumulations of electric charges develop electric potential differences around the discontinuity because the accumulated charges repel each other based on Coulomb's repelling forces among themselves. The potential difference causes potential gradient that drives eddy current away from the discontinuity. The results by finite element analysis show how electric potential differences are developed around a discontinuity and how a tangential coil develops potential differences and makes eddy current continuous.

Hidden Crack Detection with GMR Sensing of Magnetic Fields from Eddy Currents

---Ray T. Ko, **Shamachary Sathish**, Jeremy S. Knopp, and Mark P. Blodgett, University of Dayton Research Institute, Structural Integrity Division, 300 College Park Drive, Dayton, OH 45469-0120

---Giant Magneto Resistance (GMR) sensor inside a coil configuration has been utilized for same side eddy current measurements on metallic structures. Magnetic fields from eddy currents generated in a metallic structure by excitation of the coil, are detected by the GMR sensor. The signal excitation and detection is accomplished using a lock-in-amplifier which allows independent measurement of the phase and amplitude. The sensor configuration has been utilized to detect simulated hidden cracks under fastener holes. Phase and amplitude images acquired with this sensor configuration are compared with the images obtained using the coil only. The spatial resolution and sensitivity of two configurations are discussed. Further, experimental signals captured at individual locations are compared with theoretical results.

A Fast Multipole Boundary Integral Equation Method for Two-Dimensional Diffusion Problems

---**M.Yang**, Z. Chen, and N. Nakagawa, Iowa State University, Center for Nondestructive Evaluation, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011; J. Song, Iowa State University, Department of Electrical and Computer Engineering, Ames, IA 50011

---The Fast Multipole Method (FMM) is a well-established and effective method for accelerating numerical solutions of the boundary integral equations (BIE). Accelerated by the FMM, the BIE method can now solve large-scale electromagnetic wave propagation and diffusion problems with up to a million unknowns on a personal computer. The traditional BIE method requires O(N^2) operations to compute the system of equations and another O(N^2) operations to solve the system using iterative solvers, with N being the number of unknowns; in contrast, the BIE method accelerated by the two-level FMM can potentially reduce the operations and memory requirement to O(N^3/2). This paper compares numerical and exact solutions of the two-dimensional Helmholtz equation with a complex wave number for non-trivial boundary geometries, with around 10,000 unknowns. The goal of this paper is to demonstrate that the proposed method is not only efficient in meshing complicated geometries, accurate for solving singular fields or fields in infinite domains, but also practical and often superior to other methods in solving large-scale problems.---This material is based upon work supported partially by the Federal Aviation Administration under Contract #DTFA03-98-D-00008, Delivery Order #0039 and performed at Iowa State University's Center for NDE as part of the Center for Aviation Systems Reliability program.

Multi-Resolution Eddy Current Measurements

---**Tomasz Chady** and Przemyslaw Lopato, Department of Electrical Engineering, Szczecin University of Technology, Szczecin, Poland

---Eddy current testing is widely used technique for nondestructive evaluation of conducting materials. Sensitivity of the measurements depends on several factors, like dimensions of the transducer, excitation frequency and properties of tested specimen (permeability, permittivity and conductivity). Enlargement of the probe dimensions will result in a higher sensitivity and a lower spatial resolution of the measurements. Unfortunately high sensitivity and very high resolution most often may not be achieved at the same time, especially in case of shallow defects located on the opposite surface of element under examination. Usually, a compromise between all requirements has to be achieved in a stage of design. Multi-resolution eddy current measurements is another, more flexible solution of the problem. Such measurements can be carried out in two different ways: using fusion of data from two or more transducers having different size or utilizing an adaptive transducer. In case of the first solution, a smaller probe is responsible for high resolution measurements and a bigger one is responsible for high sensitivity measurements. In case of the adaptive probe, it should have ability to change its resolution, for example through changes of the transducer's dimension (i.e. using a multi-section excitation coils or variable geometry of a core). All experiments with proposed transducers were carried out using measurement system utilizing Multi-Frequency Excitation and Spectrogram method (MFES) and conducting plates with EDM notches.

Comparison of Selected Multifrequency Eddy Current Systems

---**Ryszard Sikora**, Tomasz Chady, and Piotr Baniukiewicz, Szczecin University of Technology, Department of Electrical Engineering, ul. Sikorskiego 37, 70-313 Szczecin, Poland

---A multifrequency eddy current (EC) method is one of the most popular NDT method. Typically, a specimen is under influence of varying electromagnetic field, which is generated by excitation coils. The electromagnetic field consists of various sinusoidal components, which frequencies depend on material properties. In this paper, authors take into consideration two different implementations of the multifrequency EC method. In the first implementation the excitation coils are powered by a programmable generator with a signal consisting selected sinusoidal components. An output signal from detection coils is analyzed using Fourier transform in order to obtain amplitudes of all the components. In the second method the sensor is excited by sinusoidal signal with modulated frequency. The frequency depends on an amplitude of external controlling signal. The output signal is converted into DC value using integrated RMS/DC converter and digitalized by an A/D converter. Finally, the signal is demodulated using the reference signal and utilized for cracks recognition. It is significant, that using this method, one can achieve very high resolution in the frequency domain. The method is especially suitable for mobile defectoscopy systems. For both implementations, the authors analyzed a signal to noise ratio and a probability of crack detection under various conditions. In case of the first method the influence of the number of components in the exciting signal was analyzed. In the second method, different shapes and various frequencies of the modulating signal were utilized. Results of the measurements were then evaluated. All the experiments were carried out for planar conducting specimens with artificial flaws.

Development of a Pulsed Eddy Current System and Its Characterization

---**Changqing Lee** and Norio Nakagawa, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011; Marcus J. Johnson, Optomec Design Company, Inc., Saint Paul, MN

---The pulsed eddy current (PEC) technique has shown considerable promise as a new tool for the detection and characterization of buried corrosion and crack. Included among its attributes is the ability to sense deeply buried defects and obtain important information for use in defect characterization, a result that is enabled by the presence of multiple frequency components. In this paper, a design of the pulsed eddy current system will be presented, along with the data analysis toward system characterization. The PEC system comprises a computer with analog input and motion-control boards, a 2D scanning stage and additional electronic circuit modules for energizing and conditioning the pulsed eddy current signals. Data acquisition was implemented using a LabView program. The time-domain data analysis method is based on full waveform analysis (FWA) that extracts depth information from scanning data. Specifically, recent experiments along with the FWA on simulated fastener specimens with electrical-discharge machined (EDM) notches will be reported. We will also introduce a FWA-based procedure to determine the transfer function that converts measured waveforms to native sensor responses.---This material is based upon work supported by the Air Force Research Laboratory under Contract # FA8650-04-C-5228 at Iowa State University's Center for NDE.

Optimization of Neural Network Pattern Recognition Systems for Guided Wave Damage Identification in Beams

---Chin K. Liew and **Martin Veidt,** School of Engineering, The University of Queensland, Brisbane, Qld 4072, Australia

---Neural network pattern recognition is an advanced regression technique that can be applied to analyze guided wave response signals for quantifying damages in structures. Neural networks offer a wide range of customization options that can lead to the difficulty of selecting a design with optimal damage identification performance. In addition, large uncertainties in damage prediction generally exist, if simulated patterns are used to train the neural network for identifying real damage. This paper describes a procedure to optimize the design of a multi-layer perceptron backpropagation neural network for minimizing underfitting and overfitting in the training patterns for damage identification in beams using longitudinal guided waves. The performance of the optimized neural network is further improved using a weight-range selection technique to increase the sensitivity of the network to experimental patterns. This method yields more than 25% improvement in the prediction of the damage location and significantly reduces the uncertainties in the prediction of damage size and severity. Finally, the potential of using parallel networks for multiple-sensor configurations is illustrated.

Estimation of the Tool Condition by Applying the Wavelet Transform to Acoustic Emission Signals

--- Martín P. Gómez, Departmento de Ingeniería Electrónica, FRBA, Universidad Tecnológica Nacional, Buenos Aires, Argentina; Rosa Piotrkowski, Universidad Nacional de Gral. San Martín, San Martín, Buenos Aires, Argentina; José E. Ruzzante, UA ENDE, Centro Atómico Constituyentes, Comisión Nacional de Energía Atómica, San Martín, Buenos Aires, Argentina; Carlos E. D´Attellis, Universidad Favaloro, Buenos Aires, Argentina **(Poster presented by Pablo Katchadjian)**

---The aim of this work is to follow the search of parameters indicative of the tool condition in machining processes in order to predict undesirable consequences caused by tool wear or damage. In this case, acoustic emission is the sensing technique applied to a machining process of steel samples. The obtained signals are studied using the wavelet transformation. Steel samples were machined by turning, and the tool wear was quantified as a percentage and related with the acoustic emission signals. The signals were analyzed and correlated with different tool wear levels; a correlation between signals and wear percentage of the insert was found. Some typical behaviour was identified in some wavelet parameters of AE signals, such as amplitude and frequency. Concerning amplitude, an increase in the wave energy, reflected in the power calculated with wavelet coefficients, appeared at a particular wear percentage of the tool. This increase could be associated with a critical value predicting the critical tool damage. Moreover, in the wavelet frequency domain, a shift of the wave pattern to higher values was observed when the tool wear increased.

Fusion of Microwave and Eddy Current Data for a Multi-Modal Approach in Evaluating Corrosion under Paint and in Lap Joints

---Mohammad Tayeb Ahmad Ghasr, Sergey Kharkovsky, and Reza Zoughi, University of Missouri-Rolla, Applied Microwave Nondestructive Testing Laboratory (amntl), Rolla, MO 65409; **Kapil Gupta** and Ronald Joe Stanley, University of Missouri-Rolla, Electrical and Computer Engineering Department, Rolla, MO 65409; Ajay Padwal and Matt O'Keefe, University of Missouri-Rolla, Department of Material Science and Engineering, Rolla, MO 65409; Donald Palmer and Nancy Wood, The Boeing Company, Boeing Phantom Works, St. Louis, MO 63166; James Blackshire and Gary Steffes, Air Force Research Laboratory (AFRL), Wright Patterson, OH 45433

---Critical aircraft structures are susceptible to corrosion which may be hidden under paint and in lap joints. Find-it-and-fix-it approaches may be un-acceptable and inefficient in corrosion maintenance, repair and management. As an alternative, fusion of corrosion data from distinct nondestructive evaluation (NDE) modalities has been proposed. Microwave-based NDE methods have been very effective in detecting corrosion precursor pitting under paint and evaluating pit characteristics. Eddy current-based NDE methods can provide crucial information about the severity and depth of hidden corrosion. Fusion of these methods in a complementary fashion can be input to structural analysis models to obtain a comprehensive snapshot of the corrosion environment. Decisions on repair and maintenance will be based on the assessed residual structural integrity. Localized statistical analysis and data-driven fuzzy logic techniques will be shown for generating confidence maps highlighting corrosion regions from sample scans acquired using the individual NDE modalities. Data fusion from the individual NDE methods using neural network and fuzzy logic techniques will be presented for identifying and characterizing corrosion regions. The data fusion algorithm coupled with its implementation into the structural analysis model along with a complete discussion of the results as they relate to damage tolerance will also be presented.

Ultrasonic Detection Using Correlation Images

---**Raina Cepel** and Steven P. Neal, Mechanical and Aerospace Engineering, University of Missouri-Columbia, Columbia, MO, 65211; K. C. Ho, Electrical and Computer Engineering, University of Missouri-Columbia, Columbia, MO 65211; Lori Thombs, Department of Statistics, University of Missouri-Columbia, Columbia, MO, 65211; Brett A. Rinker, Honeywell Federal Manufacturing and Technology, Kansas City, MO, Donald D. Palmer, Jr., The Boeing Company, Phantom Works, St. Louis, MO,

---In ultrasonics, image formation and detection are generally based on signal amplitude. In this paper, we describe an amplitude independent approach for image formation and detection based on the similarity of adjacent signals. Signal similarity is quantified in terms of the correlation coefficient calculated between A-scans digitized at adjacent measurement positions. Correlation coefficient images are introduced for visualizing the similarity in measured A-scans. In backscatter, the approach reveals defect signals buried in noise by showing regions of increased correlation. In pitch-catch or thru-transmission, the approach reveals defects by showing regions of decreased correlation due to signal distortion caused by interaction of the beam field with the defect. Correlation coefficient and C-scan images are shown to demonstrate flat-bottom-hole detection in a stainless steel annular ring and crack detection in an aluminum aircraft structure. Simulated data are used to show the detection of planar defects at very low signal-to-noise ratio. Using ROC analysis, performance of the correlation approach is compared to the performance of classical gated peak detection and matched filtering.

Information Theory Based Registration of Industrial Radiographs

---**Korukonda Sanghamithra** and Ramaswamy Sivaramanivas, NDE Imaging Lab, GE Global Research, GE India Technology Centre, JFWTC, EPIP, Whitefield Road, Bangalore – 560066, India

---A majority of industrial inspections in automotive industry is based on radiography, for example inspection of castings like aluminum alloy wheels. Image registration is a fundamental task in the automated analysis of radiographs. Traditional image registration involves either correlation-based techniques that are not statistically robust or comparisons between low-level and high-level image features in the time or frequency domain or both. In this paper we have presented registration studies based on information theory. Mutual Information or MI is a measure of similarity or dissimilarity between two or more sets of data. It is calculated using the joint and marginal entropies of the different data sets. Greater the MI of two images greater is the alignment of the images. Consequently, image registration becomes a problem of maximizing the MI metric. As MI is a probability density based measure it is statistically robust and is immune to shape and size of the part being inspected. Results are presented comparing MI based registration with the traditional Fourier-Mellin registration technique for aluminum alloy castings. The performance of the two techniques for various levels of Poisson-distributed noise is presented.

Comparison of Dry and Wet Developer Processes for FPI

---**Lisa Brasche**, Bill Meeker, Rick Lopez, and Dave Eisenmann, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

---FPI is a widely used inspection process, particularly in industries such as aerospace where the parts are geometrically complex and require full field inspection. A critical step in the FPI process is the application of the developer which has as it's function the acceleration of bleed out of the penetrant and the enhancement of the contract of the indications. In most applications, dry powder developer (Form A) is used typically in automated systems that include dust storm or cloud chambers or spray wands. There are also wet aqueous developers that are either water soluble (Form B) or water suspendible (Form C) which see less frequent use in the aviation industry. Nonaqueous wet developers, (NAWD - Form D)usually applied via aerosol cans, see wide spread use, particularly at the evaluation stage. All four developers types are being evaluated to determine the effect of process parameters on indication brightness. Low cycle fatigue cracks are being used to evaluate the change in brightness as a function of application method, concentration, and other relevant parameters. Results to date will be presented.--- This material is based upon work supported by the Federal Aviation Administration under Contract #DTFA03-98-D-00008, Delivery Order # 0016 and performed at Iowa State University's Center for NDE as part of the Center for Aviation Systems Reliability program. ISU staff are working in cooperation with industry partners that include Boeing Commercial, Boeing Phantom Works, Delta Airlines, United Airlines, Rolls Royce, Pratt & Whitney, General Electric, Honeywell, Sherwin Inc. and D&W Enterprises.

Summary of Emulsification Processes for FPI

---**Lisa Brasche**, Bill Meeker, Rick Lopez and Dave Eisenmann, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

---Emulsification is one of many critical steps in the flourescent penetrant inspection process. For most aerospace applications, hydrophilic emulsifiers are used to remove the excess penetrant from the component. Questions have arisen regarding the concentration of the emulsifier, the use of agitation, the effect of contact time, and application method (immersion vs. spray). A parametric study is underway looking at these variables for three representative emulsifiers. A summary of progress to date will be provided.---This material is based upon work supported by the Federal Aviation Administration under Contract #DTFA03-98-D-00008, Delivery Order # 0016 and performed at Iowa State University's Center for NDE as part of the Center for Aviation Systems Reliability program. ISU staff are working in cooperation with industry partners that include Boeing Commercial, Boeing Phantom Works, Delta Airlines, United Airlines, Rolls Royce, Pratt & Whitney, General Electric, Honeywell, Sherwin Inc. and D&W Enterprises.

Session 12

SESSION 12
X-RAY AND CT NDE
Pavilion East

3:30 PM **Recent Developments in Deterministic Radiography Simulations**
---**F. Inanc**, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

3:50 PM **Evaluation of X-Ray Spectrum Models for Industrial Radiography Applications**
---R. Chatanathody, V. Vedula, and **M. Venugopal**, John F. Welch Technology Centre, GE Global Research Centre, Bangalore, India

4:10 PM **Fractal Analysis of Weld Defect Patterns Obtained by Radiographic Tests**
---J. A. Tesser and R. T. Lopes, Department of Nuclear Engineering, Federal University of Rio de Janeiro, Rio de Janeiro, RJ, Brazil; A. P. Vieira and **L. L. Goncalves**, Department of Metallurgical and Materials Engineering, Federal University of Ceara, Fortaleza, CE, Brazil; J. M. A. Rebello, Department of Metallurgical and Materials Engineering, Federal University of Rio de Janeiro, Rio de Janeiro, RJ, Brazil

4:30 PM **Quantitative Measurements of X-Ray Scattering in Industrial Application from 20 keV to 320 keV**
---S. Wendt, **J. Gray**, and F. Inanc, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

4:50 PM **Beam Hardening Corrections in Quantitative Computed Tomography**
---V. Vedula, **M. Venugopal**, C. Raghu, and P. Pandey, John F. Welch Technology Centre, GE Global Research Centre, Bangalore, India

5:10 PM **Performance Characterization of Computed Radiography for Inspection of High-Pressure Boiler Components**
---**M. Venugopal**, R. Venkatachalam, M. Navalgund, C. Raghu, T. Prasad, and P. Pandey, John F. Welch Technology Centre, GE Global Research Centre, Bangalore, India

Recent Developments in Deterministic Radiography Simulations

---**Feyzi Inanc**, Iowa State University, Center for Nondestructive Evaluation, 1915 Scholl Road, Ames, IA 50011

---As it happened for some other NDE methods, the simulation studies for the radiography have become a distinct discipline as well. Since radiation transport plays an important role in the radiography, the simulation studies implement two major radiation transport approaches, namely deterministic transport equation based approach and Monte Carlo approach. Those two approaches are fundamentally different than each other. In this study, we will discuss two new features implemented with our integral transport equation based deterministic simulations algorithms. In contrast with the Monte Carlo approach, the deterministic methods provide the solution for the whole spatial domain regardless of where the solution needs to be known. Since the radiation detector is external to the domain where the radiation transport equation is solved, what we are interested is the boundary flux values. This provides a mean to perform a single radiation transport calculation and then compute the detector response for any given position without performing any other radiation transport calculations. In this presentation, we will discuss how this is possible and advantages of such an approach. The other issue is the type of the algorithm used to compute the flux incident upon the detector point. In our previous algorithms, we used sampling methods to compute the flux. In one of new approaches, we make use of all data points on the object boundary and compare two approaches. We will discuss if any of those approaches have any advantages over the other approach.--- This work has been performed at CNDE with support from NDE Technologies.

Evaluation of X-Ray Spectrum Models for Industrial Radiography Applications

---Raghu Chatanathody, Venumadhav Vedula, and **Manoharan Venugopal,** John F. Welch Technology Centre, GE Global Research Centre, Bangalore, India

---Physics modeling of radiographic imaging chain has been widely used for the design of novel detector systems, quantification of dose deposition in detectors, x-ray technique planning & optimization, beam-hardening correction and probability of detection studies. X-ray spectrum generation is one of the components of radiographic imaging chain, which determines the accuracy of simulation. Different mathematical models like "Birch and Marshall", "Ellery Storm", and "TASMIP model" have been explored in the present work. The simulation results from these models were validated using experimental measurements and various spectral properties available from the literature. Spectral properties like shape, average energy, half value layer, and photon Fluence per Roentgen were used as quantitative metrics. Exposure rate measurements were compared with simulation results for various industrial x-ray tubes with target angles of 20° and 45°.

Fractal Analysis of Weld Defect Patterns Obtained by Radiographic Tests

---Juliano A. Tesser and Ricardo T. Lopes, Department of Nuclear Engineering, Federal University of Rio de Janeiro, Rio de Janeiro, RJ, Brazil; Andre P. Vieira and **Lindberg L. Goncalves**, Department of Metallurgical and Materials Engineering, Federal University of Ceara, Fortaleza, CE, Brazil; João Marcos A. Rebello, Department of Metallurgical and Materials Engineering, Federal University of Rio de Janeiro, Rio de Janeiro, RJ, Brazil

---In this paper it is presented a fractal analysis of radiographic patterns obtained in specimens with the following inserted welding defects: lack of fusion, incomplete penetration and porosity. The fractal characterization of the surface constructed from radiographc images has been determined by means of minimal cover analysis and boxcounting analysis. In the study were analized patterns of carbon steel beads from radiographs of the International Institute of Welding (IIW). The digitalized patterns, where a gray scale with 256 levels has been considered, have been processed by using the program Image Pro Plus 4.0 and, in order to improve the contrasts, a median type filter was used to smooth unpredicted noise. In the numerical analysis carried out, two regions in the images of the weld bead have been considered, namely, the inner region and a limit one which included the base metal. From the results obtained it can be concluded that the fractal analysis can be an effective additional tool in the pattern recognition of weld defects detected in radiographic tests. Work partially financed by the Brazilian agencies CNPq, FINEP(CT-Petro) and Capes.

Quantitative Measurements of X-Ray Scattering in Industrial Application from 20 keV to 320 keV

---S. Wendt, **J. Gray**, and F. Inanc, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

---Effects of X-ray scattering processes are well known in radiography and other x-ray methods; however, there are a considerable number of parameters that complicate the practical description of scattered radiation. While the well known Compton scattering formula is widely referenced, it doesn't lend itself to providing insight to the generation of a typical scattering field seen in an inspection chamber. We present recent results on x-ray scattering measurements in the energy range from 20 keV through 320 keV. A key result is that scattering is controlled by four separate parameters, the volume of the material illuminated, the distance of the detector from the scatter sources, the x-ray optical length of the material and the shape of the part. It is important to note that the methodology used to measure the scattering contribution to a detector signal is very important. Quantitative measurements illustrating the result of the effects of these parameters will be presented. Of particular note is the result that at high energies the scattering can be 4-6 times that intensity of the direct flux. This has a profound impact on the loss of contrast of features in the image. We have also measured scattering spectra and can show that the energy of the scattered radiation is only marginally shifted to lower energies. This has bearing on the effectiveness of lead screens reducing scatter and having the result of better image contrast. We also will present a comparison of experimental scattering measurements to a recently developed x-ray scattering model and show excellent agreement of a wide range of scattering conditions.---This work was supported by the NSF Industry/University Cooperative Research program.

Beam Hardening Corrections In Quantitative Computed Tomography

---Venumadhav Vedula, **Manoharan Venugopal**, C. Raghu, and Pramod Pandey, John F. Welch Technology Centre, GE Global Research Centre, Bangalore, India

---Volumetric computed tomography (VCT) is the emerging 3D NDE inspection technique that gives highest throughput and better image quality. Industrial components in general demands higher x-ray energy for inspection for which polychromatic x-ray sources are used in common. Polychromatic nature of the x-rays gives rise to non-linear effects in the VCT projection data measurements called to be the beam hardening (BH) effects. BH produces prominent artifacts in the reconstructed images thereby deteriorating the image quality. Quantitative analysis such as density quantification, dimensional analysis etc., becomes difficult with the presence of these artifacts. This paper describes the BH correction using preprocessing technique for the homogeneous materials. Selection of effective energy at which the monoenergetic linear attenuation coefficient of a particular material equals to that of the polyenergetic beam is critical for BH correction. Various methods to determine the effective energy and their consequence in the quantitative measurements have been investigated in the present study. In this paper, BH corrections for hetero

Performance Characterization of Computed Radiography for Inspection of High-Pressure Boiler Components

---**Manoharan Venugopal**, Rajashekar Venkatachalam, Megha Navalgund, C. Raghu, Thapa Prasad, and Pramod Pandey, John F. Welch Technology Centre, GE Global Research Centre, Bangalore, India

---Heavy engineering industries that manufacture high-pressure boilers, are exploring suitability of Computed Radiography (CR) for testing weld integrity of thick walled components. Currently conventional film based radiography is carried out using Cobalt-60 or linear accelerator x-ray sources. CR is preferred because of lesser exposure and processing time as compared to film based radiography. It is also easy to archive digital images over many years, which is mandatory as per standards. This paper presents the quantitative metrics used for evaluating performance of CR and comparative study of CR with various film classification systems. CR images of weld specimens with defects like lack of fusion; penetration, cracks, concavity, and porosities were studied for evaluating radiographic sensitivity and imaging performance of the system. The minimum detectability of various defects was quantified using specimens with known defects.

Session 13

SESSION 13
NDE FOR CIVIL MATERIALS
Broadway I

3:30 PM **Dielectric Detection of Knots in Green Red Oak and Southern Pine Lumber**
---**J. E. Cooper**, P. H. Steele, and B. Mitchell, Department of Forest Products, Forest and Wildlife Research Center, Mississippi State University, Mississippi State, MS 39759

3:50 PM **Differentiating Curly Birch from Silver Birch by Ultrasound**
---**A. Salmi**[1], T. Hintikka[1], and E. Haeggstrom[2], University of Helsinki, [1]Department of Physical Sciences, [2]Helsinki Institute of Physics, Kustaa Hallstromin katu 2 PB 64, FIN-00014 Helsinki, Finland

4:10 PM **Defect Detection in Wooden Logs Using Ground Penetrating Radar**
---**U. B. Halabe** and S. Agrawal, Department of Civil and Environmental Engineering, West Virginia University, Morgantown, WV 26506-6103; B. Gopalakrishnan, Department of Industrial and Management Systems Engineering, West Virginia University, Morgantown, WV 26506-6107; S. Grushecky, Appalachian Hardwood Center, Division of Forestry, West Virginia University, Morgantown, WV 26506

4:30 PM **Laboratory Determination of Phreatic Surface During Seepage Through Soils Using Ground Penetrating Radar**
---**H. J. Siriwardane**, U. B. Halabe, R. Kiriakidis, and S. Pyakurel, West Virginia University, Constructed Facilities Center, Department of Civil and Environmental Engineering, P. O. Box 6103, Morgantown, WV 26506-6103

4:50 PM **Elastic Wave Propagation in Complex Systems: The Interaction of Waves with Inhomogeneities in Ultrasonic and Impact Echo Testing Studied by Modelling and by Scanning Laser Vibrometry**
---**B. Koehler**, F. Schubert, and L. Haupt, Fraunhofer IZFP-D, Kruegerstrasse 20, 01326 Dresden, Germany

Dielectric Detection of Knots in Green Red Oak and Southern Pine Lumber

---**Jerome E. Cooper**, Philip H. Steele, and Brian Mitchell, Department of Forest Products, Forest and Wildlife Research Center, Mississippi State University, Mississippi State, MS 39759

---Forest products industry automation requires accurate detection of knots in lumber. Optical detection by digital cameras has proven to be difficult even for wood from species with light clear wood and dark knots. All vision systems for accurate knot detection in lumber currently rely on detection systems such as ultrasound, x- or gamma-ray, laser or dielectric to supplement camera system information. A radio frequency system has been patented and commercialized that relies on signal attenuation to detect knots in green softwood lumber. Signal attenuation has proven less reliable for hardwood species and for application to green lumber where moisture content may range from 60 to 150 percent (dry basis). This paper reports on detection of knots in southern yellow pine and red oak lumber in the green state with a system that utilizes phase shift to supplement attenuation data. Phase shift was found to be considerably more reliable than signal attenuation for knot detection in green lumber.

Differentiating Curly Birch from Silver Birch by Ultrasound

---**Ari Salmi**[1], Tuomas Hintikka[1], and Edward Haeggström[2], University of Helsinki, [1]Department of Physical Sciences, [2]Helsinki Institute of Physics, Kustaa Hällströmin katu 2 PB 64, FIN-00014 Helsinki, Finland

---Curly birch (CB, Betula pendula var. carelica) commands a 10x higher price than silver birch. Thus it is crucial to differentiate between the two types at early as possible. We studied the possibility to use ultrasound for this differentiation. The velocity of 4 MHz longitudinal (bandwidths TX: 7.7±0.8 -1.4±0.2 MHz, -3 dB, RX: 3.1±0.4 -4.9±0.5 MHz, -3dB) ultrasonic 5 cycle burst transmitted through block samples with a cross-section of 20x20 mm comprising both curly and noncurly birch was determined. The samples originated from southern Finland and were sawn in both longitudinal and radial directions. One sample set consisted of several different sample thicknesses ranging from 2 mm to 12 mm. From time-of-flight measurements (TOF) through the samples the wave velocity under laboratory conditions (RH = 50%, T = 23°C) was determined from a least-squares-fit. The results indicate a significant difference (t-test 3.2%, velocity difference 24%) in longitudinal direction and a highly significant difference (t-test 0.1%, velocity difference 22%) in the radial direction. A probability of detection (POD) test was conducted using 50 samples originating from both different trunks and from one single trunk from curly and noncurly sections. The results indicate that ultrasound might be useful for differentiation of curly and noncurly birch in young standing specimens.

Defect Detection in Wooden Logs Using Ground Penetrating Radar

---**Udaya B. Halabe** and Sachin Agrawal, Department of Civil and Environmental Engineering, West Virginia University, Morgantown, WV 26506-6103; Bhaskaran Gopalakrishnan, Department of Industrial and Management Systems Engineering, West Virginia University, Morgantown, WV 26506-6107; Shawn Grushecky, Appalachian Hardwood Center, Division of Forestry, West Virginia University, Morgantown, WV 26506

---Presently there are no suitable non-invasive methods for precisely detecting the subsurface defects in logs in real time. Internal defects such as knots, decays, and embedded metals are of greatest concern for lumber production. Nondestructive scanning of logs using Ground Penetrating Radar (GPR) to detect defects in logs prior to sawing can greatly increase the productivity and yield of high value lumber, and prevent damage to saw blade from embedded metals. In this research, the GPR scanned data has been analyzed to detect subsurface defects such as metals, decays, and knots. Also, GPR offers high speed scanning capability which is needed for future on-line implementation in saw mills. This paper explains the advantages of the GPR technique, experimental setup and parameters used, and data processing for detection of subsurface defects in logs. The results show that GPR can be a very promising technique for future on-line implementation in saw mills.

Laboratory Determination of Phreatic Surface During Seepage Through Soils Using Ground Penetrating Radar

---**Hema J. Siriwardane**, Udaya B. Halabe, Ricardo Kiriakidis, and Sandeep Pyakurel, West Virginia University, Constructed Facilities Center, Department of Civil and Environmental Engineering, P. O. Box 6103, Morgantown, WV 26506-6103

---Ground penetrating radar (GPR) was used to detect the water level in a silty soil sample during seepage under transient conditions in the laboratory. The soil sample has dimensions of 30 cm x 25 cm x 120 cm. The soil chamber was made up of Plexiglass materials to avoid radar interference and to be able to make visual observations of the water level in the soil sample. The soil used in the experiment is silty sand. Two antennas with frequencies of 900 MHz and 1,500 MHz were used in the study. The soil sample was dry at the beginning of the experiment. The water level at one end of the soil sample was raised to a pre-determined level and radar readings were taken along the length of the sample at different times over 30 hours. The water level was also determined by using piezometers installed along the length of the sample. Aluminum foil was placed at the bottom of the soil chamber to get a clear reflection of radar signals. At the end of the experiment, the variation of moisture content with depth of the sample was determined at different locations along the length of the sample. The GPR observations were compared with measured piezometric readings in the soil sample along the length. This study includes an investigation on the transient effects of seepage on GPR measurements.

Elastic Wave Propagation in Complex Systems: The Interaction of Waves with Inhomogeneities in Ultrasonic and Impact Echo Testing Studied by Modelling and by Scanning Laser Vibrometry

---**Bernd Koehler**, Frank Schubert, and Lothar Haupt, Fraunhofer IZFP-D, Kruegerstrasse 20, 01326 Dresden, Germany

---The propagation of elastic waves in solids and their interaction with inhomogeneities like flaws can be studied by numerical modelling. For that, precise material parameters (elastic constants, density), parameters of the component geometry and of the flaw geometry are necessary. There are a lot of situations where these parameters are not known and cannot be gained easily. Especially challenging is the situation when interface conditions are not known precisely concerning to their elastic behavior. Usually, interfaces play a significant role with respect to wave propagation, especially imperfect ones. That is the case for concrete with its numerous interfaces between cement matrix and aggregates and with a complex situation when additional inclusions like tendon ducts or steel bars are present. Here - in parallel with modelling - detailed experimental study of the wave propagation can be very helpful to clarify the influence of the interfaces on wave propagation. For that reason an experimental technique to visualize the propagation of elastic waves was applied to concrete in previous papers. But several questions still remained open. The present paper studies the wave propagation for the case of a tendon duct embedded in concrete both experimentally and by numerical simulation. A direct comparison of measured and calculated wave fields leads to a better interpretation of the signals. Conclusions are drawn and possible future work is indicated.

Session 14

SESSION 14
NDE FOR MANUFACTURING AND PROCESS CONTROL
Pavilion West

3:30 PM **On-Line Monitoring of Turning and Tool Wear of a Metal Matrix Composite by Acoustic Emission Technique**
---C. K. Mukhopadhyay, **T. Jayakumar**, S. Venugopal, R. Nagarajan, S. L. Mannan, and B. Raj, Indira Gandhi Centre for Atomic Research, Nondestructive Evaluation Division, Kalpakkam, Tamil Nadu 603102 India

3:50 PM **Numerical Simulation of Ultrasound Wave Propagation in Non-Stationary Fluids**
---**M. K. KM**, S. Jeyaraman, and B. Ganesan, GE Global Research, Bangalore, Karnataka, India 560066; T. J. Batzinger, GE Global Research, Nishkayuna, NY 12309; S. Ao and J. Tilden, GE Infrastructure (Sensing), Billerica, MA 01821

4:10 PM **Ultrasonic Inspection of Energetic Materials**
---**W. N. Cobb**, University of Denver, Denver Research Institute, 2050 E. Iliff Avenue, Denver, CO 80208; B. Reddingius, U. S. Army ARDEC, Picatinny Arsenal, NJ 07806

4:30 PM **Developing Nondestructive Imaging Methods for Automotive Weld Bonded Structures**
---**C. J. Dasch**, General Motors Research & Development, MC 480-106-224, 30500 Mound Road, Warren, MI 48090

4:50 PM **Nondestructive Inspection of Large Scale Engineering Structures During the Manufacturing Process**
---**B. Bridge**, Faculty of Engineering, Science and the Built Environment, London South Bank University, London, United Kingdom

On-Line Monitoring of Turning and Tool Wear of a Metal Matrix Composite by Acoustic Emission Technique

---Chandan Kumar Mukhopadhyay, **Tammana Jayakumar**, Srinivasan Venugopal, Ramasamy Nagarajan, Sardari Lal Mannan, and Baldev Raj, Indira Gandhi Centre for Atomic Research, Non Destructive Evaluation Division, Kalpakkam, Tamil Nadu 603102, India

---Acoustic emission technique (AET) has been used for on-line monitoring of turning and associated tool wear for a silicon carbide dispersed Al-alloy metal matrix composite with 20 wt.% silicon carbide. The results have shown that increasing cutting speed increases acoustic emission (AE) generation, and increasing the temperature of cutting decreases AE generation. With increasing the speed from 110 rpm to 600 rpm at ambient temperature (298 K), peak amplitude of AE hits increased from 64 to 85 dB. However, during turning at elevated temperatures, AE hits of relatively lower peak amplitude (up to 68 dB) were generated. AE results from tool wear monitoring indicated that AE increases abruptly beyond a specific cutting distance and this is attributed to the wear of the tool. For the first time, a correlation between slope (b-parameter) of the cumulative amplitude distribution plot of the AE hits and flank wear of the cutting tool has been observed. The distribution plot shows a two stage behavior and the transition to the second stage occurs at a flank wear value of 0.45 mm. The tool insert can then be removed / replaced in order to avoid the occurrence of accelerated wear and/or catastrophic failure of the tool. This would also ensure to obtain quality surfaces with consistency and reliability.

Numerical Simulation of Ultrasound Wave Propagation in Non-Stationary Fluids

---**M. K. KM**, Satheesh Jeyaraman, and Baskaran Ganesan, GE-Global Research, Bangalore, Karnataka, India-560066; Thomas J. Batzinger, GE-Global Research, Niskayuna, NY 12309; Shirlely Ao and Jeffrey Tilden, GE-Infrastructure (Sensing), Billerica, MA 01821

---Ultrasonic forms an important tool in industrial health and process monitoring. In general, ultrasonic wave propagation studies are carried out in a stationary medium. But in certain scenarios like medical application it is essential to understand ultrasound path in a non-stationary medium. In this paper, we investigate the influence of a moving medium on the propagation of ultrasound through a finite element implementation. The coupled equation involving the velocity of the medium is solved using a weak formulation. Results for the beam drift due to the moving medium for both normal and angular incidence of the wave are presented for varying frequencies and different fluids.

Ultrasonic Inspection of Energetic Materials
---**Wes N. Cobb**, University of Denver, Denver Research Institute, 2050 E. Iliff Avenue, Denver, CO 80208; Brett Reddingius, U.S. Army ARDEC, Picatinny Arsenal, NJ 07806

---This talk will summarize recent efforts to characterize energetic materials during manufacture. Our goal is to monitor key material properties that affect the ultimate performance and safety of ordnance and munitions filled with energetic materials. In addition, we hope to reduce manufacturing costs by assuring quality at an early stage in the process. Our approach is to apply well-known ultrasonic techniques to specific energetic applications, while continuing to develop new test capabilities. Initial applications of ultrasound have been performed on two energetics processing applications. First, we have developed probes to measure the composition of TNT and plastic-bonded explosives during batch processing in a mixing kettle. The probe contacts the mix, but the sensors are isolated from the explosive. These probes are currently used to monitor the solids concentration and particle size of explosive compositions. The second application involves the inspection and materials characterization of extruded propellant grains for small rocket motors. A set of non-intrusive ultrasonic sensors measures defects and composition changes as the propellant is extruded from a die. Early detection of defects allows propellant to be recycled and avoids the additional costs of further processing. These two applications will be discussed in the presentation, and performance data presented.

Developing Nondestructive Imaging Methods for Automotive Weld Bonded Structures
---**Cameron J. Dasch**, General Motors Research & Development, MC 480-106-224, 30500 Mound Road, Warren, MI 48090

---As adhesive bonded body structures are implemented for crash performance and for joining dissimilar metals, nondestructive inspection of the adhesive joint becomes critical. Ultrasonic and pulsed thermography imaging offer special promise for on-line inspections. In this work ultrasonic through-transmission and pulse/echo methods as well as pulsed thermography are applied to automotive weld-bonded samples. These nondestructive results are then compared with quantitative peel tests of the samples. The results show that the nondestructive measurements of adhesive area, location, and thickness match the peeled surfaces and the variation of peel force along the joint.

Nondestructive Inspection of Large Scale Engineering Structures during the Manufacturing Process

---**Bryan Bridge**, Faculty of Engineering, Science and the Built Environment, London South Bank University, London, United Kingdom

---The end point of this paper is to take the world of modern fast and flexible manufacturing, presently confined to the shop floor into the manufacture of large scale structures such as ships, box girder bridges and petroleum storage tanks where traditional welding practices still prevail. A team of climbing cooperating robots under the intelligent control of a Smart Central Task Manager carry the requisite payload of work tools and constitute the mobile manufacturing cell. Distribution of the working payload over several robots allows robot sizes to be miniaturized thus permitting the cell to function on highly curved surfaces and surfaces containing obstructions. Of the multiple technical challenges involve this account focuses on the tools for real time inspection of the hot weld pool and solidified weldment and the feedback of this data to adjust the weld process parameters rapidly enough to minimize manufacturing defects and permit the repair of weld defects in the manufacturing stage, thus reducing the need for subsequent inspection and correspondingly minimizing overall manufacturing costs. The same cell serves to both minimize life cycle service costs and extend design life, through the Central Task Manager using on-line NDT data to immediately authorize weld repairs in the correct locations, eliminating the need for subsequent visits to remote sites.

Session 15

SESSION 15
BENCHMARK NDE PROBLEMS
Broadway II

3:30 PM **Results of 2006 UT Modeling Benchmark Obtained with CIVA at CEA: Beam Modeling and Flaw Signal Prediction**
---**M. Cinquin**, S. Lonné, and L. Le Ber, Commissariat à l'Énergie Atomique, SYSSC, CEA Saclay, 91191 Gif-sur-Yvette, Cedex, France

3:50 PM **The 2006 Ultrasonic Benchmark Problem – FDTD Simulations in 2D**
---**C. V. Krishnamurthy**, C. Sridharan, and K. Balasubramaniam, Centre for Nondestructive Evaluation, Department of Mechanical Engineering, Indian Institute of Technology, Madras, Chennai, Tamil Nadu India

4:10 PM **Simulating the Ultrasonic Experiments of the 2006 Ultrasonic Benchmark Problem**
---**M. S. Garton**, T. A. Gray, and L. W. Schmerr, Jr.*, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011; *Department of Aerospace Engineering

4:30 PM **Model Prediction Results for 2006 Ultrasonic Benchmark Problems**
---**H.-J. Kim** and S.-J. Song, Sungkyunkwan University, School of Mechanical Engineering, Suwon, Korea

Results of 2006 UT Modeling Benchmark Obtained with CIVA at CEA: Beam Modeling and Flaw Signal Prediction

---**M. Cinquin**, S. Lonné, and L. Le Ber, Commissariat à l'Énergie Atomique, SYSSC, CEA Saclay, 91191 Gif-sur-Yvette Cedex, France

---The main topic of the 2006 Ultrasonic benchmark is to compare experimental data proposed by the French Atomic Energy Commission (CEA) with results provided by simulation. The experimental setup chosen for this benchmark involves pulse-echo responses on planar surface breaking defects using either a 45° refracted P- or S-wave contact transducer. The reference amplitude is taken on a side drilled hole. The interest of this benchmark is to evaluate the influence of a varying slope of the backwall on the corner trap detection. CEA is using the CIVA software developed for processing and simulating NDT data. CIVA simulation tools include beam propagation and defect scattering models based on semi-analytical kernels, thus the whole inspection performances may be predicted for a wide range of applications. Results given and discussed are those obtained for the various problems of this 2006 UT Benchmark modeling session. This paper presents the comparison between experimental and simulated results which concern the echo-graphic responses of rectangular defects at different variations of the backwall slope of the block.

The 2006 Ultrasonic Benchmark Problem - FDTD Simulations in 2D

---**Chitti Venkata Krishnamurthy**, C. Sridharan, and Krishnan Balasubramanian, Centre for Nondestructive Evaluation, Department of Mechanical Engineering, Indian Institute of Technology, Madras, Chennai, Tamil Nadu, India

---The 2006 ultrasonic benchmark problem involves pulse-echo angle beam scanning of rectangular shaped surface-breaking defects where the defect is located on an inclined planar back surface. The response from a side-drilled hole is to be used as a reference. The models are to simulate (a) the peak-to-peak B-scan P- and SV- responses of the slots normalized by the appropriate SDH response and (b) the maximum peak-to-peak corner response of the slots (either mode-converted or not). At CNDE, several simulation tools are being developed to assess/predict UT response for various geometries. The Finite-Difference-Time-Difference (FDTD) scheme is one such simulation tool that has been under development in 1D, 2D and 3D. The FDTD is an explicit time domain tool that can simulate pulse propagation characteristics in acoustic/elastic media. The computational domain is limited by implementing Perfectly Matched Layers (PMLs) at the domain boundaries. We present the results of calculations based on 2D FDTD to determine the response of rectangular shaped surface-breaking defects located on an inclined planar back surface. Comparisons will be made between predictions and measurements made available for the pulse-echo response.

Simulating the Ultrasonic Experiments of the 2006 Ultrasonic Benchmark Problem

---**Michael S. Garton**[1], Timothy A. Gray[1], Lester W. Schmerr, Jr.[1,2], [1]Center for NDE and the [2]Department of Aerospace Engineering, Iowa State University, Ames, IA 50011

---A set of experiments involving ultrasonic angle beam inspections of surface-breaking crack-like geometries on an inclined surface forms the basis for the 2006 ultrasonic benchmark study. We will model the measured A-scan and B-scan responses of these experiments using a combination of beam and flaw scattering models coupled to an overall ultrasonic measurement model. We will compare the capabilities of these models for predicting the measured responses and the underlying incident and scattered wave fields.---
This work was supported by the NSF Industry/University Cooperative Research Center at Iowa State University.

Model Prediction Results for 2006 Ultrasonic Benchmark Problems

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

---The World Federation of NDE Centers (WFNDEC) has addressed the 2006 ultrasonic benchmark problems including a linear scanning of the side drilled hole (SDH) specimen and rectangular defects on 0 to 20 slope bottom specimens. The experimental signals were provided by CEA. To solve the given problems, multi-Gaussian beam models for calculation of reflected beam fields from the rectangular defects radiated from a circular planar transducer and a rectangular transducer, and 2-D ray method to calculate diffracted beam field from the edge of the rectangular defects will be adopted. The hierarchical triangular meshing (HTM) method based on the Kirchhoff approximation will be also used for calculation of far-field scattering amplitudes from the rectangular defects for the comparison of calculation results to predicted signals by multi-Gaussian beams and 2-D ray method. By integration the models, we will predict the responses of the rectangular defects and normalize the predicted signal by SDH responses. In this presentation, model prediction results and comparison results to the experiments well be presented.

WEDNESDAY

Session 16

SESSION 16
UT SCATTERING AND PROPAGATION
Broadway I

8:30 AM **Simulation of Guided Wave Inspection Based on the Reciprocity Principle and the Semi-Analytical Finite Element Method**
---**K. Jezzine** and A. Lhémery, Commissariat à l'Énergie Atomique, Laboratoire Simulation et Modèlisation, CEA-Saclay, bât. 611, 191 Gif-sur-Yvette Cedex, France

8:50 AM **Experimental and Finite Element Study of Guided Ultrasonic Wave Scattering at Structural Features in a Plate**
---**P. Fromme**, Department of Mechanical Engineering, University College London, London, United Kingdom

9:10 AM **Prediction and Direct Measurement of Scattered Plate Wave Fields Using S0 to A0 Mode Conversion at Nonsymmetric Circular Inhomogeneities**
---F. B. Cegla and **M. Veidt**, School of Engineering, The University of Queensland, Brisbane, Qld 4072, Australia

9:30 AM **2D P-SV Wave Scattering by a Crack in a Cladding**
---**P.-A. Jansson** and T. Zagbai, Department of Applied Mechanics, Chalmers University of Technology, Goteborg, Sweden

9:50 AM **Application of Fast Multipole Boundary Element Method to Multiple Scattering Analysis of Acoustic and Elastic Waves**
---**T. Saitoh** and T. Fukui, Course of Nuclear Power and Safety Engineering, Fukui University, Bunkyo 3-9-1, Fukui-shi, Fukui, Japan; S. Hirose, Department of Mechanical and Environmental Informatics, Tokyo Institute of Technology, O-okayama 2-12-1-W8-22, Meguro-ku, Tokyo, Japan

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

10:30 AM **Locating the Crack-Front of a Vertical Surface-Breaking Planar Crack**
---J.-W. Liaw, Department of Mechanical Engineering, Chang Gung University, Tao-Yuan, Taiwan 333; **M.-K. Kuo**, Institute of Applied Mechanics, National Taiwan University, Taipei, Taiwan 106

10:50 AM **Phased Array Ultrasonic Testing Model to Predict Signals from a Side-Drilled Hole in an Immersion Setup**
---**H.-J. Kim** and S.-J. Song, Sungkyunkwan University, School of Mechanical Engineering, Suwon, Korea; T. A. Gray, L. W. Schmerr*, and R. B. Thompson, Iowa State University, Center for NDE, *Department of Aerospace Engineering, Ames, IA 50011

11:10 AM **Plate Wave Transmission/Reflection of Integral Stiffeners: Model Study and Experiment**
---**R. A. Roberts** and D. E. Chimenti, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

11:30 AM **Transmission Matching for Joining Two Acoustical Waveguides**
---X. Wang, **M. J. Guers**, and B. R. Tittmann, The Pennsylvania State University, Department of Engineering Science & Mechanics, 212 Earth Engineering Sciences Building, University Park, PA 16802-6812

11:50 AM ***Lunch***

Simulation of Guided Wave Inspection Based on the Reciprocity Principle and the Semi-Analytical Finite Element Method

---**Karim Jezzine** and Alain Lhémery, Commissariat à l'Énergie Atomique, Laboratoire Simulation et Modèlisation, CEA-Saclay, bât. 611, 91 191 Gif-sur-Yvette Cedex, France

---A model is developed to simulate guided waves (GW) inspections. It is derived from the reciprocity principle and predicts the signal received by a receiver after radiation of GWs by an emitter and their scattering by a defect. Radiation, scattering and reception of GWs are solved as independent problems. First, the modal solution in a guide of arbitrary section is determined using the semi-analytical finite element method. Absorbing layers are introduced to deal with guides embedded in a medium in which GWs leak energy and therefore attenuate. Radiation and reception by transducers acting at the guide section are modeled as boundary conditions resulting in a system involving first computed modal solution. Time-dependent solution of transducer diffraction effects is obtained by Fourier synthesis. The modal solution is reused to compute the GW scattering by a defect assumed to lie in a cross section of the guide. New boundary conditions are introduced (depending on whether the defect occupies the whole section or part of it) leading to the resolution of a new system. Reflection and transmission coefficients (of one mode into another) can be deduced from this system. Comparison of predictions by the various models with theoretical or experimental results validates them.

Experimental and Finite Element Study of Guided Ultrasonic Wave Scattering at Structural Features in a Plate

---**Paul Fromme**, Department of Mechanical Engineering, University College London, London, United Kingdom

---Many technical structures contain large plate-like components, which can suffer from severe corrosion and the development of fatigue damage during their service life. Permanent monitoring of such structures can be achieved using guided ultrasonic waves, which can propagate over large distances and allow for efficient nondestructive testing of such structures with limited access. Damage often occurs at or close to structural features, e.g., stiffeners welded to the hull plates of a ship. The reflection of the Lamb wave A0 mode at a stiffener welded to a steel plate has been investigated experimentally in the laboratory. The wave propagation and scattering in the vicinity of the stiffener has been measured using a laser vibrometer and compared to Finite Element predictions; good agreement was found. The sensitivity for damage detection close to structural features has been investigated by studying the combined interaction of the guided ultrasonic wave with defects and structural features.

Prediction and Direct Measurement of Scattered Plate-Wave Fields Using S0 to A0 Mode Conversion at Non-Symmetric Circular Inhomogeneities

---Frederic B. Cegla and **Martin Veidt**, School of Engineering, The University of Queensland, Brisbane, Qld 4072, Australia

---The wave fields scattered by non-symmetric circular inhomogeneities in isotropic plates are investigated when plane S0 plate waves are incident. Theoretical predictions are compared to experimental measurements for A0 scattered wave fields created by S0 to A0 mode conversion that exists at non-symmetric inhomogeneities. Piezoceramic transducers were used to preferentially excite the S0 plate mode by causing in-plane motion of the plate, while a laser Doppler vibrometer was chosen as the receiving transducer only sensitive to out-of-plane plate displacements. Therefore, the incident field that hardly contains any out-of-plane motion remains undetected, whilst the scattered wave field that is dominated by flexural wave motion is strongly picked up. This enables a direct measurement of the scattered A0 field without the need for a subtraction of the incident field. Results are presented for added masses and non-symmetric blind holes for different ratios of interrogation wave length to inhomogeneity diameter as well as different severities of the synthetic inhomogeneities. This method has potential applications in plate-wave diffraction tomography where the wave field of the scattered flexural wave has to be accurately determined in order to reconstruct an image of laminar damage in the plate such as corrosion thinning or laminar disbonds.

2D P-SV Wave Scattering by a Crack in a Cladding

---**Per-Ake Jansson** and Theo Zagbai, Department of Applied Mechanics, Chalmers University of Technology, Goteborg, Sweden

---A situation that frequently occurs in the nuclear power industry is that of a thick plate or pipe with an austenitic cladding to reduce or prevent corrosion. A common method to apply the cladding on a ferritic base material is to use a welding process. From an ultrasonic testing point of view this leads to a number of complications. The interface between the cladding and the base material is usually corrugated, which may affect the scattering from the interface substantially. Furthermore, the cladding material is anisotropic with all the complications this may lead to. In this paper ultrasonic testing of a thick plate with a plane crack in a cladding is modeled analytically for a two-dimensional case. The effects of a corrugated interface and anisotropy are both taken into account. The wave scattering problem is solved by a hypersingular integral equation approach, where an integral equation for the crack opening displacement is derived from integral representations for the displacement fields in the two media. A model for the ultrasonic transmitter and receiver is also included. Some numerical results for the change in signal response due to the presence of the crack are given.

Application of Fast Multipole Boundary Element Method to Multiple Scattering Analysis of Acoustic and Elastic Waves

---**Takahiro Saitoh** and Takuo Fukui, Course of Nuclear Power and Safety Engineering, Fukui University, Bunkyo, 3-9-1, Fukui-shi, Fukui, Japan; Sohichi Hirose, Department of Mechanical and Environmental Informatics, Tokyo Institute of Technology, O-okayama 2-12-1-W8-22, Meguro-ku, Tokyo, Japan

---Various composite materials are used as structural materials in many industries. Since composite materials have very complicated structure, it is sometimes difficult to apply ultrasonic nondestructive testing for material evaluation and detection of defects. To enhance the quality of ultrasonic nondestructive evaluation for composite materials, it is one of the important keys to gain detailed knowledge on wave propagation behaviors by a numerical method. The Boundary Element technique is known as a very effective method for wave analysis. The Boundary Element Method, however, needs much computational time and memory for a large scale wave analysis. In this paper, Fast Multipole Boundary Element Method (FMBEM) is developed to solve 2-D (or 3-D) multiple scattering problems efficiently, which are scattering problems of acoustic and elastic waves by many scatterers in an infinite homogeneous solid. Accuracy and computational efficiency of the proposed method are shown in comparison with a conventional BEM and a FMBEM. Numerical calculations are carried out for multiple scattering problems by a lot of scatterers arranged periodically in a region subjected to normal incidence of a longitudinal plane wave. Wave fields around scatterers are shown and attenuation due to multiple scattering is discussed for the model of periodically arranged scatterers.

Locating the Crack-Front of a Vertical Surface-Breaking Planar Crack

---Jiunn-Woei Liaw, Department of Mechanical Engineering, Chang Gung University, Tao-Yuan, Taiwan, 333; **Mao-Kuen Kuo**, Institute of Applied Mechanics, National Taiwan University, Taipei, Taiwan, 106

---Two distinct methods to locate the crack tip of a surface-breaking plane vertical crack based on the arrival times of the first diffracted waves are described and compared. The uniform-depth problem and the various-depth problem derived from a plane vertical crack in three-dimensional half-plane are studied respectively to illustrate these two methods. The tip-by-tip method, while capable of detecting the crack depth of a uniform-depth crack, only recovers the *apparent depth* in a various-depth crack. The other method, *crack function*, is expressed by the polynomials and/or the Fourier cosine series in this study. The crack function is used to locate the crack tip by minimizing the cost function through the adaptive simulated annealing and simplex algorithms. In the numerical experiments, the exact arrival times are superimposed by the Gaussian errors to simulate the real exacted arrival times. These results indicate that crack function successfully estimates the crack depth and the orientation of a various-depth crack. Moreover, the crack depth is more reliable and accurate than the orientation in recovery.

Phased Array Ultrasonic Testing Model to Predict Signals from a Side-Drilled Hole in an Immersion Setup

---**Hak-Joon Kim** and Sung-Jin Song, Sungkyunkwan University, School of Mechanical Engineering, Suwon, Korea; Timothy A. Gray[1], Lester W. Schmerr[1,2], and R. Bruce Thompson[1]
[1]Center for NDE and [2]Dept. of Aerospace Eng., Iowa State University, Ames, IA 50011

---In ultrasonic nondestructive testing, phased array ultrasonic testing with small rectangular piezoelectric elements is quite often adopted in practice to detect flaws. And, a side-drilled hole (SDH) is very widely used as a standard reflector in ultrasonic testing. For proper interpretation of the measurement results of a SDH using a phased array ultrasonic testing system, it is helpful to have a complete ultrasonic measurement model. To address such a need, it is necessary to develop four main components of the complete model including the ultrasonic beam model for a phased array transducer, time delays for focusing and/or steering, a far-field scattering model for a flaw and a system function for determine the characteristics of applied system. Previously, we have proposed a highly efficient ultrasonic beam model of the rectangular transducer and an accurate scattering model of the SDH. Thus, in this study, by integrating a system function for a phased array ultrasonic testing system to be proposed in this presentation, we will develop a complete ultrasonic measurement model to predict ultrasonic signals from a SDH. Based on the model to be developed, we will calculate the ultrasonic responses from a SDH in an immersion setup to verify the accuracy of the model by comparison to the experiments.

Plate Wave Transmission/Reflection of Integral Stiffeners: Model Study and Experiment

---**R. A. Roberts** and D. E. Chimenti, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

---An improved array-based method of acoustic emission leak location is being pursued at CNDE for application to spacecraft, under NASA funding. A factor impacting the effectiveness of the method is the signal lost in transmission across stiffening ribs which are integrally machined into the spacecraft outer skins. This paper presents results of a computational study of plate wave transmission/reflection at the integral stiffener, along with comparison to experimentally observed transmission/reflection phenomena. The problem is formulated as a boundary integral equation, and treated with a boundary element analysis, where elements supporting the known asymptotic behavior of the wavefields at a distance from the rib are employed to greatly enhance computational efficiency. The computation directly yields transmission and reflection coefficients for the various plate modes generated at the rib, obtained as the weights of the corresponding asymptotic elements. Theoretically predicted behaviors will be compared to experiment for selected cases.

Transmission Matching for Joining Two Acoustical Waveguides

---Xiaowei Wang, **Manton J. Guers**, and Bernhard R. Tittmann, The Pennsylvania State University, Department of Engineering Science & Mechanics, 212 Earth-Engineering Sciences Building, University Park, PA 16802-6812

---Acoustical waveguides have valuable applications in nondestructive measurements. For example, corrosion can be detected over long distances with suitable guided waves. Remote, in situ monitoring of temperature and other parameters can also be achieved. Magnetostrictive materials, such as Remendur, have received significant attention for the generation and reception of ultrasonic waves in these applications. However, it may not be practical to use a magnetostrictive material in certain applications because of high material costs or insufficient material properties such as strength or melting temperature. It has therefore been conceived to join a small length of Remendur with steel or Tantalum. Finite element analyses and experimental verifications have been performed to evaluate joining two thin rods with a reinforcement sleeve. Results have shown that a properly designed sleeve significantly improves the transmission of ultrasonic waves and decreases unwanted reflections at the interface between the two waveguide materials. From these results it can be concluded that the sleeve type joint is an effective strategy for joining a small length of Remendur with a second waveguide material. Additional finite element models have been used to consider joining a thin rod with a plate.

Session 17

Wednesday, August 2, 2006

SESSION 17
NDE FOR RESIDUAL STRESS AND CORROSION
Pavilion East

8:30 AM **Residual Stress Measurements on Nickel-Based Superalloys Using Swept High-Frequency Eddy Currents**
---**C. Lee**, Y. Shen, C. C. H. Lo, and N. Nakagawa, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

8:50 AM **Conductivity Profile Inversion of Swept High Frequency Eddy Current Data for Shot-Peened Superalloys**
---**Y. Shen**, C. C. H. Lo, A. M. Frishman, C. Lee, and N. Nakagawa, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011-3042

9:10 AM **Correlation Between Eddy Current Signal Noise and Peened Surface Roughness**
---**S. E. Wendt**, S. R. Hentscher, D. C. Raithel, and N. Nakagawa, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

9:30 AM **Multifrequency Eddy Current Inspection of Corrosion in Clad Aluminum Riveted Lap Joints and Its Effect on Fatigue Life**
---**A. C. Okafor** and S. Natarajan, University of Missouri-Rolla, Nondestructive Evaluation and Structural Health Monitoring Laboratory, Department of Mechanical and Aerospace Engineering, 130 Mechanical Engineering Building, 1870 Miner Circle, Rolla, MO 65409-0050

9:50 AM **Estimation of Fatigue Damage for an Austenitic Stainless Steel (SUS304) Using Magnetic Methods**
---**M. Oka**, Oita National College of Technology, Department of Computer and Control Engineering, 1666 Maki, Oita, 870-0152, Japan; T. Yakushiji, Oita National College of Technology, Department of Mechanical Engineering, 1666 Maki, Oita 870-0152; Japan; Y. Tsuchida and M. Enokizono, Oita University, Faculty of Engineering, Department of Electric and Electronic Engineering, 700 Dannoharu, Oita, 870-11, Japan

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

10:30 AM **Development in Using High Energy X-Ray Diffraction for Measure Residual Stress**
---M. Al-Shorman, **J. Gray** and T. Jensen, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

10:50 AM **Love Waves in Isotropic Substrate with Surface Stress Profile**
---**M. Viens**, S. Yahiaoui, and Z. Wang, Ecole de technologie superieure, Department of Mechanical Engineering, Montreal, Quebec, Canada

11:10 AM **Optimization of Hidden Corrosion Detection in Aircraft Structures Using Lamb Waves: Numerical Predictions and Experiments Results**
---**N. Terrien**, F. Lepoutre, and A. Déom, ONERA, Structures and Damage Mechanics Department, BP 72, F-92322 Châtillon CEDEX, France; D. Royer, Laboratoire Ondes et Acoustique, ESPCI, 10 rue Vauquelin, F-75231 Paris cedex 05, France

11:30 AM **High Resolution Acoustoelastic Measurements of Materials**
---**M. J. McKenna**, S. Guy, and J. Heyman, Luna Innovations Incorporated, 130 Research Drive, Suite 300, Hampton, VA 23666

11:50 AM **Nondestructive Induced Residual Stress Assessment in Superalloy Turbine Engine Components Using Induced Positron Annihilation (IPA)**
---**C. A. Rideout**, S. Ritchie, and A. Denison, Positron Systems, Inc., 411 S. Fifth Street, Boise, ID 83702

12:10 PM ***Lunch***

Residual Stress Measurements on Nickel-Based Superalloys using Swept High-Frequency Eddy Currents

---**Changqing Lee**, Yuping Shen, Chester C.H. Lo, and Norio Nakagawa, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

---This paper reports on development of an electromagnetic method for residual stress characterization in shot-peened aerospace materials. Due to possible in-service stress relaxation, component life extension can only be realized if the residual stress profile, which typically extends to about 200 £gm, can be characterized nondestructively. Here, we present the work on an eddy current (EC) technique using sweep-frequency measurement for assessing residual stress in nickel-based superalloys. Specifically, we first describe a swept high-frequency EC measurement system with proprietary probes fabricated by the PCB technology that can operate up to 50 MHz with the smallest penetration depth of 80 ƒÝm. We next describe a model-based inversion procedure that can determine near-surface conductivity deviation profiles from the EC data. Measurements on Inconel 718 specimens have shown a clear difference before and after shot-peening in the lift-off-noise-free vertical components. The inversion procedure minimizes the error between experimental and theoretical vertical signals, as detailed in our companion paper (Y. Shen et al.). The main conclusion of this paper is the validation of the conductivity profile inversion procedure against simulated layer specimens.---This material is based upon work supported by the Air Force Research Laboratory under Contract # FA8650-04-C-5228 at Iowa State University's Center for NDE.

Conductivity Profile Inversion of Swept High Frequency Eddy Current Data for Shot-Peened Superalloys

---**Y. Shen**, C.C.H. Lo, A. M. Frishman, C. Lee, and N. Nakagawa, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011-3042

---This paper reports recent progress in developing electromagnetic residual-stress characterization method. Eddy current (EC) methods are capable of measuring near-surface conductivity deviation profiles, from which residual stress states arising from the shot peening can be assessed. Earlier, we introduced a model-based inversion procedure to obtain conductivity profiles from swept frequency EC signals, applicable to shot peened superalloys. The forward model and inversion algorithm are built around an empirical form of the conductivity profile. This inverse procedure has been validated against simulated layer specimens, as reported in our companion paper (C. Lee et al.). Here, we apply the validated procedure to a series of swept high frequency EC data from shot-peened Inconel 718 specimens, and derive the main result of this paper, namely, the inverted conductivity profiles in the depth range within 400 micrometers. In addition, we describe a preliminary convergence test of this model on shot-peened Al7075 plate, and a series of sensitivity tests of the inverted conductivity profiles on various parameters including lift-offs and bulk conductivity. We also discuss the step toward deducing residual stress profiles from the inverted conductivity profiles.---This material is based upon work supported by the Air Force Research Laboratory under contract # FA8650-04-C-5228 at Iowa State University Center for NDE.

Correlation Between Eddy Current Signal Noise and Peened Surface Roughness

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

--- For advanced uses of eddy current (EC) NDE models in, e.g., model-assisted POD, there is a need to understand the origin of EC noise sources, so that noise estimations can be made for a given set of specimen conditions, in addition to predicting defect signals. This paper focuses on the material-oriented noise sources that exhibit some universality, when isolated from electrical and mechanical noises. Specifically, we report on experimental measurements that show explicit correlations between surface roughness and EC noise, as seen in post-peen EC measurements of shot-peened roughness specimens. The samples are 3"-by-3" Inconel 718 and Ti-6Al-4V blocks, pre-polished and shot-peened at Almen intensities ranging from a low of 4N to as high as 16A, created by smaller (~350 μm) and larger (~1 mm) diameter zirconium oxide shots. Strong correlations are observed between the Almen intensities and the measured surface roughness. The EC noise correlates equally strongly with the Almen intensities for the superalloy specimens. The correlation for the Ti-alloy samples is only apparent at higher intensities, while being weak for lower intensities, indicating the grain noise dominance for smoother surfaces.---This work is sponsored by National Aeronautics and Space Administration (NASA) under the Grant #NAG102098 and #NNL05AA19G.

Multifrequency Eddy Current Inspection of Corrosion in Clad Aluminum Riveted Lap Joints and Its Effect on Fatigue Life

---**A. Chukwujekwu Okafor** and Shridhar Natarajan, University of Missouri-Rolla, Nondestructive Evaluation and Structural Health Monitoring Laboratory, Department of Mechanical and Aerospace Engineering, 130 Mechanical Engineering Building, 1870 Miner Circle, Rolla, MO 65409-0050

---Aging aircrafts- aircrafts operated beyond their design life are prone to damages, like corrosion and fatigue cracks in riveted lap joints of fuselage skin panels. These damages are often difficult to detect by conventional methods and can lead to catastrophic failure if not repaired. The present high cost of "find-it-fix-it" corrosion maintenance activities necessitates a more cost-effective NDE technique to detect and characterize corrosion damage and its effect on structural integrity of aircrafts. This paper presents the results of multifrequency eddy current (EC) inspection of corrosion in clad Aluminum 2024-T3 riveted lap joints and its effect on fatigue life. Single, double and triple column riveted lap joint specimens were corroded in an accelerated corrosion chamber for 20 weeks. Specimens were removed every 4 weeks from the chamber, cleaned of corrosion products with mass loss measurement and subjected to manual scanning EC inspection and fatigue loading till failure. Pitting and crevice type of corrosion were observed. Simulated material loss by machining in different layers of lap joint calibration specimens were detected and located with EC inspection. Corroded specimens were divided into zones for EC inspection and the peak amplitude of impedance plane signal for each zone was recorded. Material loss in different layers of corroded specimens were detected and located. The EC inspection and fatigue tests results are presented.

Estimation of Fatigue Damage for an Austenitic Stainless Steel (SUS304) Using Magnetic Methods

---**Mohachiro Oka**, Oita National College of Technology, Department of Computer and Control Engineering, 1666 Maki, Oita, 870-0152, Japan; Terutoshi Yakushiji, Oita National College of Technology, Department of Mechanical Engineering, 1666 Maki, Oita, 870-0152, Japan; Yuji Tsuchida and Masato Enokizono, Faculty of Engineering, Oita University, Department of Electric and Electronic Engineering, 700 Dannoharu, Oita, 870-11, Japan

---Since austenitic stainless steels show excellent corrosion resistance, it is widely used in a lot of fields. For instance, many of pipe lines used in the chemical plants or the power stations are made of austenitic stainless steels. From the viewpoint of economy and safety, it is necessary to prevent accidents caused by the degradation of the structural component made of them. In addition, extension of the in-service period of those structural components is important from the viewpoint of the saving resource and the energy saving. Accordingly, we are investigating some methods for evaluation of fatigue damage of structural components made of austenitic stainless steels. One method of them is the remanent magnetization method. This method is effective to evaluate fatigue damage of them in the laboratory. However, this method was hard to use on the site. Then, we are developing the excitation method as other method that can be used on the site. SUS304 (ANSI304) is a typical austenitic stainless steel. Therefore, SUS304 was chosen as a test material. In this paper, the results of the fatigue damage evaluation of SUS304 using some magnetic methods are reported. Some magnetic fatigue evaluation methods will be also compared.

Development in Using High Energy X-Ray Diffraction for Measure Residual Stress

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

---We are developing high energy diffraction, between 50 and 150 KeV, method for use in measuring internal strain of moderately sized objects. Traditional x-ray strain measurements are limited to a few microns depths due to the use of Cu Kα and Mo Kα radiation. The high energy that we are using allows for greater penetration. We have completed demonstrations of high energy diffraction in aluminum and titanium with penetration depths of 300 microns. The spatial resolution of this depth profile is ~50 microns and at present we have demonstrated sensitivity to a lattice parameter change of 0.01 angstroms. We have also developed a simulation program for modeling the effect of monochromator slit alignment, detector collimator configurations and several scanning means. We will present recent results on the development of this new tool and on x-ray diffraction measurement at high energy, typically in the range of 60-100 keV.---This material is based upon work supported by the Air Force Research Laboratory under Contract #FA8650-04-C-5228 at Iowa State University's Center for NDE.

Love Waves in Isotropic Substrate with Surface Stress Profile

---**Martin Viens**, Samir Yahiaoui, and Zuoqing Wang, Department of Mechanical Engineering, Ecole de Technologie Superieure, Montreal, Quebec, Canada

---Partial wave method is used to compute velocity dispersion of a horizontally polarized shear (Love) wave propagating on the surface of an initially isotropic substrate subjected to in-plane uniaxial residual stresses whose amplitude vary with depth. Propagation direction both parallel and perpendicular to stress axis are investigated. It is shown that, under uniaxial stress, the initially isotropic medium becomes transversely isotropic. In such a case, it can be found that both eigenvalues and eigenvectors of the partial waves can be expressed in explicit algebraic formulas. Eigen solutions can thus be directly substituted into the boundary conditions so as to enable evaluation of dispersion relations. Stress profile under substrate surface is approximated by a series of uniform layers having slightly different stiffness. Effective elastic constants of each of these layers are evaluated from either acousto-elastic constants or second and third order elastic constants of the material. Relations are given to show the links between these three notation methods.

Optimization of Hidden Corrosion Detection in Aircraft Structures Using Lamb Waves: Numerical Predictions and Experimental Results

---**N. Terrien**, F. Lepoutre, and A. Déom, ONERA, Structures and Damage Mechanics Department, BP 72, F-92322 Châtillon CEDEX, France; D. Royer, Laboratoire Ondes et Acoustique, ESPCI, 10 rue Vauquelin, F-75231 Paris cedex 05, France

---To increase the sensitivity of Lamb waves to the presence of hidden corrosion in aircraft structures, a preliminary step is to understand phenomena governing the interaction between these waves and corroded areas. A hybrid model combining a finite element approach and a modal decomposition method is developed to investigate the interaction of Lamb modes with corrosion pits and is validated both numerically and experimentally. Compared to previous simulations, it allows investigating the interaction of Lamb modes generated at high frequency with micro-defects as corrosion pitting. During non-destructive tests, some parts of the experimental signals, which correspond to superposition of waves diffracted by the corroded area, appear as very complex and difficult to analyze. The simulations presented in this paper make easier the interpretation of these measured waveforms. Finally, numerical results permit to extract significant information from the transmitted waveform and thus to optimize the signal processing for monitoring corroded area at a very early stage. As a conclusion, this paper presents measurement procedures deduced from numerical simulations which improve the sensitivity of this non-destructive technique for corrosion monitoring.

High Resolution Acoustoelastic Measurements of Materials

---**Mark J. McKenna**, Samuel Guy, and Joseph Heyman, Luna Innovations Incorporated, 130 Research Drive, Suite 300, Hampton, VA 23666

---As materials become more complex, there is an increasing need for high resolution measurements to characterize strength and damage in the materials. Typically, the criterion for rejecting a part is based on the detection of a flaw of a specific size in a critical location. Interestingly, if a low stress field exists at the flaw site, the flaw may not grow over time. Similarly, in a part that shows no unacceptable indications, a high stress state may cause the flaw to quickly grow through the part leading to failure. In other cases, a controlled amount of stress (in a specific direction or type) is purposely added to the material to prevent flaw growth. Inspection time intervals are based knowing and controlling the stress environment to predict the flaw growth. Luna Innovations Incorporated has developed a high resolution ultrasonic instrument that can enhance the integrity of critical hardware by measuring changes in the stress state in a material. Knowledge of the stress state plus knowledge of crack sizes greatly improves structural engineers' capability of life prediction. System data will be shown for tests to stresses near holes in laboratory fabricated aircraft metal samples. Scans of the spatial distribution of stresses will be compared with finite element models of the structure.

Nondestructive Induced Residual Stress Assessment in Superalloy Turbine Engine Components Using Induced Positron Annihilation (IPA)

---**Curtis A. Rideout** and Scott Ritchie, Positron Systems, Inc., Boise, ID 83702; Jagoda Urban-Klaehn and Alan W. Hunt, Idaho Accelerator Center, Pocatello, ID 83702

---Induced Positron Annihilation (IPA) has demonstrated the ability to nondestructively quantify shot peening/surface treatments and relaxation effects in single crystal superalloys, steels, titanium and aluminum with a single measurement as part of a National Science Foundation SBIR program and in projects with commercial companies. IPA measurement of surface treatment effects provides a demonstrated ability to quantitatively measure initial treatment effectiveness along with the effect of operationally induced changes over the life of the treated component. Test specimens of steel and CMSX-4, a nickel-based superalloy, were prepared and measured at incremental shot peening intensities ranging from 0-20A. The CMSX-4 samples were then subjected to a range of fatigue and thermal conditions to assess relaxation effects and to assess subsurface residual stresses. The IPA technology proved to be highly sensitive to the induced changes in surface treatment intensity and accurately measured the relaxation of the shot peening intensity induced by varying degrees of simulated operational conditions. In addition, the tests demonstrated IPA technology's ability to quantify subsurface residual stresses in test specimens. Use of IPA to nondestructively quantify surface and subsurface residual stresses in turbine engine materials and components will lead to improvements in current, conservative engineering designs and maintenance procedures.

Session 18

SESSION 18

NDE SENSORS AND PROBES
Broadway II

8:30 AM **Magnetostrictive Acoustic Transducer Based Torsional Wave Generation in Pipes Using Magnetic Tapes**
---**E. Kannan**, B. Maxfield, and K. Balasubramaniam, Indian Institute of Technology Madras, Center for Nondestructive Evaluation and Department of Mechanical Engineering, Chennai 600 036, India

8:50 AM **Stress Sensing Characteristics of Non-Contact Magnetoelastic Sensors Based on Substituted Cobalt Ferrite**
---**C. C. H. Lo**, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

9:10 AM **Development of Electromagnetic Techniques for Hydrogen Content Assessment in Coated Linepipe Steel Specimens**
---**A. N. Lasseigne-Jackson**, D. L. Olson, B. Mishra, and J. E. Jackson, Colorado School of Mines, Department of Metallurgical and Material Engineering, Golden, CO 80401

9:30 AM **AMR Sensors for the Measurement of the Thermoelectric Magnetic Field**
---N. Tralshawala, **W. Faidi**, and Y. Plotnikov, GE Global Research Center, Nondestructive Technologies Laboratory, 1 Research Circle, Niskayuna, NY 12309

9:50 AM **Direct-Write Strain and Temperature Sensors for Harsh Environments**
---**C. Gouldstone**, MesoScribe Technologies, Inc., 25 Health Sciences Drive, Stony Brook, NY 11790

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

10:30 AM **Design of Energy Scavengers with the Help of Finite Element Packages**
---**I. N. Tansel**, Florida International University, Department of Mechanical and Materials Engineering, 10555 West Flagler Street, (EAS-3473) Miami, FL 33174

10:50 AM **Embedded Piezoelectric Wafer Active Sensors for Sensing Acoustic Emission in Thin Plates**
---R. Gangadharan, **C. R. L. Murthy**, and M. R. Bhat, Indian Institute of Science, Department of Aerospace Engineering, Bangalore, Karnataka 560012, India

11:10 AM **Parametric Study for Optimization of Bobbin Coil ECT Probe Design by Electromagnetic Numerical Analysis**
---**Y. B. Kong**, C.-H. Kim, H.-J. Yu, and S.-J. Song, Sungkyunkwan University, School of Mechanical Engineering, Suwon, Korea; H. J. Lee and M. W. Nam, Korea Electric Research Institute, Nondestructive Evaluation Center, Daejeon, Korea

11:30 AM **Electromagnetic Surface Testing of Weld Over Painting by Uniform Eddy Current Probe**
---**H. Hoshikawa**, K. Koyama, and Y. Kawate, Nihon University, Izumicho Narashino Chiba 275-8575, Japan

11:50 AM **Use of Non-Equilibrium Atmospheric Pressure Plasma in NDE**
---**A. May**, General Electric Global Research, Niskayuna, NY 12309

12:10 PM ***Lunch***

Magnetostrictive Acoustic Transducer Based Torsional Wave Generation in Pipes Using Magnetic Tapes

---**Elankumaran Kannan**, Bruce Maxfield, and Krishnan Balasubramaniam, Center for Nondestructive Evaluation & Dept of Mechanical Engineering, Indian Institute of Technology Madras, Chennai 600 036, India

---Long range Torsional guided wave generation in pipes using magnetostrictive sensor with potential application in nondestructive pipe line testing in oil and gas industry is reported in this paper. Generally, in this type of sensors systems, strips made of Nickel or Cobalt alloys are glued onto the surface of the pipe and an ac field is applied to copper coil that is wound over the strips to generate the torsion waves under bias field. Permanents magnets are used to generate the required bias field. Though the technique is an established one, still it requires improvements. For example, corrosion and oxidation of the sensor strips will be a problem in the long run. In such a situation any magnetic oxide material with good magnetostrictive properties is a fine replacement for the metallic strips as the magnetic oxides are less prone to corrosion and oxidation. In addition, if one uses another soft magnetic strip with a small magnetostriction over the strip that is used for generating torsional waves as a field concentrator strip, it would reduce the high ac field required to be applied to the coil. We have made an attempt using Video tape as our magnetostrictive strip, and permalloy strips as the field concentrator. Video tape is chosen as it is cheaply available and it is also made of cobalt doped iron oxide that makes it a good magnetostrictive material. The quality of the torsional wave in terms of the amplitude and its frequency dependence obtained under different conditions viz., the orientation of magnetostrive strip with respect to the pipe axis and the number of the strips will be reported.

Stress Sensing Characteristics of Non-Contact Magnetoelastic Sensors Based on Substituted Cobalt Ferrite

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

---We have investigated the stress sensing characteristics of magnetoelastic sensors based on magnetostrictive cobalt ferrite composites, which hold promise for non-contact stress sensing applications due to their high stress sensitivity and low cost. The sensors operate by the fact that applied stresses induce changes in magnetization, which can be detected by measuring the changes in surface magnetic field or permeability. In our previous studies the magnetic and magnetomechanical properties of cobalt ferrite have been improved by chemical substitution and magnetic annealing. In this work, we compared the stress sensing characteristics of the improved cobalt ferrite materials with respect to their sensitivity and linearity. Magnetomechanical tests were performed on selected cobalt ferrite samples bonded to aluminum alloy bars in either tensile or three point bending configurations. Results show that cobalt ferrite substituted with a small amount of manganese or chromium for iron exhibit higher stress sensitivities than the pure cobalt ferrite. This can be interpreted by the results of our recent studies showing that the magnetocrystalline anisotropy, which works against stress-induced changes in magnetization, is lower for the substituted cobalt ferrite.---This research was supported by the National Aeronautical and Space Administration (NASA) under the award No NAG-1-02098.

Development of Electromagnetic Techniques for Hydrogen Content Assessment in Coated Linepipe Steel Specimens

---**Angelique N. Lasseigne-Jackson**, David L. Olson, Brajendra Mishra, and Joshua E. Jackson, Department of Metallurgical and Material Engineering, Colorado School of Mines, Golden, CO 80401

---With the rapid introduction of high strength linepipe steels (in excess of 70 ksi yield strength) for operation and use at higher pressures and wall thicknesses, the need for new approaches for hydrogen management needs to be addressed. Through the use electromagnetic analyses, a new non-destructive, non-contact sensor has been developed for in-situ determination of diffusible hydrogen content in coated linepipe steel specimens. This electromagnetic technique allows for a rapid, non-destructive assessment of hydrogen accumulation in coated steel line pipe and thus an evaluation of the linepipe integrity. The use of induced current resistivity measurements for hydrogen content determination in X80 linepipe steel specimens is demonstrated and discussed.

AMR Sensors for the Measurement of the Thermoelectric Magnetic Field

---Nilesh Tralshawala, **Waseem Faidi**, and Yuri Plotnikov, GE Global Research Center, Nondestructive Technologies Laboratory, 1 Research Circle, Niskayuna, NY 12309

---Thermo-electric effect has been used to study changes in material properties of metals with low thermal conductivity, such as super alloys. We are developing a system using Anisotropic Magneto-Resistive (AMR) sensors to measure the thermoelectric magnetic field signals. The system includes three orthogonally arranged AMR sensors to measure the normal and tangential components of the magnetic field. AMR sensors are thin film sensors and this allows us to achieve a very small (1 mm or less) lift-off distance between the AMR sensor and the sample, establishing a great benefit of enhanced magnetic field strength measured at the sensor over other bulk effect sensors such as Fluxgate magnetometers that have a nominal lift-off distance of about 10 mm or more, even when the tip is placed on the sample surface. Furthermore, this close proximity of AMR to the sample, along with its well defined planar sensing area and smaller lateral dimensions can result in a much better spatial resolution. The AMR sensors are flanked by hot and cold air nozzles, which provide a temperature gradient of ~ 1 °C/mm on low thermal conductivity samples. The system was used to establish a comparison with published data for Fluxgate measurements of the thermoelectric magnetic field due to tin inclusions in a copper sample. Then, measurements were carried out to obtain the thermoelectric magnetic signal from the heat-affected zone around a Ti-6Al-4V friction stir weld sample. A theoretical model was developed to predict the thermoelectric magnetic field for the anomalies under consideration. Experimental results, with some comparison to the theoretical calculations will be presented.

Direct-Write Strain and Temperature Sensors for Harsh Environments

---**Christopher Gouldstone**, MesoScribe Technologies, Inc., 25 Health Sciences Drive, Stony Brook, NY 11790

---Direct-write (DW) is a high-precision deposition process which is able to create fine features on non-flat substrates with harsh environment tolerance. Single- and multi-layer devices may be constructed from a variety of polymers, ceramics and metals. DW has been applied to fabrication of strain gages, thermocouples and other environmental sensors. The advantages of direct-write for harsh environments include: superior adhesion to substrates without marginally-tolerant epoxies; flexibility to select temperature-tolerant and substrate-compatible device materials; ability to produce low-mass, low-profile multi-layers for rotating and wetted components; ability to embed devices within functional coatings; and batch reproducibility through automated processing, minimizing cost and reject rate. Resistive direct-write strain gages exhibit consistent and repeatable strain-reporting. Through a ceramic device-substrate interface, the device tracks axial deformation of the instrumented component. Automated, integrated alignment and deposition processes simplify sensor installation and improve accuracy. Direct-write thermocouple junctions are innately suited to surface temperature measurements, offering higher fidelity thermal interfaces than conventional contact thermocouples. Direct-write thermocouple compositions produce thermoelectric output consistent with NIST standards, for compatibility with available infrastructures e.g., extension leads, junctions and readers.

Design of Energy Scavengers With the Help of Finite Element Packages

---**Ibrahim N. Tansel**, Florida International University, Department of Mechanical and Materials Engineering, 10555 West Flagler Street, (EAS-3473) Miami, FL 33174

---Self powering sensors have been desired for the future air and space vehicles to minimize wiring and related problems. Selection of the proper area of piezoelectric patches at various operating conditions is an important challenge. Selection of a large patch area increases the complexity and weight. The small patch area could not provide energy to operate the electronics continuously. Many Finite Element Method (FEM) packages are capable to estimate the electricity after the stress and strain distribution is calculated. In this paper, the required energy for a smart sensor was discussed and use of FEM was suggested for selection of the size of the piezoelectric patch. The power consumption of the recently developed low energy consuming electrical components is extremely low. It is possible to reduce energy consumption further by reducing the clock speed. Once the required energy is known, the proper piezoelectric patch size could be obtained by using the FEM since most of the commercial packages have proper tools to connect the mechanical and electrical properties of the material. The study indicated that energy harvesting devices could generate the necessary power for low power consuming microprocessors continuously if a reasonable size of piezoelectric patch is attached to a vibrating surface.

Embedded Piezoelectric Wafer Active Sensors for Sensing Acoustic Emission in Thin Plates

---R. Gangadharan, **C. R. L. Murthy**, and M. R. Bhat, Indian Institute of Science, Department of Aerospace Engineering, Bangalore, Karnataka 560012, India

---Recent advances have led to the development of PZT wafer active sensors (PWAS) which can be embedded or surface mounted, especially for actuation and sensing in both Acoustic Emission and Ultrasonic modes for Health Monitoring of Aerospace structures. For the fabrication of PWAS wafers, soft PZT formulation (SP-5H Grade containing dopants like Ba, Sm, Ca, Zn, Y and Hf) was used. The piezoelectric charge constants (d33) were measured by a d33 meter. As a first step towards the final objective of developing Health monitoring methods with embedded PZT films, numerical modeling of wave propagation in aluminum and composite plates was performed using ANSYS Finite Element package. Using it, the response to an impulse at the center of the plate was studied by picking up the displacement at a particular nodal position away from the center. Experiments were also conducted on aluminum and composite plates of finite dimensions with surface mounted sensors. The AE source was simulated by breaking 0.5mm pencil lead against the surface of the thin plate for establishing the sensitivity by picking up the lamb waves by a PWAS source and a standard AE sensor. A comparison of results of numerical and experimental work shows good agreement.

Parametric Study for Optimization of Bobbin Coil ECT Probe Design by Electromagnetic Numerical Analysis

---**Young Bae Kong**, Chang-Hwan Kim, Hyung-Ju Yu, and Sung-Jin Song, Sungkyunkwan University, School of Mechanical Engineering, Suwon, Korea; Hee Jong Lee and Min Woo Nam, Korea Electric Power Research Institute, Nondestructive Evaluation Center, Daejeon, Korea

---Eddy current testing (ECT) is widely adopted for inspection of steam generator tubes in nuclear power plants. The characteristics of ECT signals produced by a differential bobbin coil probe usually vary according to the probe parameters such as the number of turns, coil width, and the gap between two coils. Therefore, it is necessary to understand the effects of such parameters on the signal characteristics for both probe design optimization and proper signal analysis. To address such a read, in the present study, parametric study to investigate the effects of probe parameters on the signal characteristics is carried using electromagnetic numerical analysis software. Especially, influence of gap size between two coils on the ECT signal is investigated for the optimization of bobbin coil ECT probe design.

Electromagnetic Surface Testing of Weld Over Painting by Uniform Eddy Current Probe

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

---Just one scan of the uniform eddy current probe detects longitudinal flaws by eddy current testing and transversal flaws by magnetic testing over full weld width. The probe is composed of a tangential exciting coil and a rectangular flat detecting coil. The exciting coil generates the magnetic flux parallel to the material surface and the detecting coil picks up the magnetic flux perpendicular to the material surface. In order to conduct electromagnetic testing of weld, the probe is arranged to generate the magnetic flux parallel to the weld direction and to induce the eddy current perpendicular to the direction. When a transversal flaw in weld zone leaks some of the magnetic flux out of the material, the probe detects the flaw by picking up the leaking flux. When a longitudinal flaw disturbs the eddy current, the probe detects the flaw by picking up the perpendicular magnetic flux generated by the disturbed eddy current. If the lengths of those two coils in the probe are larger than the width of the weld, just one scan of the probe can detect all surface flaws on the full weld width. In principle the probe is lift-off noise free and generates little noise by the position variation of the probe with regard to the weld zone. The probe can also detect flaws with a larger lift-off from the material than the conventional eddy current probes. Thus the probe has a good feasibility of detecting flaws fast and reliably over anti-corrosion painting.

Use of Non-Equilibrium Atmospheric Pressure Plasma in NDE

---**Andrzej May**, General Electric Global Research, Niskayuna, NY 12309

---Plasma is a state of matter that has strongly coupled electrical and mechanical properties similar to viscous conductive gas. Until recently, generating and using plasma for NDE has been limited to spark testing of flaws in dielectric materials using plasmas at low frequencies and discharge currents (0 - 3kHz, 1 - 10mA). This paper summarizes recent developments in the generation and use of radio-frequency (1 - 100MHz) non-destructive atmospheric pressure plasma for NDE, specifically: (1) transduction of air-coupled ultrasound, (2) as a medium and acoustic impedance matching layer for transmission of ultrasound; (3) for clearance and gaseous flow sensing in harsh environments (up to 1800 degrees C); (4) for measuring thickness, porosity, break-down voltage, and dielectric coefficient of non-conductive coatings, and (5) for identifying material composition through non-destructive ionization spectroscopy. A new type of high-efficiency, low current RF plasma source suitable for creating non-damaging, low EMI plasmas in the 0.5- 100MHz range will also be described.

Session 19

SESSION 19

FLAW IMAGING AND CHARACTERIZATION
Pavilion West

8:30 AM **3-D Flaw Imaging by Inverse Scattering Analysis Using Ultrasonic Array Transducer**
---**K. Nakahata**, Ehime University, Department of Civil and Environmental Engineering, Ehime, Japan; T. Saito, Fukui University, Department of Nuclear Power and Safety Engineering, Fukui, Japan; S. Hirose, Tokyo Institute of Technology, Department of Mechanical and Environmental Informatics, Meguro, Tokyo

8:50 AM **Imaging and Characterizing Damage Using Nonlinear Time Reversed Acoustics**
---**T. J. Ulrich** and P. A. Johnson, Los Alamos National Laboratory, Geophysics Group EES-11, Los Alamos, NM 87545; A. M. Sutin, Stevens Institute of Technology, Hoboken, NJ 07030

9:10 AM **Super Resolution Imaging: Experimental Results**
---**M. Fleming**, F. Simonetti, M. J. S. Lowe, and P. Cawley, Imperial College, Mechanical Engineering, London, United Kingdom

9:30 AM **Finite Element Modeling of Guided Wave Propagation in Plates**
---M. Godbole, B. Ganesan, **M. K. KM**, V. Kommareddy, and S. Ramaswamy, GE-Global Research, John F. Welsh Technology Center, #122, Pioneer, Hoodi Village, Whitefield Road, Bangalore, Karnataka 560066, India

9:50 AM **A New Method to Produce High Resolution Porosity Images by Means of Active Thermography**
---**G. Hendorfer**, G. Mayr, G. Zauner, M. Haslhofer, and R. Pree, University of Applied Sciences Wels, Sensors and Microsystems/Fachhochshule Wels, Roseggerstrasse 23, A-4600 Wels, Austria

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

10:30 AM **Crack Profile Reconstruction by Means of Potential Drop Measurements**
---**G. Sposito** and P. Cawley, Imperial, 682 Mechanical Engineering, Exhibition Road, London SW7 2AZ, United Kingdom; P. B. Nagy, University of Cincinnati, Aerospace Engineering & Engineering Mechanics, Cincinnati, OH 45221-0070

10:50 AM **Markov Chain Monte Carlo Defect Identification and Signal Analysis in NDE Images**
---**A. Dogandzic**, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

11:10 AM **Data Fusion for Combining Techniques to Detect and Size Surface and Near-Surface Defects**
---**R. S. Edwards** and S. Dixon, University of Warwick, Department of Physics, Coventry, United Kingdom; A. Sophian and G.-Y. Tian, University of Huddersfield, School of Computing and Engineering, Huddersfield, United Kingdom

11:30 AM **Enhanced ID Pit Sizing Using Multivariate Regression Algorithm**
---**K. Krzywosz**, Electric Power Research Institute, 1300 West WT Harris Blvd., Charlotte, NC 28262

11:50 AM **Modeling Bulk and Guided Wave Propagation in Unbounded Elastic Media Using Absorbing Layers in Commercial FE Packages**
---**M. Drozdz** and M. J. S. Lowe, Imperial College, Mechanical Engineering, London, United Kingdom; E. Skelton and R. Craster, Imperial College, Mathematics, London, United Kingdom

12:10 PM ***Lunch***

3-D Flaw Imaging by Inverse Scattering Analysis Using Ultrasonic Array Transducer

---**Kazuyuki Nakahata,** Dept. of Civil and Environmental Engineering, Ehime University, Ehime, Japan; Takahiro Saito, Dept. of Nuclear Power and Safety Engineering, Fukui University, Fukui, Japan; Sohichi Hirose, Dept. of Mechanical and Environmental Informatics, Tokyo Institute of Technology, Meguro, Tokyo

---Ultrasonic matrix array transducers have the advantage of receiving flaw echoes simultaneously at various points on a flat surface of test materials. Here we propose new 3-D imaging techniques to reconstruct flaw shapes with array transducers. These methods are based on linearized inverse scattering methods together with numerical algorithm of the synthetic aperture focusing technique in the frequency domain. Since these methods are performed by means of the Fourier fast transform, high-speed imaging of flaw shapes is possible at small computational cost. Efficient performance of the 3-D imaging technique is demonstrated by numerical simulations using the fast multipole BEM.

Imaging and Characterizing Damage Using Nonlinear Time Reversed Acoustics

---**Timothy J. Ulrich** and Paul A. Johnson, Los Alamos National Laboratory, Geophysics Group EES-11, Los Alamos, NM 87545; Alexander M. Sutin, Stevens Institute of Technology, Hoboken, NJ

---Nonlinear elastic wave spectroscopy (NEWS) has been shown to exhibit a high degree of sensitivity to both distributed and isolated nonlinear scatterers (e.g. damage) in solids. In the case of an isolated nonlinear scatterer such as a crack, by combining the elastic energy localization of the time reversed acoustics (TRA) with NEWS, it is shown here that one can isolate and image surfacial damage in solids. The experiments presented here are conducted in a doped glass block applying two different fixed frequency time reversed signals at each focal point and scanning over a localized nonlinear scatterer (a complex crack). The results show a distinct increase in nonlinear response, via intermodulation distortion, over the damaged area. The techniques described herein provide the means to discriminate between linear (e.g., voids and interfaces) and nonlinear scatterers (i.e., damage), and thus to ultimately image and characterize damaged regions.

Super Resolution Imaging: Experimental Results

---**Matthew Fleming**, Francesco Simonetti, Michael J. S. Lowe, and Peter Cawley, Mechanical Engineering, Imperial College, London, United Kingdom

---Over the past decade, the tremendous progress in medical ultrasound and the increasing need for more accurate defect evaluation techniques have driven the development of sophisticated array imaging systems for non-destructive testing. State-of-the-art phased array technology produces subsurface images of an object by focusing and steering an ultrasonic beam within the region to be imaged. The image of a point is then obtained by measuring the scattered field produced by the ultrasonic beam focused at that point. We have shown that such an approach is constrained by the resolution limit according to which, it is not possible to resolve subwavelength features. In this paper we interpret the imaging problem as the solution to the inverse scattering problem. Some of the algorithms that are available to deal with the inverse problem are reviewed. It is crucial to base the reconstruction algorithms on more scattering models which can account for features such as multiple scattering and which are robust against random noise. As an illustration of this approach and its applicability to real situations we present some experiments performed with a commercially available phased array imaging system. The experiments were performed on a mild steel block with two through thickness holes with an interaxial separation of 1.5mm at a centre frequency of 2MHz. While the commercial system was not able to separate the two scatterers, due to the half wavelength spacing of the holes, the use of novel imaging algorithms led to a completely resolved image, beating the classical Rayleigh resolution limit by a factor of 2.5.

Finite Element Modeling of Guided Wave Propagation in Plates

---Mandar Godbole, Baskaran Ganesan, **Manoj Kumar KM**, Vamshi Kommareddy, and Sivaramanivas Ramaswamy, GE-Global Research, John F. Welsh Technology Center, #122, Pioneer, Hoodi Village, Whitefield Road, Bangalore, Karnataka 560066, India

---This paper aims at developing a numerical model for guided wave propagation in plates and the interaction of modes with defects using Finite Element Modeling (FEM). In last year's QNDE, we presented a paper in which interaction of A0 and S0 mode of the guided wave with different orientations of flaw was studied. A time-frequency representation of the acquired guided wave mode signals was discussed to show the mode sensitivity with flaw orientation. In this paper, FEM is used to examine interaction of A0 and S0 mode independently with the flaws of various sizes in a plate. An attempt has been done to quantify the signal response with flaw size. A study on effect of flaw orientation/size causing any mode conversion of the guided wave is carried out. Interaction of second modes A1 and S1 with varying flaws sizes and orientation is studied.

A New Method to Produce High Resolution Porosity Images by Means of Active Thermography

---**Günther Hendorfer**, Günther Mayr, Gerald Zauner, Michael Haslhofer, and Ronald Pree, University of Applied Sciences Wels, Sensors and Microsystems/Fachhochschule Wels, Roseggerstrasse 23, A-4600 Wels, Austria

---We present a new approach based on active thermography by which it is possible to produce images of porosity in Carbon Fibre Reinforced Plastics. We applied the method of Pulsed Thermography by using flashes of light for the generation of heat. The evolution of surface temperatures which depends on the diffusivity of the sample and on the sample's geometry could be well fitted by means of a heat conduction model. We applied a new kind of evaluation by which the influence of the light intensity on the data is eliminated. Thus corrections due to the lateral distribution of the heat generation are not necessary. Corrections due to the influence of geometry, however, had to be taken into account. We correlated the porosity of the samples with its diffusivity and produced images as a result. The latter were compared with corresponding images as obtained by state of the art ultrasonic testing. We show that the thermographic method exhibits a better resolution of porosity by about a factor of five. Measurements have been performed on samples with porosities between 0 and 5 %. With some modifications our method can be applied for the quantitative characterization of delaminations of multi-layered samples as well.

Crack Profile Reconstruction by Means of Potential Drop Measurements

---**Giuseppe Sposito** and Peter Cawley, Imperial, 682 Mechanical Engineering, Exhibition Road, London SW7 2AZ, United Kingdom; Peter B. Nagy, University of Cincinnati, Aerospace Engineering & Engineering Mechanics, Cincinnati, OH 45221-0070

---Crack sizing is a problem of major interest in many industrial applications, since the depth of a defect is often a critical parameter in calculations of structural integrity. It has been shown that Potential Drop (PD) techniques are more suitable for defect sizing than other electromagnetic methods such as conventional Eddy Current Testing. The present study aims to investigate the possibility of using PD techniques to determine the depth profile of long defects such as fatigue or stress corrosion cracks. In order to assess the lateral resolution of PD measurements, tests at different frequencies were run with a four-point probe on specimens with notches of variable depth; a simple three-dimensional Finite Element (FE) model was developed and found to be able to accurately predict the experimental results. The indications of this model served as guidelines for the design of a small array probe, which was then used in measurements on specimens with laboratory-grown fatigue cracks. The results of this study show the feasibility of crack profile reconstruction and represent a step towards the development of an experimental setup for impedance tomography.

Markov Chain Monte Carlo Defect Identification and Signal Analysis in NDE Images

---**Aleksandar Dogandzic**, Iowa State University, Center for Nondestructive Evaluation, 1915 Scholl Road, Ames, IA 50011

---It has been of recent interest to develop defect detection methods that account for both the defect amplitude (signal level) and area. Here, we derive an automatic method for identifying elliptically-shaped regions with elevated signal levels in NDE images. We utilize a hierarchical Bayesian approach to model and estimate the defect signals from the noisy measurements. Markov chain Monte Carlo (MCMC) algorithms are developed for simulating from the posterior distributions of the model parameters and defect signals. In this paper, we simulate the model parameters using a shrinkage slice sampling algorithm that is simpler to implement than the algorithm that we presented at QNDE 2005. The proposed algorithms are then utilized to identify potential defect regions and estimate their size and reflectivity parameters. Our approach provides Bayesian confidence regions (credible sets) for the estimated parameters, which are important in NDE applications. We also develop a) a sequential method for identifying multiple potential defect regions and estimating their parameters, b) methods for assessing "relevance" of the obtained potential defect regions, and c) a simple classification scheme for separating defects from non-defects using estimated mean signals and areas of the potential defects. We apply the proposed methods to it to experimental ultrasonic C-scan data from an inspection of a cylindrical titanium billet.---This work was supported by the NSF Industry-University Cooperative Research Program, Center for Nondestructive Evaluation (CNDE), Iowa State University.

Data Fusion for Combining Techniques to Detect and Size Surface and Near-Surface Defects

---**Rachel S. Edwards** and Steve Dixon, Department of Physics, University of Warwick, Coventry, United Kingdom; Ali Sophian and Gui-Yun Tian, School of Computing and Engineering, University of Huddersfield, Huddersfield, United Kingdom

---In NDT it is important to have a high probability of detection and reliable sizing of defects in a sample. This can be gained by using several techniques, which leads to an increase in cost and time for testing. Another option is to use several techniques combined into a single probe, in which case data fusion for the techniques is possible. We report measurements using a dual probe containing a pair of electro-magnetic acoustic transducers (EMATs) generating and detecting low frequency broadband ultrasonic surface waves, combined with a pulsed eddy current (PEC) probe. These two techniques are complementary but can also be combined to work as competitive or cooperative sensors depending on the type of defect being investigated. Our work gives the depth of surface breaking defects by performing data fusion on certain features of each technique, with data fusion by mathematical algorithm or by means of a neural network. Further analysis of the results can give details of the type of defect, for example surface breaking or near surface, and can measure the angle of the defect with respect to the sample surface. The data fusion process has been demonstrated on several samples, including aluminum and steel samples with several defects machined into them, and real defects in metal samples.

Enhanced ID Pit Sizing Using Multivariate Regression Algorithm

---**Kenji Krzywosz**, Electric Power Research Institute, 1300 West WT Harris Blvd., Charlotte, NC 28262

---EPRI is funding a program to enhance and improve the reliability of ID pit sizing for balance-of plant heat exchangers, such as condensers and component cooling water heat exchangers. More traditional approaches to ID pit sizing involve the use of frequency-specific amplitude or phase angles. The enhanced multivariate regression algorithm for ID pit depth sizing incorporates three simultaneous input parameters of frequency, amplitude, and phase angle. A set of calibration data sets consisting of machined pits of various rounded and elongated shapes and depths was acquired in the frequency range of 100 kHz to 1 MHz for stainless steel tubing having nominal wall thickness of 0.028 inch. To add noise to the acquired data set, each test sample was rotated and test data acquired at 3, 6, 9, and 12 o'clock positions. The ID pit depths were estimated using a second order regression function by relying on normalized frequency, amplitude and phase angle information. Due to unique damage morphology associated with the microbiologically-influenced ID pits, it was necessary to modify the algorithm by relying on the destructive sectioning results. This paper presents the use of transformed multivariate regression algorithm to estimate ID pit depths from field-removed samples and compare the results with the traditional univariate phase angle analysis. Both estimates were then compared with the destructive sectioning results.

Modeling Bulk and Guided Wave Propagation in Unbounded Elastic Media Using Absorbing Layers in Commercial FE Packages

---**Mickael Drozdz** and Michael J S Lowe, Mechanical Engineering, Imperial College, London, United Kingdom; Elizabeth Skelton and Richard Craster, Mathematics, Imperial College, London, United Kingdom

---The Finite Element (FE) method is widely used in research to model wave propagation in elastic media and some commercially available FE packages have proven to perform very well as they offer robust memory-efficient solvers and powerful post processing viewing modules. In the field of NDE, FE has become established as a dependable means for predicting wave scattering. Wave radiation out of the area of study is often an essential part of the simulations. The simplest approach to achieve this is to extend the geometric size of the model outside the area of study. This is acceptable for simple models but often put larger or more complex ones beyond modeling capabilities. Several techniques have been developed to obtain radiation out of the area of study at a more reasonable cost by simulating unboundedness of the elastic medium. Well known ones are infinite elements, non-reflecting boundary conditions (NRBC) and absorbing layers, including perfect matching layers (PML) and damped absorbing regions (DAR). This study demonstrates that PML and DAR offer good practical solutions to the wave radiation issue for bulk and guided wave propagation in elastic media as they can be easily implemented in standard FE packages (i.e., no need to develop the code) and achieve high quality results at a reasonable cost. Implementation, use and performance of these techniques are presented.

Session 20

SESSION 20

LASER ULTRASONICS
M. Dubois, Chairperson
Broadway I

1:30 PM **Keynote: Limits of Effective Medium Approximation in Characterization of Finely Patterned Thin Film Structures by Optical and Opto-Acoustic Techniques**
---**A. Maznev**, Philips Advanced Metrology Systems, Natick, MA 01760

2:10 PM **Differential Confocal Fabry-Perot for the Optical Detection of Ultrasound**
---**A. Blouin**, C. Padioleau, C. Néron, D. Lévesque, and J.-P. Monchalin, Industrial Materials Institute, National Research Council of Canada, 75 de Mortagne Blvd., Boucherville, Québec J4B 6Y4, Canada

2:30 PM **Quantitative Evaluation of Damage Threshold for Laser Generation of Ultrasound in Polymer-Matrix Composites**
---**T. E. Drake** and M. Dubois, Lockheed Martin, Laser Ultrasonic Technology Center, Fort Worth, TX 76101

2:50 PM **Laser-Ultrasonics in Harsh Environment: Recent Advancement for On-Line Steel Tube Thickness Gauge**
---**M. Choquet**, S. A. Bérubé, J. Blain, O. Jolicoeur, M. A. Nadeau, J. Paradis, L. Pouliot, C. Trudel, and F. Nadeau, Tecnar Automation Ltd., Saint-Bruno, Québec, Canada

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

3:30 PM **Spectral Analysis of Surface Waves Combined to Laser Ultrasonics for the Non-Destructive Testing of High Performance Materials and Composites**
---**E. F. Lafond** and X. Zhang, Georgia Institute of Technology, Institute of Paper Science and Technology Department, Atlanta, GA 30332

3:50 PM **Transport Properties of Phononic Crystals by Non-Contact Laser Ultrasonics**
---**X. Zhang** and E. Lafond, Georgia Institute of Technology, Atlanta, GA 30332; P. Deymier, University of Arizona, Tucson, AZ ; J. Vasseur, Univeristy of Lille, UFR de Physique

4:10 PM **Ceramic Coating Inspection Using Laser-Based Ultrasonics and Nanoindentation**
---**T. L. Steen** and T. W. Murray, Boston University, Department of Aerospace and Mechanical Engineering, Boston, MA 02215; S. N. Basu and V. K. Sarin, Boston University, Department of Manufacturing Engineering, Boston, MA 02215

4:30 PM **Application of Laser-Ultrasonics to the Non-Contact, Pulse-Echo Measurement of the Thickness of Micron Thin Metallic Coatings**
---**M. A. Nadeau**, M. Choquet, and F. Nadeau, Tecnar Automation Ltd., Laser-NDE, Saint-Bruno, Québec, Canada; F. Martin, Institut National de Recherche Scientifique, Ènergie, matériaux et télécommunication, Varennes, Québec, Canada; A. Blouin and M. Lord, Conseil National de Recherche, Institut des Matériaux Industriels, Boucherville, Québec, Canada

Keynote: Limits of Effective Medium Approximation in Characterization of Finely Patterned Thin Film Structures by Optical and Opto-Acoustic Techniques

---**Alexei Maznev**, Philips Advanced Metrology Systems, Natick, MA 01760

---Optical and opto-acoustic techniques are used to control various process steps in the fabrication of semiconductor devices. One of the trends in semiconductor process metrology is towards making more measurements on finely patterned samples, either directly in the device area or on dedicated test structures. A common approach to modeling optical and acoustical behavior of finely patterned thin films is Effective Medium Approximation (EMA) in which the structure is replaced by a continuous medium with “effective” material properties. EMA requires that the characteristic size of the structure be much smaller than the optical or acoustic wavelength, with the continuous drive to smaller and smaller structures helping to meet this requirement. Often overlooked is another requirement of EMA, namely that the structure size be small compared to the film thickness. In reality, a lot of structures of interest have aspect ratio (lateral size to thickness) on the order of unity or less. Surprisingly, EMA modeling of such structures works quite well in some cases, while yielding highly inaccurate results in others. In this presentation, we will investigate different approaches to modeling patterned thin films and discuss the limits of the applicability of EMA. The discussion will be illustrated by examples from laser-induced surface acoustic wave spectroscopy and infrared reflectometry of various sub-micron structures fabricated on silicon wafers.

Differential Confocal Fabry-Perot for the Optical Detection of Ultrasound

---**A. Blouin**, C. Padioleau, C. Néron, D. Lévesque, and J.-P. Monchalin, Industrial Materials Institute, National Research Council of Canada, 75 de Mortagne Blvd, Boucherville, Québec J4B 6Y4, Canada

---Optical systems for the detection of ultrasound based on a confocal Fabry-Perot interferometer are now widely used in laboratories and industries all over the world for process control during manufacturing or for nondestructive evaluation of parts in service. The best detection limit, i.e. the minimum ultrasonic surface displacement that can be measured, is obtained with systems limited by the shot-noise. However, typical laser oscillators are not free of intensity and phase fluctuations, also called laser noise, and above a given laser light power, these noise sources exceed the shot-noise level. Moreover, since typical industrial surfaces are rough and absorbing, laser amplifiers are commonly used to increase the light power collected back from the surface for improving the detection limit. These amplifiers add both intensity and phase fluctuations to the initial laser beam. The laser intensity fluctuations can be simply eliminated or strongly reduced by a differential scheme made by picking up a small light power collected from the surface. Phase fluctuations are more problematic and up to now no simple scheme has been proposed to reduce this noise source. We will present a simple differential scheme that reduce both the laser intensity and phase noises. Experimental results on the noise reduction reached in the laboratory and in practical applications will also be presented. The implications of this differential approach to relax some laser requirements for optical detection of ultrasound, and its impact on the laser cost, will then be discussed.

Quantitative Evaluation of Damage Threshold for Laser Generation of Ultrasound in Polymer-Matrix Composites

---**Thomas E. Drake** and Marc Dubois, Lockheed Martin, Laser Ultrasonic Technology Center, Fort Worth, TX 76101

---Laser-ultrasonic inspection of polymer-matrix composite components has been successfully employed in manufacturing at Lockheed Martin Aeronautics Company since June of 2000. The technology, called LaserUT®, uses a short-pulsed CO_2 laser to thermoelastically generate ultrasonic waves that are detected by another long-pulsed laser coupled to an interferometer. The CO_2 laser, although adequate, does not have optimum wavelength or pulse characteristics for ultrasound generation in polymers. In previous works, the ultrasonic generation efficiency has been demonstrated to be related to the wavelength-dependent optical penetration of the laser radiation. However, in practice, laser-induced damage limits the total usable laser pulse energy. In this paper, a quantitative approach to evaluate the damage threshold as a function of wavelength is presented. This approach consists of measuring the visible light emitted by the interaction of the infrared generation radiation with a composite sample. The resulting damage threshold measurement is a quantitative precursor to any visual indication of laser-induced damage. A new parameter called laser generation potential is introduced and defined as the product of the measured damage threshold with the measured laser-generation ultrasound efficiency. This laser generation potential as a function of wavelength indicates what wavelengths can safely produce the largest ultrasonic displacements, consequently the largest signal-to-noise ratio for laser-ultrasonic inspection.

Laser-Ultrasonics In Harsh Environment: Recent Advancement for On-Line Steel Tube Thickness Gauge

---**M. Choquet**, S. A. Bérubé, J. Blain, O. Jolicoeur, M. A. Nadeau, J. Paradis, L. Pouliot, C. Trudel, and F. Nadeau, Tecnar Automation Ltd, Saint-Bruno, Québec, Canada

---Laser-ultrasonic is an established technique for non-contact ultrasonic inspection. Use of laser-ultrasonics under laboratory conditions has been made over a wide range of materials and applications, ranging from thin coatings to composite aircraft parts. Transitioning of laser-ultrasonics from laboratory to industrial environment presents a series of challenges. Environmental conditions such as high temperature, dirt, dust, noise and vibrations are often encountered, especially in the steel tube manufacturing industry. Reliability of a sensor is often more important to industry than sensitivity. A technology can sometimes be rejected by industry, not because of lack in performance of the sensor but because of lack of robustness of the sensor. Given these considerations, the presentation will described a robust laser-ultrasonic wall thickness gauge for the steel industry. Examples of three different industrial implementations of the wall thickness gauge will be given, showing how to address the industry challenges and how these solutions can be used in other laser-ultrasonic industrial applications.

Spectral Analysis of Surface Waves Combined to Laser Ultrasonics for the Non-Destructive Testing of High Performance Materials and Composites

---**Emmanuel F. Lafond** and Xinya Zhang, Institute of Paper Science and Technology Dept., Georgia Institute of Technology, Atlanta, GA 30332

---In the 90s and in this current decade, applications of Laser Ultrasonic have progressed further from the research laboratories to the factories. Laser Ultrasonic systems are now penetrating little by little the mills in both the areas of process control and nondestructive testing. Recently, a signal processing technique for ultrasonic waves has emerged, which is used not only in seismology but also in the analysis of the mechanical properties of concrete multilayers or pavements. This technique is called spectral analysis of surface waves (SASW) and examines the variations in the velocity of the Rayleigh waves as function of wavelength and frequency. Combining SASW at high frequencies, to laser ultrasonics creates an excellent opportunity for solving some non-destructive testing challenges of multilayered high performance products as well as products having a gradient in their mechanical properties. We present experimental results obtained on high performance multilayered materials using a laser-ultrasonics laboratory instrument and software entirely developed at Georgia Tech. We used the 2 Dimensional Fast Fourier Transform (2D-FFT) method to obtain vivid representations of surface wave velocities at high frequencies in multilayered samples.

Transport Properties of Phononic Crystals by Non-Contact Laser Ultrasonics

---**Xinya Zhang** and Emmanuel Lafond, Georgia Institute of Technology, Atlanta, GA 30332; Pierre Deymier, University of Arizona, Tucson, AZ; Jerome Vasseur, UFR de Physique, University of Lille

---Phononic structures and acoustic bandgaps based on bulk materials have been researched in length in the past decades. However few investigations have been performed on phononic structures on thin plates to form surface acoustic wave (SAW) bandgaps. In this presentation, we report a new type of phononic crystals by patterning periodical air-filled holes on thin plates. Their acoustic transport properties were characterized by a non-contact laser ultrasonic instrument. The laser ultrasonic instrument is comprised of ultrasound generation unit, ultrasonic probe, home-built photo-refractive two-wave-mixing interferometer for demodulating ultrasound amplitude, signals processing, data acquisition and analysis system. We confirmed the existence of SAW bandgaps in the created phononic crystals experimentally the laser ultrasonic instrument. Wide multiple SAW bandgaps and special structures such as narrow pass-bands within a bandgap were evident in the experiments. The gaps center frequencies and bandwidths were demonstrated to vary with the scaling of phononic crystal lattices and the thickness of the plates.

Ceramic Coating Inspection Using Laser-Based Ultrasonics and Nanoindentation
---**Thomas L. Steen** and Todd W. Murray, Department of Aerospace and Mechanical Engineering, Boston University, Boston, MA 02215; Soumendra N. Basu and Vinod K. Sarin, Department of Manufacturing Engineering, Boston University, Boston, MA 02215

---A combination of laser-based ultrasonic (LBU) inspection and nanoindentation testing is used to evaluate the thickness uniformity and through-thickness mechanical property distributions in 5-20mm thick CVD environmental barrier coatings. Mullite (3Al2O3 2SiO2) coatings grown on silicon carbide substrates are studied in order to provide feedback on the growth process under a range of operating conditions. Nanoindentation tests are performed on polished coating cross sections, and the depth dependence of the elastic modulus of each coating is found. In the LBU experiments, a modulated continuous wave (CW) source is used for surface wave generation. The source is held at a fixed temporal frequency as it is scanned over the surface of the coating. At each temporal frequency of interest, the spatial frequencies of the acoustic modes are found, allowing for phase velocities to be determined. The mean values of elastic moduli found using the LBU approach compare well with the nanoindentation results. It is also found that the functional form of the elastic modulus distribution in a coating can be extracted from the LBU measurements, and that this distribution shows general agreement with nanoindentation results.

Application of Laser-Ultrasonics to the Non-Contact, Pulse-Echo Measurement of the Thickness of Micron Thin Metallic Coatings
---**M. Alexandre Nadeau**, Marc Choquet, and François Nadeau, Tecnar Automation Ltd, Laser-NDE, Saint-Bruno, Quebec, Canada ; François Martin, Institut National de Recherche Scientifique, Énergie, matériaux et télécommunication, Varennes, Quebec, Canada ; Alain Blouin and Martin Lord, Conseil National de Recherche, Institut des Matériaux Industriels, Boucherville, Québec, Canada

---The general scope of this work is the development of an industrial, non-contact sensor for online monitoring of coating thicknesses as thin as 10 micrometers using laser-ultrasonics in the conventional pulse echo configuration. Experiments were first performed using a femto-second laser to generate ultra short compression wave pulses. Coating/substrate interface echoes were detected with a confocal Fabry-Perot coupled to a MISER type, continuous Nd:YAG laser. The results show that the confocal Fabry-Perot is often inappropriate for the detection of ultrasound pulses having spectral widths much larger than the interferometer's free spectral range. A second experimental session was conducted using a pico-second laser for the generation and an amplified (long pulsed) Nd:YAG laser coupled to an In-P-Fe photorefractive interferometer for the detection. Multiple echoes of broad band compression waves (up to 500 MHz) were successfully detected on electrodeposited metallic coatings of zinc on steel substrates. The results show very little dispersion and attenuation in the zinc coatings. Thicknesses from 27 to 100 microns were measured and well correlated to the micrometer measurements. Although the majority of results were obtained with single, ablative, generation shots, good measurements were also obtained by averaging multiple thermoelastic shots that left the surface absolutely unmarked.

Session 21

SESSION 21

STRUCTURAL HEALTH MONITORING I

K. Jata, Chairperson
Pavilion East

1:30 PM **Ultrasonic Sensing and Life Prediction for the DARPA Structural Integrity Prognosis System**
---**J. E. Michaels**, T. E. Michaels, and A. C. Cobb, Georgia Institute of Technology, School of Electrical and Computer Engineering, Atlanta, GA 30332; G. J. Kacprzynski, Impact Technologies LLC, Rochester, NY 14627

1:50 PM **Systems and Structural Health Monitoring: A Cost Benefits Analysis**
---**J. C. Duke, Jr**., Virginia Tech, ESM Department, 225 Norris Hall, MC 0219, Blacksburg, VA 24061-6063

2:10 PM **Probabilistic Risk Assessment: Impact of Human Factors on Nondestructive Evaluation and Sensor Degradation on Structural Health Monitoring**
---**J. C. Aldrin**, Computational Tools, Gurnee, IL; E. A. Medina, Enrique Medina & Associates, Beavercreek, OH 45430; J. S. Knopp and E. A. Lindgren, Air Force Research Laboratory, Wright Patterson AFB, OH 45433-7817; D. A. Allwine, Austral Engineering & Software, Inc., Athens, OH 45701

2:30 PM **Development of Piezoelectric Strain Gages for Structural Health Monitoring Applications**
---A. Yenilmez, A. Yapici, C. Velez, and **I. N. Tansel**, Florida International University, Department of Mechanical and Materials Engineering, Miami, FL 33174; K. V. Jata, Metals, Ceramics and NDE Division, Wright Patterson Air Force Base, OH 45433-7816

2:50 PM **Direct-Write Strain and Temperature Sensors for Harsh Environments**
---**C. Gouldstone**, MesoScribe Technologies, Inc., 25 Health Sciences Drive, Stony Brook, NY 11790

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

3:30 PM **A Novel Ultrasonic Wireless SHM System for Structural Integrity Monitoring of an Aircraft Wing**
---**X. Zhao**, T. Qian, G. Mei, and G. Zhang, Intelligent Automation, Inc., Rockville, MD 20855

3:50 PM **Application of Wave Propagation and Vibration-Based Structural Health Monitoring Techniques to Friction Stir Weld Plate and Sandwich Honeycomb Panel**
---**S. Sundararaman**, J. R. White, D. E. Adams, Purdue University, School of Mechanical Engineering, 585 Purdue Mall, West Lafayette, IN 47907-2088; K. V. Jata, Materials and Manufacturing Directorate, Air Force Research Laboratory, Dayton, OH 45433-7816

4:10 PM **Effect of Adhesive Material Properties on Induced Stresses in Bonded Sensors**
---**S. A. Martin**[1] and J. L. Blackshire[2], [1]Wright Patterson AFB, NDE Branch, Air Force Research Laboratory, OH; [2]NDE Computational Consultants, Dublin, OH 43016

4:30 PM **The Effect of Transducer Placement on the Monitoring of Fatigue Cracks Emanating from Fastener Holes**
---**A. C. Cobb**, J. E. Michaels, and T. E. Michaels, Georgia Institute of Technology, School of Electrical and Computer Engineering, 777 Atlantic Drive, NW, Atlanta, GA 30332-0250

4:50 PM **Algorithm for Health Monitoring of Anisotropic Plates Using Flexible Ultrasonic Patches**
---**B. V. S. Sekhar** and K. Balasubramaniam, Indian Institute of Technology, Department of Mechanical Engienering, Machinde Design Section, Madras, Chennai, India; C. V. Krishnamurthy, Indian Institute of Technology, Center for NDE, Madras, Chennai, India

Ultrasonic Sensing and Life Prediction for the DARPA Structural Integrity Prognosis System

---**Jennifer E. Michaels**, Thomas E. Michaels, and Adam C. Cobb, School of Electrical and Computer Engineering, Georgia Institute of Technology, Atlanta, GA 30332; Gregory J. Kacprzynski, Impact Technologies LLC, Rochester, NY

---The overall objective of DARPA's Structural Integrity Prognosis System (SIPS) program is to develop technologies to advance material damage state condition assessment with limited or no dedicated maintenance action. As a part of a laboratory-based initiative in this program, an in situ ultrasonic sensing method was developed and demonstrated to detect cracks initiating from fastener holes and provide an estimate of total crack area. Crack area estimates were combined with load history data, projected future loads, and life prediction models to determine a probability density function for time-to-failure. The ultrasonic method utilizes two shear wave angle beam transducers operating in through transmission mode which are mounted on either side of the hole. The transmitted wave travels through the area of expected cracking, and the presence of cracks around the fastener holes decreases the amount of acoustic energy that is received. Furthermore, as cracks open and close during the fatigue process, the received energy is modulated, i.e., decreased when the cracks are open versus closed, and this non-linear behavior is the basis of algorithms developed to detect and size fastener holes cracks. The ultrasonic method was demonstrated as part of an integrated SIPS demonstration whereby aircraft-grade aluminum subcomponents were fatigued to failure. Results are presented from both the ultrasonic measurements and the integrated life prediction software.

Systems and Structural Health Monitoring: A Cost Benefits Analysis

---**John C. Duke, Jr.**, Virginia Tech, ESM Department, 225 Norris Hall, MC 0219, Blacksburg, VA 24061-6063

---Systems and structural health monitoring has become an area of high activity lately. Research regarding innovative sensors, wireless instrumentation, energy scavenging or harvesting, and data mining are some of the areas being studied. It is perhaps useful to pause and assess the practicality and feasibility of these efforts. Often engineering design approaches fail to effectively integrate such monitoring into the process and at times give it no consideration at all. NDE practitioners are quick to argue for design for inspectability which might be expanded to include health monitoring. However, is systems and structural health monitoring a cost effective element of the engineering asset management process. This paper seeks to provide a framework for determining the benefits of health monitoring and considers some examples. It also offers a suggestion for a design paradigm that lends itself to effective utilization of health monitoring and prognosis.

Probabilistic Risk Assessment: Impact of Human Factors on Nondestructive Evaluation and Sensor Degradation on Structural Health Monitoring

---**John C. Aldrin**, Computational Tools, Gurnee, IL; Enrique A. Medina, Enrique Medina & Associates, Beavercreek, OH; Jeremy S. Knopp and Eric A. Lindgren, Air Force Research Laboratory, Wright-Patterson AFB, OH; Daniel A. Allwine, Austral Engineering & Software, Inc., Athens, OH 45701

---Prior work addressed development of a strategy and software platform to enable analysis of tradeoffs in NDE and structural health monitoring (SHM) design in terms of product life cycle outcomes. Issues in nondestructive inspection discovered through recent probability of detection studies generated an interest in determining the impact of inspection performance on total service life. For inspection problems that include manual scanning, complex procedures, and low frequencies of finding critical flaws, there is a potential for some critical sites to not be inspected effectively due to the requirements of the inspection process, or there are inconsistent requirements for calling marginal defects. A related topic concerning SHM systems is the problem of managing sensor degradation over time. To investigate these issues, quantitative studies are presented evaluating the effects of variations in probability of detection associated with human factors, plus in-situ sensor degradation on life cycle measures such as cost and probability of failure. Design tools have also been integrated in the software platform to easily explore variable number of inspection intervals and variable length of each service period. In addition, the assumption of statistical independence for multiple measurements of the same component or inspection system over time will be considered.

Development of Piezoelectric Strain Gages for Structural Health Monitoring Applications

---Aylin Yenilmez, Ahmet Yapici, Carlos Velez, and **Ibrahim N. Tansel**, Department of Mechanical and Materials Engineering, Florida International University, Miami, FL 33174; Kumar V. Jata, Metals, Ceramics and NDE Division, Wright Patterson Air Force Base, OH

---Strain distribution characteristics of the structures are a well known indicator of structural integrity and widely used to evaluate the condition of the parts of air vehicles. Resistive strain gages have been widely used in engineering applications. A new trend in the structural health monitoring is development of self powered sensors to attach them even to the most hard to reach places, to increase system reliability and to minimize the wiring problems. Efficient use of the electricity is the main concern in these sensors. Instead of using a bridge, strain gages, and amplifier, measurement of the voltage coming from a piezoelectric sensor is a very attractive solution. However, the accuracy and the crosstalk are serious problems for the piezoelectric patches. In this study, the characteristics of the piezoelectric strain gages are studied numerically by using Finite Element Method (FEM) and the results are experimentally verified. Piezoelectric patches are sensitive to the loadings in any direction. Experimental evaluation of the crosstalk of the piezoelectric patches and strain gages are very time consuming and costly. In this study ANSYS FEM package was used to evaluate the characteristics of piezoelectric patches to various loading conditions. The strain of a beam was measured with a resistive strain gage and piezoelectric patch experimentally at the same time under different loading conditions. The FEM program output was calibrated with the experimental data. A good agreement was observed between the estimated characteristics of the piezoelectric patch and experimental results. Based on the study an optimized design is proposed.

Direct-Write Strain and Temperature Sensors for Harsh Environments

---**Chris Gouldstone**, MesoScribe Technologies, Inc., 25 Health Sciences Drive, Stony Brook, NY 11790

---Direct-write (DW) is a high-precision deposition process which is able to create fine features on non-flat substrates with harsh environment tolerance. Single- and multi-layer devices may be constructed from a variety of polymers, ceramics and metals. DW has been applied to fabrication of strain gages, thermocouples and other environmental sensors. The advantages of direct-write for harsh environments include: superior adhesion to substrates without low-T_m epoxies; flexibility to select temperature-tolerant and substrate-compatible device materials; ability to produce low-mass, low-profile multi-layers for rotating and wetted components; ability to embed devices within functional coatings; and batch reproducibility through automated processing, minimizing cost and reject rate. Resistive direct-write strain gages exhibit consistent and repeatable strain-reporting. Through a ceramic device-substrate interface, the device tracks axial deformation of the instrumented component. Automated, integrated alignment and deposition processes simplify sensor installation and improve accuracy. Direct-write thermocouple junctions are innately suited to surface temperature measurements, offering higher fidelity thermal interfaces than conventional contact thermocouples. Direct-write thermocouple compositions produce thermoelectric output consistent with NIST standards, for compatibility with available infrastructures e.g., extension leads, junctions and readers.

A Novel Ultrasonic Wireless SHM System for Structural Integrity Monitoring of an Aircraft Wing

---**Xiaoliang Zhao**, Tao Qian, Gang Mei, and Guangfan Zhang, Intelligent Automation, Inc., Rockville, MD 20855

---A wireless, in-situ ultrasonic guided wave structural health monitoring (SHM) system will be demonstrated for an aircraft wing panel inspection. The system consists of small and light weight PZT transducers that are permanently attached to the inner surface of the wing, an embedded diagnosis device that incorporates a local miniature ultrasonic pulser to produce 350 kHz, 70 V peak-to-peak tone-burst signal, a microprocessor controlled multiplexer and A/D chip for multi-channel data acquisition, programmable gain amplifier for channel compensation and a wireless radio module for data transmission, and an X-band microwave rectenna for wirelessly powering the embedded sensors and electronics in the wing. For the algorithm part, reference ultrasonic data are collected first at the normal state as the baselines. Data collected afterward in correlation with the reference data can monitor the initiation and growth of defects like loose rivets, cracks at rivet holes, and corrosion, etc. The defect location can also be estimated through a probabilistic reconstruction algorithm. In the demo, real-time data collection with the wireless SHM system on an E-2 aircraft wing panel and some test results on drilling a rivet out to simulate a loose rivet, and cutting a notch at the rivet hole to simulate cracks will be shown.

Application of Wave Propagation and Vibration-Based Structural Health Monitoring Techniques to Friction Stir Weld Plate and Sandwich Honeycomb Panel

---**Shankar Sundararaman**, Jonathan R. White, Douglas E. Adams, Purdue University, School of Mechanical Engineering, 585 Purdue Mall, West Lafayette, IN 47907-2088; Kumar V. Jata, Materials and Manufacturing Directorate, Air Force Research Laboratory, Dayton, OH 45433-7816

---Wave propagation and vibration-based structural health monitoring methodologies are presented to detect, locate and quantify dent/crack, thermal debond, and corrosion damage in a solid aluminum friction stir weld plate and a sandwich honeycomb thermal protection panel. A wave propagation based method can identify small defects because propagating waves typically consist of small wavelengths while a vibration-based scheme is better equipped to quantify damage over wide areas of large structures. Near-real time online diagnostics is achieved by using localized sensing (wave propagation) and distributed sensing (vibration-based) in an active measurement array. Sensor/actuator arrays have been developed to implement these techniques and portable health management systems have been developed based on the combination of damage detection algorithms, active sensing, and graphical user interface. Wave propagation damage detection has a heightened sensitivity to damage located at the anti-nodes of a friction stir wed plate forced by low frequency environmental vibrations. Measurement of the input forcing in the vibration-based method increases the sensitivity to the quantification of damage.

Effect of Adhesive Material Properties on Induced Stresses in Bonded Sensors

---**Steven A. Martin**[1] and James L. Blackshire[2], [1]Wright-Patterson AFB, NDE Branch, Air Force Research Laboratory, OH; [2]NDE Computational Consultants, Dublin, OH 43016

---An analysis of the stresses induced in adhesively bonded sensors from a biaxial stress field in the underlying substrate is presented. Recent Structural Health Monitoring work has looked at using surface bonded sensors to detect and characterize damage in aircraft structures. In addition to the proper design of these systems, it is important that they be able to survive in a sometimes hostile operating environment in terms of weather, vibration, temperature, and mechanical loading of the structural members of the airframe. The analysis first considers the load transfer mechanism from the substrate through the adhesive layer into the sensor. The partitioning of the load between the substrate and sensor is found to depend on the substrate stiffness, the sensor thickness, and the shear modulus and thickness of the adhesive. The analysis then shows that for an elliptically shaped sensor whose maximal dimension is small compared to the substrate in-plane dimensions the stress induced by a biaxial state of stress can be determined using inclusion theory. It is further shown that the stresses in a circular sensor on a substrate subjected to a hydrostatic state of stress can be calculated using equations derived from those used to determine the interfacial pressure for an interference fit between annular cylinders. Finally, the analysis considers the induced bending stresses caused by the asymmetric change in thickness in the region where the bonded sensor resides.

The Effect of Transducer Placement on the Monitoring of Fatigue Cracks Emanating from Fastener Holes

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

---In situ ultrasonic methods for structural health monitoring have the potential to provide early detection and sizing of fatigue cracks in aircraft components, specifically cracks initiating from fastener holes. A dual angle beam technique where the transducers are mounted on either side of the hole has been shown to be a viable configuration for monitoring of fastener hole cracks. The shear wave incident upon the hole mode converts to a spiral creeping wave which then “leaks” back to the receiver as a shear wave. This technique takes advantage of the interference of the creeping wave with cracks opening and closing under load, and the ratio of received energy under a reference load to that under no load is monitored for crack detection and sizing. While prior work with this method has been very promising, transducer placement can significantly influence its performance. Here we consider the effect of transducer placement on the sensitivity of the energy ratio algorithm, using the expected location of cracking to guide placement of transducers; the strategy is to ensure that the path of the largest received echo is centered on the most probable crack location. Experimental results are compared to predictions using a simple model, and are also compared to results obtained using the original transducer locations. Agreement with the model is reasonable, and the results with the new transducer placement show increased sensitivity and earlier detection compared to those obtained with the original transducer placement.

Algorithm for Health Monitoring of Anisotropic Plates Using Flexible Ultrasonic Patches

---**B. V. Soma Sekhar** and Krishnan Balasubramaniam, Indian Institute of Technology, Department of Mechanical Engineering, Machinde Design Section, Madras, Chennai, India; C. V. Krishnamurthey, Indian Institute of Technology, Center for Nondestructive Evaluation, Madras, Chennai, India

---Fiber reinforced composite plate-like structures have been used to achieve substantial reductions in the structural weight of both military and commercial aircrafts. For large area and layered structures, damage detection using any conventional testing methods is time consuming. Structural Health Monitoring (SHM) of such structures is seen as a new paradigm that will reduce maintenance costs and increase safety. The aim of the technology is not simply to detect structural failure, but also provide an early indication of physical damage. The early warning provided by an SHM system can then be used to define remedial strategies before the structural damage leads to failure. This paper describes the development and successful demonstration of a SHM system using Smart Flexible Sensor Patch (FSP) that has a built-in network of Piezoelectric Wafer Active Sensors (PWAS) embedded on a thin film of dielectric material. These PWAS are arranged such that conventional cross-hole tomography (CHT) as well as modified cross-hole tomography (MCHT) can be carried out using Lamb waves. Using MCHT the lateral extent of the damage for barely visible low-velocity impact damages (BVID) on Composite structures like wing and aileron are imaged with reasonable accuracy. The conventional CHT was deployed in a region of large aspect-ratio such as stiffeners. It was observed that disbonds of stiffener in Elevon and other structures may be effectively monitored by this method.

Session 22

SESSION 22

UT PHASED ARRAYS

B. Addison, Chairperson
Broadway II

1:30 PM **Investigating the Influence of the Constituent Materials on the Performance of Periodic Piezoelectric Composite Arrays**
---G. Harvey, R. L. O'Leary, A. C. S. Parr, G. Hayward, and **A. Gachagan**, University of Strathclyde, Centre for Ultrasonic Engineering, Glasgow, United Kingdom; A. Troge and R. A. Pethrick, University of Strathclyde, Department of Chemistry and Applied Chemistry, Glasgow, United Kingdom

1:50 PM **Dynamic Control of Aperture Width Using DDF Phased Array Instrumentation**
---**R. Roberts**, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

2:10 PM **Phased Array Inspection of Irregular Surfaces**
---**R. Long** and P. Cawley, Imperial College, Mechanical Engineering, Exhibition Road, London, SW7 2AZ, United Kingdom

2:30 PM **An Improved Conformable Array Structure for the NDE of Irregular Surfaces**
---G. Harvey, J. Mackersie, and **A. Gachagan**, University of Strathclyde, Centre for Ultrasonic Engineering, Glasgow, United Kingdom

2:50 PM **Optimization of Array Controlling for Complex NDT-Problems**
---**E. Kuehnicke**, Technische Universität Dresden, Fakultät Elektrotechnik, Institute für Festkörperelektronik, 01062 Dresden, Germany

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

3:30 PM **Implementation of Advanced Array Signal Processing Techniques in Commercial Array Controller**
---**P. D. Wilcox**, C. Holmes, and B. W. Drinkwater, University of Bristol, Department of Mechanical Engineering, Bristol, United Kingdom

3:50 PM **Simulation and Data Processing for Ultrasonic Phased-Array Applications**
---S. Chaffai-Gargouri, S. Chatillon, S. Mahaut, and **L. Le Ber**, CEA-LIST, Commissariat à l'Energie Atomique, Saclay, France

4:10 PM **SAFT Applied to Anisotropic and Attenuative Materials Using Sparse Array Data and Signal Processing**
---**M. Spies** and H. Rieder, University of Saarland, Fraunhofer Institute for Nondestructive Testing IZFP, Physical Basics Department, Bldg. E3.1, 66123 Saarbruecken, Germany

4:30 PM **Approximate Evaluation of Acoustical Focal Beams by Phased Array Probes for Austenitic Weld Inspection**
---**N. Kono** and M. Miki, Hitachi, Ltd. Power & Industrial Systems R&D Laboratory, 7-2-1 Omika-cho, Hitachi-shi, Ibaraki-ken, 319-1221, Japan; M. Nakamura, Hitachi, Ltd., Nuclear Systems Division, 1-1 Saiwai-cho, Hitachi-shi, Ibaraki-ken, 317-8511, Japan; K. Ehara, Hitachi, Ltd., Quality Assurance Division, 3-1-1 Saiwai-cho, Hitachi-shi, Ibaraki-ken, 317-8511, Japan

4:50 PM **Diagnostic Capability of Processed Phased-Array Images for Spot Weld Inspection**
---**D. L. Hopkins** and W. B. Davis, Lawerence Berkeley National Laboratory, Engineering Division, Mailstop 46A-1123, 1 Cyclotron Road, Berkeley, CA 94720; F. Reverdy, Commissariat a l'Energie Atomique, Paris, France

Investigating the Influence of the Constituent Materials on the Performance of Periodic Piezoelectric Composite Arrays

---Gerald Harvey, Richard L. O'Leary, Agnes C. S. Parr, Gordon Hayward, and **Anthony Gachagan**, Centre for Ultrasonic Engineering, University of Strathclyde, Glasgow, United Kingdom; A Troge and Richard A. Pethrick, Department of Chemistry and Applied Chemistry, University of Strathclyde, Glasgow, United Kingdom

---Ultrasonic transducer arrays are regularly employed in both biomedicine and sonar systems and are now finding application in a number of inspection procedures within NDE. The piezoelectric composite configuration is commonly used as the active material, where selection of the constituent materials is crucial in the design process. In recent years, new piezoelectric and polymeric materials have been shown to improve array sensitivity, bandwidth and imaging performance in biomedical and sonar applications. These same potential benefits can be realized when implemented as a NDE array. This paper describes a theoretical investigation into the influence of the constituent materials on periodic composite array transducer performance. A finite element (FE) model is used to analyze the performance of a wedge coupled array transducer operating into a steel component. Here, the improvements offered by new single crystal piezoelectric materials are compared to standard pzt-based configurations. In addition, new passive polymer materials, possessing low longitudinal loss and high shear loss, are evaluated for their potential to significantly reduce inter-element mechanical cross talk. The FE results provide a clear indication of the next generation of array transducers incorporating these new materials and this is highlighted in the A-scan predictions from simulated defects.

Dynamic Control of Aperture Width Using DDF Phased Array Instrumentation

---**Ronald Roberts**, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

---Dynamic Depth Focusing in phased array instrumentation is a powerful technology that allows the focal depth of a receiver to be varied in real time, so as to track the position of an interrogating pulse as it travels into a medium. In most available hardware, this capability is implemented such that the number of array elements used in reception is fixed throughout the dynamic sweep of the focal depth. As a consequence, the degree of beam focus decreases with distance from the array. This result is undesirable in applications calling for a constant degree of focus on reception. Although it is in principle possible to implement a dynamic control of aperture width in electronic hardware (i.e. turn on outer elements with increased focal depth), such hardware is generally not available on commercial instrumentation. This paper presents an alternative means to dynamically control aperture width utilizing the current capabilities of commercially available DDF hardware, in which all elements in the aperture are always receiving. The algorithm maintains elements outside the desired aperture in a state of self-cancellation until it is time for them to contribute, at which time they are temporally aligned with the contributing elements of the receiving aperture. The underlying concept of the control scheme will be discussed and demonstrated using model simulations. Experimental results will then be presented demonstrating hardware implementation.

Phased Array Inspection of Irregular Surfaces

---**Robert Long** and Peter Cawley, Mechanical Engineering, Imperial College, Exhibition Road, London, SW7 2AZ, United Kingdom

---The purpose of this work is to research and develop new conformable phased arrays that allow reliable ultrasonic inspection of components with irregular surfaces. The intention is to replace radiography with ultrasonic techniques wherever possible. Investigations have been conducted to evaluate the relative merits of two alternative approaches for the application of phased arrays to complex surfaces: flexible contact arrays in which the array itself conforms to the surface and a conformable membrane (water-wedge) system in which a standard array is coupled to the surface via a fluid-filled membrane. A linear flexible contact phased array was purchased from CEA France and a conformable membrane device, with an integral standard linear phased array transducer, was designed and manufactured at Imperial College. Initial investigations were conducted to evaluate both approaches when coupling to test pieces with machined surfaces representative of typical welded pipes without removal of the weld caps. The research incorporated beam modeling using the CEA CIVA software and comparisons with experimental measurements. It is shown that the conformable membrane approach using a standard array transducer is competitive with the bespoke flexible array.

An Improved Conformable Array Structure for the NDE of Irregular Surfaces

---Gerald Harvey, John Mackersie, and **Anthony Gachagan**, Centre for Ultrasonic Engineering, University of Strathclyde, Glasgow, United Kingdom

---Inspection of the many complex component geometries found in NDT would benefit greatly from an efficient flexible piezoelectric material. Additionally, a 2D array configuration can enhance the coverage map and defect detection capability of an inspection process. This paper describes a novel composite array structure that combines the performance advantages of a conventional 1-3 piezocomposite with the increased flexibility associated with the piezo-platelet arrangement. Specifically, each array element in the 2D matrix is a fine scale piezocomposite structure, with a relatively large soft polymer phase between each element. By careful choice of the polymer phases within the piezocomposite structure and between each array element (these need not necessarily be the same material), an efficient and very flexible (roc < 5mm) piezoelectric material can be achieved. Experimental measurements of electrical impedance, surface displacement and mechanical cross talk in this structure demonstrate good correlation with Finite Element (FE) results, employing the PZFlex code. Moreover, this material demonstrates a sensitivity and bandwidth comparable with a conventional 1-3, while exhibiting superior conformability, when operating directly into a steel pipe test specimen.

Optimization of Array Controlling for Complex NDT-Problems

---**Elfgard Kuehnicke**, Technische Universität Dresden, Fakultät Elektrotechnik, Institute für Festkörperelektronik, 01062 Dresden, Germany

---The controlling modes of a curved broadband array for pipe inspection and of a plane array for testing of half finished products are optimized by means of calculating the time harmonic and transient fields. The sound fields are calculated both in the water delay and in steel. Essentially there are four problems to get a correct controlling: a limitation of steering angle, incorrectness of the geometrically determined steering angle, grating lobes and a false orientation of element with respect to the resulting wave train. If side lobes are classify and assign to the different effects an intentional optimization of controlling is possible. For both arrays the middle element distance is about a half wavelength regarding to steel and about two wavelengths regarding to water. Therefore grating lobes exist in water delay only and do not transfer into steel. However, there is an energy loss for the sound field in steel that depends on the magnitude of the grating lobes in water. Especially for the curved array, side lobes also appear in steel. They are caused by an incorrect steering of the outer elements and by the false orientation of elements. These side lobes can be reduced by controlling.

Implementation of Advanced Array Signal Processing Techniques in Commercial Array Controller

---**Paul D. Wilcox,** Caroline Holmes, and Bruce W. Drinkwater, Department of Mechanical Engineering, University of Bristol, Bristol, United Kingdom

---At previous QNDE meetings the authors have presented various algorithms for improving the characterization of small (sub-wavelength) defects by post-processing the data from an ultrasonic array. These include the Total Focusing Method (TFM) for optimizing the resolution of an image, the Vector TFM (VTFM) for determining reflector orientation and a method of measuring the specularity of a reflector. All these techniques require access to the full matrix of time-domain signals from every transmitter receiver combination in an array. Previously, the process of performing full matrix capture (FMC) was achieved using single channel ultrasonic equipment and a PC controlled multiplexer, a process that is laborious and time-consuming. In this paper the practical use of FMC in a commercial array controller is presented and implementation issues are discussed. It is shown that this gives a 20 dB improvement in signal to random noise ratio compared to the previous multiplexed solution and significantly reduces the taken to perform FMC, the rate determining step currently being the data transfer rate between array controller and PC. Results will be presented that show the application of the TFM, VTFM and specularity algorithms to various samples containing a variety of sub-wavelength reflectors. It will also be shown how these algorithms can be applied to the data obtained from an array scanned over the surface of a component, which increases the effective aperture and range of probing angles for the algorithms.

Simulation and Data Processing for Ultrasonic Phased-Array Applications

---Chaffai-Gargouri, Sylvain Chatillon, Steve Mahaut, and Laurent **Le Ber**, CEA-LIST, Commissariat à l'Energie Atomique, Saclay, France

---The use of phased -arrays techniques have considerably contribute to extend the domain of application and the performances of ultrasonic methods on complex configurations. Their adaptability offers a great freedom for conceiving the inspection leading to a wide range of functionalities gathering electronic commutation, applications of different delay laws and so on. This advantage allows to circumvent the difficulties encountered with more classical technique especially when the inspection is assisted by simulation at the different stages: probe design (optimization of the number et characteristics of the elements), evaluation of the performances in terms of flaw detection (zone coverage) and characterization), driving the array (computation of adapted delay laws) and finally analyzing the results(versatile modeled based imaging tools allowing in particular to locate the data in the real space). The CEA is strongly involved in the development of efficient simulation-based tools adapted to these needs. In this communication we present the recent advances done at CEA in this field and show several examples of complex NDT phased arrays applications. On these cases we show the interest and the performances of simulation-helped array design, array-driving and data analysis.

SAFT Applied to Anisotropic and Attenuative Materials Using Sparse Array Data and Signal Processing

---**Martin Spies** and Hans Rieder, Physical Basics Department, Fraunhofer Institute for Nondestructive Testing IZFP, University of Saarland, Bldg. E3.1, 66123 Saarbruecken, Germany

---Ultrasonic inspection plays an important role in many industrial fields. One of the main tasks with respect to quantitative nondestructive evaluation is the determination of location, shape, size and orientation of defects. In this respect, the Synthetic Aperture Focusing Technique (SAFT) has been successfully applied to isotropic materials over the years. Its application is particularly interesting when attenuative media have to be inspected, since the method leads to improved signal-to-noise ratios in defect reconstruction. For composite materials, its application requires the consideration of the direction dependence of the ultrasonic velocities, the beam skewing effect and the modified transducer radiation characteristics, which are due to the anisotropic nature of such materials. A corresponding SAFT imaging algorithm - implemented for orthotropic material symmetry - has been presented previously. In this contribution, improved SAFT imaging methodologies are presented. The problem of unfavorable beam fields of conventional transducers - occurring for specific elastic material properties - is solved by using a two-dimensional array for beam focusing and steering. Additionally, redundant sets of rf-data are acquired and used for image reconstruction by exciting the transmit and receive elements, respectively, in variable subsets (‘sparse array’). Also, various signal processing schemes have been applied and checked in view of their efficiency. Experiments have been performed on unidirectional composite material and on a highly attenuative Duplex stainless steel.

Approximate Evaluation of Acoustical Focal Beams by Phased Array Probes for Austenitic Weld Inspection

---**Naoyuki Kono** and Masahiro Miki, Hitachi, Ltd., Power & Industrial Systems R & D Laboratory, 7-2-1 Omika-cho, Hitachi-shi, Ibaraki-ken, 319-1221, Japan; Motoyuki Nakamura, Hitachi, Ltd., Nuclear Systems Division, -1-1 Saiwai-cho, Hitachi-shi, Ibaraki-ken, 317-8511, Japan; Kazuya Ehara, Hitachi, Ltd., Quality Assurance Division, 3-1-1 Saiwai-cho, Hitachi-shi, Ibaraki-ken, 317-8511, Japan

---A Phased array technique is capable of sensitive detection and precise sizing of flaws or cracks because it has arbitral focal beams with various depths, positions and angles. Quantitative investigation of the focal beam is essential for the optimization of the probes, especially for austenitic weld inspection in order to improve detectability, sizing accuracy and signal-to-noise ratio. In the present work, focal beams generated by the phased array probe are calculated based on the Fresnel-Kirchhoff diffraction theory, and an approximation formula between actual focal depth and optical focal depth is proposed as an extension of the theory for conventional single circular focus probes with a spherical surface. The validity of the approximation formula is confirmed for array probes in comparison with numerical calculation results. Additionally, effects of curvature of test surface are estimated by calculations and experiments. The main results are as follows. 1) Actual focal depths for phased array probes are shorter than optical focal depths in similar to conventional focus probes. The relation between actual and optical focal depths is estimated by the extended formula for the single focus probe. 2) Aspect ratio of rectangle phased array probes for linear focusing is optimized using the approximation formula.

Diagnostic Capability of Processed Phased-Array Images for Spot Weld Inspection

---**Deborah L. Hopkins** and W. Bart Davis, Lawrence Berkeley National Laboratory, Engineering Division, Mailstop 46A-1123, 1 Cyclotron Road, Berkeley, CA 94720; Frederic Reverdy, Commissariat a l'Energie Atomique, Paris, France

---Experiments performed on test specimens provided by automotive partners demonstrated the concept feasibility of imaging spot welds using a high-frequency phased-array probe in conjunction with a miniature mechanical scanning system to measure up to 3000 signals in a few seconds. Work to date has demonstrated that signal-processing algorithms developed to analyze the full echo train in either the time or frequency domain provide good correlation with weld quality. For those welds on production parts where it is difficult to obtain multiple echoes, other measures are being assessed to determine their diagnostic capability. These measures include the relative energy in the first interface echo and the indentation of the surfaces caused by the welding electrodes. Results are presented to illustrate how different measures can be used in combination to increase the confidence of weld evaluations, provide feedback to the welding process, and to evaluate welds that are otherwise difficult to measure. The ability to provide a dimensional analysis of the welds is being evaluated by comparing results to weld buttons obtained via destructive teardown of the welded joints. Results are presented for both test coupons and production parts.

Session 23

SESSION 23

NDE TECHNIQUES AND APPLICATIONS
Pavilion West

1:30 PM **Ultrasonic Velocity Measurements of Grease as a Quality Control Tool**
---**D. Utrata**, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

1:50 PM **Quantitative Magnetic Field Measurements in the NanoTesla Region for Eddy Current NDE**
---N. Poulakis, University of West Macedonia, Energy Department, Bakola & Sialvera, 50100 Kozani, Greece; **T. Theodoulidis**, University of West Macedonia, Energy Department, Kozani, Greece

2:10 PM **A Tool Measuring Remaining Thickness of Notched Acoustic Cavities in Primary Reaction Control Thruster NDI Standards**
---**Y. Sun**, C. Sun, and H. Zhu, Innovative Materials Testing Technologies, Inc., Superior, CO 80027; B. Wincheski, NASA Langley Research Center, Hampton, VA 23681

2:30 PM **Algorithms for Processing Data Collected During Low Earth Orbit by a Handheld Infrared Detector**
---**P. A. Howell**, W. P. Winfree, K. E. Cramer, C. Antill, and D. Haakenson, NASA Langley Research Center, MS 231, 3B E. Taylor Road, Hampton, VA 23681

2:50 PM **Quantitative Performance Assessment of Computed Radiography for Corrosion Detection in Process Pipes**
---R. Venkatachalam, V. Vedula, P. Thapa, and **M. Venugopal**, John F. Welch Technology Centre, GE Global Research Centre, Bangalore, India

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

3:30 PM **Application of the Surface and Volumetric Positron Techniques for the Assessment of Material Damage in Real Life Conditions**
---**C. A. Rideout** and S. Ritchie, Positron Systems, Inc., 411 S. Fifth Street, Boise, ID 83702; J. Urban-Klaehn and A. W. Hunt, Idaho Accelerator Center, Pocatello, ID 83201

3:50 PM **Aging Aircraft NDE: Capabilities, Opportunities, and Challenges**
---**E. A. Lindgren**, J. S. Knopp, J. C. Aldrin*, G. J. Steffes, and C. F. Buynak, Nondestructive Evaluation Branch, Materials Directorate, Air Force Research Laboratories, Building 655, Suite 1, 2230 10th Street, WPAFB, OH 45433, *Computational Tools

4:10 PM **Comparison of the Structural Irregularity and Damage Evaluation Routine (SIDER) Inspection Method with Ultrasonic and Thermographic Inspections to Locate Impact Damage on an A-320 Vertical Stabilizer**
---**R. M. Crane**, Naval Surface Warfare Center, Composite and Structures Department, Carderock Division, Code 655, 9500 MacArthur Boulevard, West Bethesda, MD 20817-5700

4:30 PM **The Role of NDT in Forensic Engineering**
---**T. Leon-Salamanca**, Reinhart & Associates, Inc., P. O. Box 81545, Austin, TX 78708-1545

4:50 PM **A Critical Assessment of SBIR NDT Projects**
---**E. R. Reinhart**, Reinhart & Associates, Inc., P. O. Box 81545, Austin, TX 78708-1545

Ultrasonic Velocity Measurements of Grease as a Quality Control Tool

---**David Utrata,** Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

---Grease is used in a variety of industries where it is desirable to hold a lubricating film, such as petroleum oil, in place without having this lubricant leak or run from the region of interest. Various thickeners and additives are used to hold the base oil in place, extend the operating temperature range of the grease, and enhance corrosion and wear resistance. The characteristic of grease that perhaps most dictates its usefulness for a given application is its consistency: too thin and the grease may not adhere to the surfaces needing lubrication; too thick and it may not flow properly. In some applications, the ambient temperature of the operating system can vary widely over a period of time and therefore require either routine grease changes or use of multi-viscosity grease. Grease consistency is rated by the National Lubricating Grease Institute (NLGI) and relates to the depth of cone penetration in specific tests. This work correlates ultrasonic velocity of various greases to their consistency grade. Results suggest that not all systems of grease formulations respond well to such predictive attempts, but some promise may exist for the use of velocity measurement as a quality control tool.

Quantitative Magnetic Field Measurements in the NanoTesla Region for Eddy Current NDE

---Nikolaos Poulakis, University of West Macedonia, Energy Department, Bakola & Sialvera, 50100 Kozani, Greece; **Theodoros Theodoulidis**, University of West Macedonia, Energy Department, Kozani, Greece

---In this paper we perform a feasibility study regarding the use of a HTS-SQUID magnetometer for quantitative measurements in eddy current NDE. The difference with other studies so far is the use of the SQUID in absolute rather than in gradiometric mode. Thus, we investigate the possibility of taking accurate measurements in ambient noise environments. After addressing a number of practical issues prior to the measurements we focus our study on the examination of deep penetration eddy current testing and especially on the comparison of experimental results to theoretical ones. Various configurations are considered including conductive plates with or without flaws. We also demonstrate the unique features of SQUID magnetometry, like measuring from a distance, and finally we discuss the merits of using magnetic field measurements instead of impedance ones in practical low frequency eddy current testing.

A Tool Measuring Remaining Thickness of Notched Acoustic Cavities in Primary Reaction Control Thruster NDI Standards

---**Yushi Sun**, Changhong Sun, and Haiou Zhu, Innovative Materials Testing Technologies, Inc., Superior, CO 80027; Buzz Wincheski, NASA Langley Research Center, Hampton, VA 23681

---Stress corrosion cracking at relief radius area of a space shuttle primary reaction control thruster is a major issue of concern. Current approach for control of crack growth is nondestructive inspection (NDI) of remaining thickness (RT) through acoustic cavities using an Eddy Current (ET) or Remote Field Eddy Current (RFEC) probe. NDI Standards with EDM notches of designed length, L, and notch orientation angle, q, have been built and being built for calibration of different NDI techniques. The designed RT can be calculated from L and q, as RT = T - L* Cos(q) ----(1) Where T is the axial distance from relief radius to acoustic cavity wall. EDM manufacturers are capable of control L precisely. However, they have difficulty to provide accurate control of q in the EDM process. Therefore, errors in q is out of control. Inaccuracy of q introduces error in RT calculated from Equation (1). The error becomes significant when RT << T. The greater q or L is, the greater the error in the calculated RT will be. Our practice in fabricating EDM notches in the two oil bronze standards supports the above statement. In STD #1 there should be a through notch, RT = 0, but the test signals are close to those from a 0.020" RT cavity. In STD #2 we can see a through notch in a cavity, but the calculated RT is 0.020". Significant error in RT values of NDI calibration standards would be misleading to wrong judgment of cracking condition of a thruster under inspection. A tool based on eddy current principle has been developed to measure the RT of each acoustic cavity which is close to an EDM notch of a calibration standard. It provides much more precise value of RT and would help with validating the RT values of EDM notches made on primary reaction control thruster NDI standards. The details of the tool working principle and test results will be given in the paper.

Algorithms for Processing Data Collected During Low Earth Orbit by a Handheld Infrared Detector

---**Patricia A. Howell**, William P. Winfree, K. Elliott Cramer, Charles Antill, and Dave Haakenson, NASA Langley Research Center, MS 231, 3B E. Taylor Road, Hampton, VA 23681

---After the Shuttle Columbia accident, thermography was used extensively to quantify impact damage to the orbiter's wing leading edge material as part of NASA's Return to Flight program. Based on its success and with the support of the astronaut crew, a handheld infrared camera was developed to test the ability of thermography to detect possible damage during a mission. This paper delineates the major differences in boundary conditions that effect the measurements between the thermography inspections conducted on the ground versus the conditions and limitations inherent on-orbit, and how those differences were managed in order to provide a potential inspection capability during a mission. Processing algorithms were developed to correct for the motion between the object and the camera. To save on weight and power requirements, a commercially available microbolometer was modified to withstand the space environment. Since a microbolometer has significant associated noise, an algorithm was added to the processing that spatially smooths the data while maintaining information along defect edges. This algorithm is shown to substantially improve the image quality for this detector. The boundary conditions existing during orbit for both heating and cooling are significantly different than those existing for ground experiments. These differences and their effect on the measurement technique are discussed. These techniques and algorithms were applied to laboratory specimens. Comparisons of the results to ground-based flash infrared inspection are presented.

Quantitative Performance Assessment of Computed Radiography for Corrosion Detection in Process Pipes

---Rajashekar Venkatachalam, Venumadhav Vedula, Prasad Thapa, and **Manoharan Venugopal,** John F. Welch Technology Centre, GE Global Research Centre, Bangalore, India

---Evaluation of integrity of process pipes in service is an important preventive maintenance issue for power generation and petrochemical industries. Ultrasonic wall thickness gauges are traditionally used to measure wall loss due to corrosion. This technique cannot be used on insulated pipelines as well as the accuracy of measurement is lesser at higher temperature. Many have attempted computed radiography to quantify corrosion in pipelines as an alternative technique. Computed Radiography can be carried out without removing insulation and also at higher temperatures. However, the minimum detectability limit of wall thickness loss is limited by various physics complications in radiographic imaging process i.e. scattering, modulation due to detector response, focal spot blurring, the effective thickness of insulation and fluid inside pipe. An attempt has been made to study the effect of insulation and fluid inside pipe on detectability of wall loss due to corrosion using physics simulations and experiments.

Application of the Surface and Volumetric Positron Techniques for the Assessment of Material Damage in Real Life Conditions

---**Curtis A. Rideout** and Scott Ritchie, Positron Systems, Inc., 411 S. Fifth Street, Boise, ID 83702; Jagoda Urban-Klaehn and Alan W. Hunt, Idaho Accelerator Center, Pocatello, ID

---Positron Annihilation measurements have been successfully performed on operational aluminum, titanium, stainless steel alloys and nickel-based super-alloy specimens and components such as turbine engine disks and blades, fuel injector stems inside auxiliary power unit gas generators and structural components, used broadly in the airspace industry. In a military sponsored study, aerospace material damage level and its behavior under uniaxial tensile strain testing and strain controlled fatigue testing at different strain amplitude load levels and fatigue cycles were measured and the remaining life was assessed. Results indicate an increasing S-parameter value response that correlates with increasing plastic deformation/strain up to 5-7% elongation and increasing fatigue damage to about 50-75% of fatigue life of the specimen. The measurement dynamic range and the sensitivity depend on the material type and the strain amplitude levels/fatigue cycles used in the testing. Calibration efforts are made to correlate the S parameter value to the strain and the load/fatigue levels for different materials. Additionally, the capability to assess material treatment effects such as shot peening, cold working and nitriding on metals and thermal damage effects on composites have been demonstrated.

Aging Aircraft NDE: Capabilities, Opportunities, and Challenges

---**Eric A. Lindgren**, Jeremy S. Knopp, Gary J. Steffes, and Charles F. Buynak, Nondestructive Evaluation Branch, Materials Directorate, Air Force Research Laboratories, Building 655, Suite 1, 2230 10th Street, WPAFB, OH 45433

---The average age of aircraft in the inventory of the US Air Force continues to increase. As these aircraft are managed by a Damage Tolerance Assessment (DTA) methodology, NDE plays a critical role in insuring the flight safety of these aircraft. This presentation gives a short overview of the current status of NDE capabilities, including recent developments that are being deployed. This includes automated and hand-held inspection techniques. However, continued use of DTA methods and the potential to migrate to a Condition-Based Maintenance (CBM) approach for aircraft will require improvements in the use of NDI for aircraft structures. Specifically, NDI must evolve from the current method of only detecting defects to characterizing the location and size of the defect. This represents a number of significant challenges. Unlike pipes and other simple geometric structures, which already use some advanced techniques to size cracks, aircraft have many material and geometry factors that complicate similar analysis. These include fastener hole geometry, irregular sealant conditions, variations in fastener hole fit conditions, and consideration of multiple repairs. This presentation provides a strategy to resolve these factors and highlight progress implemented on existing aircraft structures.

Comparison of the Structural Irregularity and Damage Evaluation Routine (SIDER) Inspection Method with Ultrasonic and Thermographic Inspections to Locate Impact Damage on an A-320 Vertical Stabilizer

---**Roger M. Crane**, Naval Surface Warfare Center, Composite and Structures Department, Carderock Division, Code 655, 9500 MacArthur Blvd., West Bethesda, MD 20817-5700

---The U.S. Navy is currently involved in the development of several large area composite structures for fleet implementation such as the DDG 1000 topside and M80 Stiletto. Techniques to provide rapid nondestructive inspection of large area composite structural components are required for these applications. An inspection technique, Structural Irregularity and Damage Evaluation Routine, SIDER, has been developed by the Navy to rapidly locate areas of stiffness variation that results from processing anomalies and in-service damage. SIDER was used to locate impact damage created on an A320 vertical stabilizer. Various impact energy levels were used, from 50 J, simulating barely visible impact damage, to 120 J, simulating significant impact damage. The entire structure was inspected using SIDER as well as conventional ultrasonic and thermographic techniques. A comparison of the capability of each of these techniques to locate the impact damage will be presented. In addition, results from the use of MEMs sensors to perform the SIDER inspection are presented.

The Role of NDT in Forensic Engineering
---**Teodoro Leon-Salamanca**, Reinhart & Associates, Inc., P. O. Box 81545, Austin, TX 78708-1545

---Forensic engineering refers to a comprehensive investigation of the root cause of failures in structures and operating equipment, usually dealing with the relation and application of engineering facts to legal problems and product liability. The investigation covers an interdisciplinary use of nondestructive testing (NDT), operating environment, materials testing, finite element stress analysis (FEA) and fracture mechanics. The results of the investigation can be used in litigation, to correct design problems, modify operation, perform remedial repairs and determine the most cost effective program for future maintenance and inspection. The process can also be used to determine the cause of failures and/or defects in a wide range of engineered structures and equipment, ranging from static structures to complex dynamic equipment such as steam and gas turbines. The first and often most critical step, and one often eliminated by metallurgical laboratories, is to use NDT to fully define the size, shape, and possible nature of all defects in the failed item prior to performing destructive tests. These NDT examinations are very useful when remedial inspection programs are conducted and also define the performance envelope of the various NDT methods as related to defect detection and analysis. After destructive testing (DT), the results are compared to NDT data as a means to upgrade future NDT processes. Examples of cases where NDT played a critical role will be presented.

A Critical Assessment of SBIR NDT Projects
---**Eugene R. Reinhart**, Reinhart & Associates, Inc., P. O. Box 81545, Austin, TX 78708-1545

---The Small Business Innovative Research (SBIR) program, funded by various United States government agencies (DOD, DOE, NSF, etc.) has provided funds for Research and Development (R&D) of nondestructive testing (NDT) techniques and equipments. This program has provided valuable seed money for NDT development by small business firms and stimulated cooperative programs with universities. Capturing these programs requires a unique combination of technical, business and marketing skills. Also, transfer of technology to provide an NDT service or product is the most difficult step in the program. Since the unique technique or instrument developed in the project was for the specific needs of a government agency, such as the department of defense, the results may have limited commercial application. A review and critical assessment of the SBIR program as related to NDT is presented and should provide insight into reasons for or against pursuing this source of R&D funding for small business. Examples of various SBIR NDT projects and recommendations for improving the program are also presented.

SPECIAL EVENING SESSION
Pavilion East

8:00 PM **NASA Engineering and Safety Center NDE Super Problem Resolution Team**
---**William H. Prosser**, NASA Langley Research Center, NASA Engineering and Safety Center, Building 1230B, Room 185, Hampton, VA 2381-0001

---The NASA Engineering and Safety Center (NESC) is an independent organization, which was charted in the wake of the Space Shuttle Columbia accident to serve as an Agency-wide technical resource focused on engineering excellence. The objective of the NESC is to improve safety by performing in-depth independent engineering assessments, testing, and analysis to uncover technical vulnerabilities and to determine appropriate preventative and corrective actions for problems, trends or issues within NASA's programs, projects and institutions. Critical to the NESC are teams of experts in a number of core disciplines including nondestructive evaluation (NDE). These teams, designated Super Problem Resolution Teams (SPRTs), draw upon the best engineering expertise from across the Agency and include partnerships with other government agencies, national laboratories, universities and industry. The NESC NDE SPRT provides a ready resource of NDE technical expertise to support NESC Independent Technical Assessments and Investigations. The purpose of this session will be to provide an overview of the NESC and the NDE SPRT along with a few examples of NDE related problems that the team has addressed for NASA Programs. It is hoped that this session will be of interest to the general NDE community and will foster contacts with additional NDE experts that might provide future support to the NASA NESC NDE SPRT.

THURSDAY

Session 24

SESSION 24

STRUCTURAL HEALTH MONITORING II
Pavilion East

8:30 AM **Systems Health Monitoring – From Ground to Air – The Aerospace Challenges**
---**M. A. Austin**, Pratt and Whitney, 400 Main Street, MS 163-14, East Hartford, CT 06118

8:50 AM **A Wave-Based Damage Index for Damage Localization and Size Estimation**
---**V. K. Sharma**, Millennium Dynamics, Acworth, GA 30101; M. Ruzzene, School of Aerospace Engineering, Georgia Institute of Technology, Atlanta, GA 30332-0150; S. Hanagud, Georgia Institute of Technology, School of Aerospace Engineering, Atlanta, GA 30332-0150

9:10 AM **Magnetic Carpet Probe for Large Area Instant Crack Detection and Health Monitoring**
---**Y. Sun**, T. Ouyang, X. Yang, and H. Zhu, Innovative Materials Testing Technologies, Inc., Superior, CO 80027

9:30 AM **The Factors Affecting the Sensitivity of the Ultrasonic Inter-Modulation Technique**
---C. R. Courtney, **B. W. Drinkwater**, S. A. Neild, and P. D. Wilcox, University of Bristol, Department of Mechanical Engineering, Bristol, United Kingdom

9:50 AM **Frequency-Wavenumber Domain Filtering for Improved Damage Visualization**
---**M. Ruzzene**, Georgia Institute of Technology, School of Aerospace Engineering, Atlanta, GA 30332

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

10:30 AM **Damage Localization in Inhomogeneous Plates Using a Sparse Array of Ultrasonic Transducers**
---**J. E. Michaels** and T. E. Michaels, Georgia Institute of Technology, School of Electrical and Computer Engineering, 777 Atlantic Drive, NW, Atlanta, GA 30332-0250

10:50 AM **Acoustic Emission Detection and Prediction of Fatigue Crack Propagation in Composite Patch Repairs Using Neural Networks**
---**A. C. Okafor**, Navdeep Singh, and Navrag Singh, University of Missouri-Rolla, Department of Mechanical and Aerospace Engineering, Rolla, MO 65409-0050

11:10 AM **Quantification of Acoustic Emission from Crack Growth in Plate Structures**
---**P. D. Wilcox**, C.-K. Lee, and B. W. Drinkwater, University of Bristol, Department of Mechanical Engineering, Bristol, United Kingdom: J. J. Scholey, M. R. Wisnom, and M. I. Friswell, University of Bristol, Department of Aerospace Engineering, Bristol, United Kingdom

11:30 AM **Representation of the Characteristics of Piezoelectric Fiber Composites with Neural Networks**
---**I. N. Tansel**, Florida International University, Department of Mechanical and Materials Engineering, 10555 West Flagler Street, (EAS-3473) Miami, FL 33174

11:50 AM **Aircraft Component Inspection for Fatigue Damage and Life Prediction Using Induced Positron Annihilation**
---**C. A. Rideout**, Positron Systems, Inc., 411 S. Fifth Street, Boise, ID 83702

12:10 PM **Lunch**

Systems Health Monitoring – From Ground to Air – The Aerospace Challenges

---Mary A. Austin, Pratt and Whitney, 400 Main Street, M/S 163-14, East Hartford, CT 06118

---The aerospace industry and the government are significantly investing in jet engine systems health monitoring. Government organizations such as the Air Force, Navy, Army, National Labs and NASA are investing in the development of state aware sensing for health monitoring of jet engines such as the Joint Strike Fighter, F119 and F100's. This talk will discuss on-going work in systems health monitoring for jet engines. Topics will include a general discussion of the approaches to engine structural health monitoring and the prognosis of engine component life. Real-world implementation challenges on the ground and in the air will be reviewed. The talk will conclude with a prediction of where engine health monitoring will be in twenty years.

A Wave-Based Damage Index for Damage Localization and Size Estimation

---**Vinod K. Sharma**, Millennium Dynamics, Acworth GA; Massimo Ruzzene, School of Aerospace Engineering, Georgia Institute of Technology, Atlanta GA; Sathya Hanagud, School of Aerospace Engineering, Georgia Institute of Technology, Atlanta GA

---This paper presents a time-domain damage index defined as the distribution of strain energy ratio associated with propagating elastic waves. The formulation is based on the comparison of damage and undamaged information related to the transient response of inspected components. As in most instances undamaged data may not be available or may be varying with usage, a technique is presented where the baseline is synthesized using the dynamic response of a given structure in its current state through the use of spatial decimation. Laser Doppler Vibrometry provides an ability to acquire dynamic response data at an unprecedented rate and flexibility, and allows synthesizing baseline data for comparison. The technique is first illustrated using numerical simulations followed by demonstration on a plate specimen with artificial cracks of controlled dimensions. The sensitivity of the proposed damage index formulation is assessed through the analysis of cracks of increasing depth and length. In addition, the capability of the index to provide depth, orientation and length is demonstrated. The presented experimental results show the potential of the technique and highlight its limitations, and thus provide useful guidelines for the future enhancements of the technique.

Magnetic Carpet Probe for Large Area Instant Crack Detection and Health Monitoring

---**Yushi Sun**, Tianhe Ouyang, Xinle Yang, and Haiou Zhu, Innovative Materials Testing Technologies, Inc., Superior, CO 80027

---Large area crack detection and health monitoring have a big concern for NDE society for different applications, especially aircraft and helicopter industry. Recently a new NDE tool, Magnet Carpet Probe (MCP), has recently developed to meet the above demands. MCP is a two-dimensional coil array built on a piece of very thin flexible printed circuit board, FPCB. Placing an MCP on top of a metallic surface under inspection one can finish the inspection, with out moving anything, and see the crack identification image on the instrument screen in a few second. Actually a two-dimensional scan is going on electromagnetically within the MCP. A few prototype MCPs have been developed by Innovative Materials Testing Technologies, Inc., supported by FAA W.H. Hughes Technical Center. Recent test results show that it can detect 0.030 x 0.016" EDM notches on an aluminum and Titanium standards, as well as 0.024" ~ 0.036: real cracks on titanium standards. More information regarding MCP and its performances in crack detection will be present at the conference and included in the paper. The advantages of the MCP technique include: 1.) High sensitivity to cracks because there is no mechanical movement and, hence, no noise introduced by mechanical movement at all; 2.) High inspection speed due to the fact that the two-dimensional scan is done electromagnetically; 3.) Light weight. 4.) Inexpensive because the fabrication and most of the installation can be done in massive production exactly like PC components and other electronic applicants. 5.) Possible to be used as an embedded sensor and applied in aircraft structure health and usage monitoring.

The Factors Affecting the Sensitivity of the Ultrasonic Inter-modulation Technique

---Charles R. Courtney, **Bruce W. Drinkwater**, Simon A. Neild, and Paul D. Wilcox, Department of Mechanical Engineering, University of Bristol, Bristol, United Kingdom

---This paper discusses the ultrasonic inter-modulation technique for damage detection. The specimen is excited by two continuous sinusoidal ultrasonic signals at different frequencies and the resultant vibration signal is captured for interrogation. The presence of nonlinearities within the test structure causes inter-modulation which can then be observed in either the spectrum or bispectrum. Ultrasonic frequencies are used which excite very high order modes of the structure and appear to offer high sensitivity to defects such as cracking and relatively low sensitivity to other external effects such as the support conditions. In this paper the inter-modulation technique is investigated with a view to its eventual application to engineering structures. Two distinct systems are considered. Firstly a thick section (60 mm by 60 mm) steel beam containing fatigue-cracks is shown to produce a strong mixing effect and that the frequency mixing is sensitive to the length of the crack; potentially allowing the quantification of the crack length. Secondly, thin (3 mm) aluminum samples similar to those used in the aerospace industry are tested. These contained fatigue cracks and other benign sources of nonlinearity such as rivets and bolted joints. In both cases, the robustness of the approach to changes in the experimental conditions such as applied frequency, amplitude and transducer location is discussed.

Frequency-Wavenumber Domain Filtering for Improved Damage Visualization

---**Massimo Ruzzene**, School of Aerospace Engineering, Georgia Institute of Technology, Atlanta GA 30332

---This paper presents a technique for the analysis of full wavefield data in the wavenumber/frequency domain as an effective tool for damage detection, visualization and characterization. Full wavefield data contain a wealth of information regarding the space and time variation of propagating waves in damaged structural components. Such information can be used to evaluate the response spectrum in the frequency/wavenumber domain, which effectively separates incident waves from reflections caused by discontinuities encountered along the wave paths. This allows removing the injected wave from the overall response through simple filtering strategies, thus highlighting the presence of reflections associated to damage. The concept is first illustrated on analytical and numerically simulated data, and then tested on experimental results. In the experiments, full wavefield measurements are conveniently obtained using a Scanning Laser Doppler Vibrometer, which allows the detection of displacements and/or velocities over a user-defined grid, and it is able to provide the required spatial and time information in a timely manner. Tests performed on a simple aluminum plate with artificially seeded slits simulating longitudinal cracks, and on a disbonded tongue and grove joint show the effectiveness of the technique and its potential for application to the inspection of a variety of structural components.

Damage Localization in Inhomogeneous Plates Using a Sparse Array of Ultrasonic Transducers

---**Jennifer E. Michaels** and Thomas E. Michaels, Georgia Institute of Technology, School of Electrical and Computer Engineering, 777 Atlantic Drive, NW, Atlanta, Georgia, 30332-0250

---A variety of Lamb wave methods have been shown to be effective in localizing damage in homogeneous plates. However, many structural components of interest are not simple plates of constant thickness, but are plate-like in geometry with inhomogeneities present in the form of thickness variations. Here we consider aluminum plates with thickness transitions typical of realistic structures. A sparse array of piezoelectric disc transducers is mounted on the plate, and artificial defects are created to simulate various types of damage. Signals recorded from the sparse array after damage is introduced are compared to baseline signals recorded from the undamaged plate. In addition, complete wavefield images are acquired over the surface of the plate to help interpret the direct, scattered and reflected wave arrivals present in the signals recorded from the fixed array. Both geometrical and beam forming algorithms are implemented to localize damage, taking into account changes in propagation velocity in the regions of different thickness. Results are shown for several plate, transducer and damage scenarios.

Acoustic Emission Detection and Prediction of Fatigue Crack Propagation in Composite Patch Repairs Using Neural Networks

---**A. Chukwujekwu Okafor**, Navdeep Singh, and Navrag Singh, University of Missouri-Rolla, Department of Mechanical and Aerospace Engineering, Rolla, MO 65409-0050

---An aircraft is subjected to severe structural and aerodynamic loads during its service life. These loads can cause damage or weakening of the structure especially for aging military and civilian aircraft thereby affecting its load carrying capabilities. Hence composite patch repairs are being increasingly used to repair damaged aircraft metallic structures. This calls for a reliable method for assessing the integrity of bonded repairs and detecting the propagation of the crack after the application of the patch without stripping the repair. This paper presents the results of Acoustic Emission (AE) monitoring of cracked 2024-T3 Clad aluminum panels repaired with adhesively bonded octagonal and elliptical single sided boron/epoxy composite patches using FM-73 adhesive under tension-tension fatigue loading. Four AE sensors were used to monitor crack propagation. The AE signals were acquired and processed in time and frequency domain to identify sensor features correlated with fatigue cycle and crack propagation. Also crack propagation gages were used to monitor crack initiation. The identified sensor features were used to train neural networks for predicting crack length. Methods for AE waveform analysis and noise reduction that are necessary for accurate source location, crack monitoring and prediction are presented. The results show that AE events are correlated with crack propagation. It was also found that even at high noise condition of 10 Hz loading, the AE system was able to detect crack propagation. It has been shown that the noise generated from the sources such as electrical interference and slipping of the grips can be distinguished from AE stress waves generated by crack propagation. Three back-propagation cascade feed forward networks were trained to predict crack length based on the number of fatigue cycles, AE event number, and both the Fatigue Cycles and AE events, together as inputs respectively. The results are presented.

Quantification of Acoustic Emission from Crack Growth in Plate Structures

---Paul D. Wilcox, Chee-Kin Lee, and Bruce W. Drinkwater, Department of Mechanical Engineering, University of Bristol, Bristol, United Kingdom; Jonathan J. Scholey, Michael R. Wisnom, and Michael I. Friswell, Department of Aerospace Engineering, University of Bristol, Bristol, United Kingdom

---Acoustic emission (AE) is a highly efficient mechanism on which to base a Structural Health Monitoring (SHM) system for large structures, since its sensitivity to damage growth is very high and the required sensor density is very low. However, a key obstacle to AE based SHM in safety critical structures, such as airframes or power plant, is a lack of quantitative modeling capability. The authors are developing a forward modeling framework for AE, which separates the phenomena of generation, propagation and detection into separate modules. A key component of this is modeling the source of AE. The main source that has been examined to date is fatigue crack growth in an isotropic plate structure. An experiment is described that enables the AE radiation pattern from fatigue crack growth in a plate to be characterized, and the difficulties in conducting such an experiment are discussed. The development of a finite element (FE) modeling procedure that simulates the emission of stress waves from incremental crack growth in a plate is presented and the results from this model are compared to those from the experiment. The FE model is then used to perform a parametric study of AE from different crack growth situations and conclusions are drawn about the implications for AE based SHM.

Representation of the Characteristics of Piezoelectric Fiber Composites with Neural Networks

---**Ibrahim N. Tansel**, Florida International University, Department of Mechanical and Materials Engineering, 10555 West Flagler Street, (EAS-3473) Miami, FL 33174

---Ideal sensors for the future should be smart, cheap, extremely efficient, and obtain the operating power from their environment. To minimize the power consumption of the sensors, every component should be selected very carefully. Use of piezoelectric fiber composites with a low power microprocessor is proposed to measure the amplitude of periodic forces in this paper. The piezoelectric fiber composite generated small electricity under the loading. The microprocessor estimated the amplitude of the load by using a backpropagation type neural network program. PZT fiber composites are easy to build. Their characteristics could be adjusted according to the application easily by selecting the matrix and fiber density. They generate significant amount of charge when they are subjected to forces and the voltage could be easily measured with the A/D ports of low power microprocessors. This direct approach reduces power consumption, the number of the necessary components, and weight of the system. However, the relationship between the force and the sensor output is not perfectly linear at different frequencies. Backpropagation type neural networks are very convenient for representation and compensation of this nonlinear characteristic. The experimental data was collected by applying force to a small piezoelectric fiber composite cylinder and used to train the neural network. The piezoelectric fiber composite and the low power microprocessor with backpropagation type neural network estimated the amplitude of the load at a large frequency band.

Aircraft Component Inspection for Fatigue Damage and Life Prediction Using Induced Positron Annihilation

---**Curtis A. Rideout** and Scott Ritchie, Positron Systems, Inc., Boise, ID 83702; Jagoda Urban-Klaehn and Alan W. Hunt, Idaho Accelerator Center, Pocatello, ID

---Advanced technologies are needed to better understand material effects on aging aircraft components and provide cost effective inspection and remaining life determination of critical aircraft components. A new, advanced physically-based nondestructive inspection technology utilizing Induced Positron Annihilation (IPA) spectroscopy is now available to inspect aircraft components for accumulated microstructural level changes induced by operations and fatigue damage from the as-manufactured condition to failure and may be used to determine remaining life of critical components. IPA has demonstrated the capability to detect and determine near surface or buried damage in aerospace components such as landing gears, wing splice joints, wing attach fittings and turbine engine components. The IPA technologies work in metals, alloys, composites, polymers and ceramics and detect nano scale level damage prior to crack initiation through failure. The IPA technologies can provide an improved understanding of microstructural states, failure mechanisms, and have demonstrated the ability to provide data that is suitable for use in developing current damage and remaining life estimates and maintenance schedules. Specific examples of testing and damage assessments will be presented and discussed.

Session 25

SESSION 25

TERAHERTZ IMAGING
H. Ringermacher, Chairperson
Broadway I

8:30 AM **Keynote: Material Inspection Using THz and Thermal Wave**
---**C. Zhang**, Capital Normal University, Department of Physics, Beijing 100037, China

9:10 AM **Time Domain Terahertz Structural Imaging Methods and Analysis**
---**D. Zimdars**, J. S. White, G. Stuk, A. Chernovsky, G. Fichter, G. Sucha, and S. Williamson, Picometrix, LLC., 2925 Boardwalk Drive, Ann Arbor, MI 48104

9:30 AM **Portable THz Systems for Imaging and Spectroscopy**
---**V. G. Kozlov**, Microtech Instruments, Inc., 132 East Broadway, Suite 810, Eugene, OR 97401

9:50 AM **Crack Detection in Sprayed on Foam Insulation with Pulsed Terahertz Frequency Electromagnetic Waves**
---**W. P. Winfree** and R. F. Anastasi, NASA Langley Research Center, Nondestructive Evaluation Sciences Branch, Hampton, VA 23681; J. P. Seebo, Lockheed Martin Aeronautics Company, Hampton, VA 23681

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

10:30 AM **Terahertz NDE: Potential and Pitfalls**
---**M. W. Burke**, Lawrence Livermore National Laboratory, Center for Nondestructive Characterization, 7000 East Avenue, P. O. Box 808, Livermore, CA 94551

10:50 AM **Imaging and Modeling Techniques for Terahertz Inspection of NASA SOFI**
---**V. R. Melapudi**, N. V. Nair, S. S. Udpa, and L. Udpa, Michigan State University, Nondestructive Evaluation Laboratory, ECE Department, East Lansing, MI 48823; W. P. Winfree, NASA Langley Research Center, Nondestructive Evaluation Sciences Branch, Hampton, VA 23681

11:10 AM **2D Modeling of Pulsed THz Interrogation of SOFI with Knit Lines**
---H. T. Banks and **N. L. Gibson**, NCSU, Center for Research in Scientific Computation, Raleigh, NC 27606; W. P. Winfree, NASA Langley Research Center, Hampton, VA 23681

11:30 AM **Signal Processing Approaches for Terahertz Data Obtained from Inspection of the Shuttle External Tank Thermal Protection System Foam**
---**D. J. Roth**, NASA Glenn Research Center, MS 6-1, 21000 Brookpark Road, Brookpark, OH 44135; J. P. Seebo, Lockheed Martin; J. L. Walker, NASA Marshall Space Flight Center; J. C. Aldrin, Computational Tools

11:50 AM **Processing of Terahertz Ray Data in Space Shuttle Inspection**
---**C.-P. Chiou**[1], R. B. Thompson[2], B. Winfree[2], E. Madaras[2], and J. Seebo[3], [1]Iowa State University, Center for NDE Evaluation, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011; [2]NASA Langley Research Center, Hampton, VA 23681; [3]Lockheed Martin, Hampton, VA 23681

12:10 PM ***Lunch***

Keynote: Material Inspection Using THz and Thermal Wave

---**Cunlin Zhang**, Department of Physics, Capital Normal University, Beijing 100037, China

---Terahertz (THz) and thermal wave imaging technologies are complementary inspection modalities for use in non-contact and non-destructive material evaluations. I will present recent results obtained through the use of these methods in aerospace material quality control. Graphite fiber composite materials, such as carbon fibers, are widely used in the aerospace industry. The real-time evaluation ability to identify material quality is essential for industrial applications. Both THz and thermal wave imaging technologies are applied in order to evaluate fire-damage on a variety of carbon fiber composite samples. The majority of carbon fiber materials have polarization-dependent reflectivities in the THz frequency range and the polarization dependence change versus the burn damage level is observed. Additionally, the THz temporal waveform and its correlation with a reference waveform acquired through a THz time-domain spectroscopy system provide the damage depth information in layered composites. I will also report the test of a large number of insulation foam panels used in NASA's External Fuel Tank through pulse and CW terahertz systems. Thermal wave imaging is another effective technique for the evaluation of defects in composite materials. A thermal wave imaging system provides an integrated thermographic inspection. Finally, the study of defects in selected materials, including metal plates, carbon fibers, glass fibers, carbon silicon composites, etc is also shown. The two non-destructive image technologies are discussed in terms of their applications to defense and aerospace industries.

Time Domain Terahertz Structural Imaging Methods and Analysis

---**David Zimdars**, Jeffrey S. White, G. Stuk , A. Chernovsky, G. Fichter, G. Sucha, and S. Williamson, Picometrix, LLC., 2925 Boardwalk Dr., Ann Arbor, MI 48104

---We will discuss the technology and methods of high speed time domain terahertz (THz) imaging non-destructive examination (NDE) for 2 and 3 dimensional structural and material content characterization. THz imaging can be utilized non-contact transmission and/or monostatic reflection inspection of non-conductive materials such as plastics, foam, composites, ceramics, paper, wood and glass. We will show penetration characteristics through building materials, and demonstrate the ability of THz to sub-surface image building structures such as framing and wiring. We will describe analysis methods for the 3D layer extraction from clean and "noisy" waveforms. Additional terahertz security imaging applications for the detection of weapons and explosives will also be discussed, as well as the application of terahertz sensors for high speed industrial process monitoring and quality control.

Portable THz Systems for Imaging and Spectroscopy

---**Vladimir G. Kozlov**, Microtech Instruments, Inc., 132 East Broadway, Suite 810, Eugene, OR 97401

---Applications of THz technology have been limited by lack of compact and efficient sources. Our portable THz systems are based on two types of recently developed THz sources, utilizing electronic and optical approaches to THz generation. The electronic sources, operating in the range 0.1-1.5 THz, are based on vacuum diode tubes integrated with solid state frequency multipliers. The optical generators, based on difference frequency generation, operate in frequency range 1.0-3.0 THz. High power, efficiency and compact size of these THz generators enable portable THz systems for imaging and spectroscopy applications.

Crack Detection in Sprayed on Foam Insulation with Pulsed Terahertz Frequency Electromagnetic Waves

---**William P. Winfree** and Robert F. Anastasi, Nondestructive Evaluation Sciences Branch, NASA Langley Research Center, Hampton, VA 23681; Jeffrey P. Seebo, Lockheed Martin Aeronautics Company, Hampton, VA 23681

---Detection of cracks in the sprayed on foam insulation is difficult primarily due to its low density and nonhomogeneous properties. This detection becomes more difficult as crack gap width decreases. Pulsed electromagnetic waves at terahertz frequencies are applicable for quantitative evaluation of cracks and other flaws in sprayed on foam insulation. The short wavelengths of terahertz waves make them ideal for imaging flaws in foam. This paper examines the application of terahertz pulses for crack detection. Of particular interest is detection of cracks aligned along or nearly along the wave propagation path. The dependence of crack detectability on the angle between the crack and the propagation path is presented. Filling the cracks with alcohol significantly increases their detectability. This is a particularly effective technique if the specimen can be imaged with the alcohol present and absent. The technique is demonstrated on gaps between foam blocks and on real cracks in foam.

Terahertz NDE: Potential and Pitfalls
---**Michael W. Burke**, Lawrence Livermore National Laboratory, Center for Nondestructive Characterization, 7000 East Avenue, P. O. Box 808, Livermore, CA 94551

---Technology generating probing radiation in the terahertz (THz) region of the spectrum has become more accessible. We will discuss Lawrence Livermore National Lab's acquisition of a THz time-domain spectrometer for use in our NDE program. We will present how this new and exciting technology may be applied to NDE characterization of materials and components, and in Homeland Security. There are also a great many pitfalls in its application that a practitioner has to be aware of. Finally, we will discuss the overall potential for applying THz technology to solving NDE problems, and compare its capabilities to other NDE techniques.

Imaging and Modeling Techniques for Terahertz Inspection of NASA SOFI
---**Vikram R. Melapudi**, Naveen V. Nair, Satish S. Udpa, and Lalita Udpa, Michigan State University, Nondestructive Evaluation Lab, ECE Dept., East Lansing, MI 48823; William P. Winfree, Nondestructive Evaluation Sciences Branch, NASA Langley Research Center, Hampton, VA 23681

---Short-pulsed terahertz imaging techniques have found application in recent years especially in the areas of nondestructive evaluation, homeland security and biomedical imaging. One such application involves the inspection of the bond between spray on foam insulation (SOFI) and the external tank in the NASA space shuttle. This work discusses a suite of image enhancement techniques that was developed to improve the probability of detection. In addition to experimental data we developed a model employing ray-tracing technique is used to simulate the inspection process. Results obtained using model and experimental images will be presented.

2D Modeling of Pulsed THz Interrogation of SOFI with Knit Lines

---H. T. Banks and **Nathan L. Gibson,** Center for Research in Scientific Computation, NCSU, Raleigh, NC 27606; William P. Winfree, NASA Langley Research Center, Hampton VA 23681

---Pulsed THz frequency waves have been shown to be particularly useful in the detection of voids in the Sprayed on Foam Insulation (SOFI) used on the Space Shuttle's Thermal Protection System (TPS). The foam is applied in layers, where the interfaces between layers have increased density (``knit lines'') which scatter the interrogating waveform. This paper describes our efforts to understand and quantify the scattering mechanisms, as well as to minimize their effects by the use of focusing and/or altering the angle of incidence. We model the electromagnetic field using the TE mode of the 2D Maxwell's equations, which are then solved with a finite-element time-domain method. We use a truncated sine curve in the THz frequency regime as a source current. The plane wave is focused by reflecting off of a curved boundary. The knit lines are modeled by using the classical Clausius-Mossotti equation to estimate the dielectric constant assuming only a change in density. We consider slanted and curved knit lines, as well as voids occurring between sprayed-on layers.

Signal Processing Approaches for Terahertz Data Obtained from Inspection of the Shuttle External Tank Thermal Protection System Foam

---**Don J. Roth**, NASA Glenn Research Center, MS 6-1, 21000 Brookpark Road, Brookpark, OH 44135; Jeffrey P. Seebo, Lockheed Martin; James L. Walker, NASA Marshall Space Flight Center; John C. Aldrin, Computational Tools

---Foam shedding from the shuttle external tank remains a critical problem regarding Shuttle orbiter safety. Flaws present in the foam can result in initiation sites for foam loss, and NASA is continuing to look at improving existing NDE methods for foam inspection as well as developing new methods. Terahertz NDE, greatly enhanced over the last several years with respect to its use for external tank foam inspection, has been a focus for continued improvement through signal and image processing improvements. In this study, results from various signal processing approaches to improve external tank foam terahertz inspection image quality and resolution are described.

Processing of Terahertz Ray Data in Space Shuttle Inspection

---**Chien-Ping Chiou**[1], R. Bruce Thompson[2], Bill Winfree[2], Eric Madaras[2], and Jeff Seebo[3], [1]Iowa State University, Center for Nondestructive Evaluation, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011; [2]NASA Langley Research Center, Hampton, VA 23681; [3]Lockheed Martin, Hampton, VA 23681

---Terahertz ray (T-ray) imaging is one of the most capable techniques to inspect space shuttle insulation structures. The effectiveness of this technique, however, has been limited in its current practice using indirect substrate reflections. A new approach working directly on the flaw responses was recently proposed to overcome these limitations. Based on the governing T-ray physics, this new approach carries out a series of signal processing operations on the multidimensional flaw waveform/image data. In this paper, we report recent progresses made in detecting flaws that were previously missed by the current protocol. These include processing results of drilled holes, simulated delamination and realistic flaw inserts embedded in foam blocks and test panel. The approach was further refined via time-frequency analyses in exploring new features to distinguish flaw signals from other interferences.---This material is based on work supported by NASA under award NAG-1-029-98.

Session 26

SESSION 26

NEW TECHNIQUES
Pavilion West

8:30 AM **An RF Therapy System for Breast Cancer Treatment Using Deformable Mirro**
---**K. Arunachalam**, S. S. Udpa, and L. Udpa, Michigan State University, Department of Electrical and Computer Engineering, 2120 Engineering Building, East Lansing, MI 48824-1226

8:50 AM **Lockin-Speckle-Interferometry: Advances in Dynamic Object Excitation for Defect Visualization**
---**H. Gerhard**, F. Hesselbach, and G. Busse, Institute for Polymer Testing and Polymer Science, Nondestructive Testing, Stuttgart, Germany

9:10 AM **Laser Triangulation Applied to Online Thickness Monitoring of Thermally Sprayed Coatings**
---**M. A. Nadeau**, L. Pouliot, F. Nadeau, J. Blain, and S. A. Berube, Tecnar Automation Ltd., Saint-Bruno, Quebec, Canada; C. Moreau and M. Lamontagne, Institut des Matériaux Industriels, Conseil National de Recherche, Boucherville, Quebec, Canada

9:30 AM **Fast NDE of Superconducting Magnet Wires Using a Flow-Through SQUID Microscope**
---**J. Matthews** and F. C. Wellstood, University of Maryland, Department of Physics, Center for Superconductivity Research, College Park, MD 20742

9:50 AM **Nonlinear Dynamics of Cracks and Time Reversed Acoustic Imaging**
---**T. J. Ulrich** and P. A. Johnson, Los Alamos National Laboratory, Geophysics Group EES-11, Los Alamos, NM 87545; R. A. Guyer, University of Massachusetts, Physics Department, Amhearst, MA 01002

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

10:30 AM **Ultrasonic Wave Generation by Lasers on Different Metal Surfaces**
---**Silvio E. Kruger** and M. Lord, Industrial Materials Institute, 75, Boul. De Mortagne, Boucherville, Quebec J4B 6Y4, Canada

10:50 AM **Protocol and Assessment of Signal Processing and Feature Extraction Methods for Terahertz NDE for Spray-on Foam Insulation**
---**John C. Aldrin**, Computational Tools, Gurnee, IL; Don J. Roth, NASA Glenn Research Center, Cleveland, OH; Jeffrey P. Seebo, Lockheed Martin, Hampton, VA; William P. Winfree, NASA Langley Research Center, Hampton, VA

11:10 AM **In-Line NDI of Mechanical Dents on Pipelines with Circumferential Guided SH Wave EMAT**
---**X. Zhao**, G. Mei, and B. Ayhan, Intelligent Automation, Inc., Rockville, MD 20855; V. K. Varma, Oak Ridge National Laboratory, Nuclear Science & Technology Division, Oak Ridge, TN 37831

11:30 AM **Measurement of the Properties of Fluids Inside Pipes Using Guided Longitudinal Waves**
---**J. Ma**, M. J. S. Lowe, and F. Simonetti, Imperial College, Mechanical Engineering, London, United Kingdom

11:50 AM **Noninvasive Approach for a Pressure Measurement**
---**M. J. Guers**, D. R. Zilinskis, and B. R. Tittmann, The Pennsylvania State University, Department of Engineering Science & Mechanics, 212 Earth-Engineering Sciences Building, University Park, PA 16802-6812

12:10 PM ***Lunch***

An RF Therapy System for Breast Cancer Treatment Using Deformable Mirror

---**Kavitha Arunachalam**, Satish S. Udpa and Lalita Udpa, Michigan State University, Department of Electrical and Computer Engineering, 2120 Engineering Building, East Lansing, MI, USA 48824-1226

---Cancer is the second leading cause of deaths in the United States. Amongst women in the United States, breast cancer is the second leading cause of cancer deaths and accounts for nearly 1 in 3 cancers that are diagnosed. In this decade, there has been significant interest in the application of radiofrequency (RF) techniques in medicine and especially for cancer treatment. The ability of the non-ionizing RF waves to penetrate deep inside the biological tissue is investigated as an effective means for delivering adjuvant and ablation therapy to destroy the cancerous cells selectively. We propose in this paper, an alternative mode of RF radiation therapy using a deformable membrane mirror. The deformable mirror with reflective coating functions as an adaptive focusing mirror and delivers preferential energy deposition at the tumor site in the breast. System feasibility study and preliminary results obtained using model simulations for the proposed deformable mirror based RF therapy system will be presented with application to breast cancer treatment.

Lockin-Speckle-Interferometry: Advances In Dynamic Object Excitation for Defect Visualization

---**H. Gerhard**, F. Hesselbach, and G. Busse, Nondestructive Testing, Institute for Polymer Testing and Polymer Science, Stuttgart, Germany

---Electronic-speckle-pattern-interferometry is an optical NDE method which measures the deformation field of an object. The observation field is recorded by a camera, which records images of the object at different deformation states. The superposition of the two speckle patterns related to the two deformation states results in a fringe pattern that displays lines of equal surface deformation. Defects and inhomogeneities in the material are detected when the fringe pattern and therefore also the deformation is irregular. To use this technique for NDE the object must be deformed in a remote way e.g. by heating or by exposing the object to a different air pressure. Normally the user takes one image before, during and after the excitation and then calculates the deformation fields. The result is the image with the best defect contrast. But heating produces a large deformation gradient due to internal stresses. On this dominating background of overall deformation it is difficult to detect small deformation changes caused by defects hidden. We therefore suggest to modulate the surface temperature. The excited thermal wave penetrates into the object where it is reflected at boundaries like defects. The stack of deformation images obtained during the modulated irradiation of the object is first demodulated to display total deformation and then at each pixel Fourier transformed at the modulation frequency. This way the information is narrowband filtered and the extracted information finally compressed into an amplitude and a phase image (lockin principle) of local information. Due to the reduction of the frequency bandwidth the signal-to-noise ratio is significantly improved. Furthermore information is obtained about the depth of the defect. We also applied this lockin principle to modulate the hydrostatical pressure. Thereby the defect detectibility increased which allows to load the object with lower pressure differences. Simulation of the process was performed as well.

Laser Triangulation Applied to Online Thickness Monitoring of Thermally Sprayed Coatings

---**M. Alexandre Nadeau**, Luc Pouliot, François Nadeau, Jacques Blain, and Simon Alex Berube, Tecnar Automation Ltd, Saint-Bruno, Quebec, Canada ; Christian Moreau and Mario Lamontagne, Institut des Matériaux Industriels, Conseil National de Recherche, Boucherville, Quebec, Canada

---Thermally sprayed coatings are now extensively used in many industries to increase key surface properties such as wear or heat resistance, and to significantly improve component life time or combustion efficiency. The aim of this work was to develop a technology enabling online, real-time, non-contact monitoring of the thickness of these coatings during the spraying process. Current thickness measurement methods have limited precision and are mostly performed offline, which translates into significant production time losses. The approach presented in this paper uses optical triangulation to measure the height difference between two layers of coating. The measurement is done while spraying, monitoring the edge between the current pass and the previously deposited layer. A laser line is shined across that edge and custom anamorphic optics is used to image the scattered light from the surface. Micron-level resolution has been achieved independently from: (a) the nature of the sprayed material (b) the nature of the substrate (c) the surface roughness (4) the thermal expansion of the part. Industrial results obtained at early adopter sites are presented. Finally, current fields of application and future developments are discussed.

Fast NDE of Superconducting Magnet Wires Using a Flow-Through SQUID Microscope

---**John Matthews** and F. C. Wellstood, Center for Superconductivity Research, Department of Physics, University of Maryland, College Park, MD 20742

---We have developed a High-Tc SQUID microscope for fast non-destructive evaluation (NDE) of long, 2-3 mm diameter, NbTi superconducting magnet wires. A feedthrough mechanism pulls the wire at speeds of up to 20 cm/s through a thin mylar tube that separates the room temperature wire from the SQUID. We present results on test wires where we detect defects down to about 0.3 mm diameter. We discuss how we extract information from the data, such as defect size and location, and also outline a method for fast automated detection of defects in long wires.

Nonlinear Dynamics of Cracks and Time Reversed Acoustic Imaging

---**Timothy J. Ulrich** and Paul A. Johnson, Los Alamos National Laboratory, Geophysics Group EES-11, Los Alamos, NM 87545; Robert A. Guyer, Physics Department, University of Massachusetts, Amherst, MA

---The Holy Grail of nonlinear time reversed acoustics (TRA) is the detection and imaging of nonlinear scatterers without a priori knowledge of the nonlinear features. While this end product will necessarily be an amalgamation of linear tomography, experimental nonlinear elastic wave spectroscopy (NEWS) and numerical TRA modeling, the first step is to show the success of the technique experimentally in a real physical system. The work presented here is that first step where a metal sample, with a known crack, is determined “damaged” using NEWS, and consequently nonlinear TRA is employed to highlight the damage with acoustic energy. The location of the acoustic focusing is then experimentally discerned, and verified to be on the crack. Further nonlinear TRA measurements also show the ability to investigate crack interaction dynamics and the origins of the nonlinear phenomenon.

Ultrasonic Wave Generation by Lasers on Different Metal Surfaces

---**Silvio E. Kruger** and Martin Lord, Industrial Materials Institute, 75, Boul. de Mortagne, Boucherville, Quebec J4B 6Y4, Canada

---Ultrasonic wave generation by short pulsed laser is revisited in this paper with new experimental work. The generation laser pulse is fiber delivered and a virtually uniform intensity spot is obtained. Ultrasonic pulses strength versus laser pulse energy is obtained for various aluminum and steel surface conditions. To have a best reproducibility, the sample moves after each measurement in order to have a fresh surface for each laser shot. Results show strong effect of the surface condition. Special attention is paid to the determination of the transition from thermoelastic to the ablation regime and to the frequency dependence of the generated ultrasonic waves for different laser intensities. The problem of the optimum spot size for a given laser pulse energy is discussed.

Protocol and Assessment of Signal Processing and Feature Extraction Methods for Terahertz NDE for Spray-on Foam Insulation

---**John C. Aldrin**, Computational Tools, Gurnee, IL; Don J. Roth, NASA Glenn Research Center, Cleveland, OH; Jeffrey P. Seebo, Lockheed Martin, Hampton, VA; William P. Winfree, NASA Langley Research Center, Hampton, VA

---The development of an NDE procedure for the NASA shuttle external tank spray-on foam insulation is of high interest to support return to flight and long-term reliability. Terahertz NDE has demonstrated potential through initial design studies; however, signals can be noisy, while delaminations, cracks, and some voids can be difficult to detect. In order to accurately compare potential signal processing methods, a quantitative assessment protocol was developed. Automated feature extraction methods were implemented to replicate the important visual classification characteristics of the defect and noise used by inspectors. Both global and local image analysis methods were introduced for quantitative evaluation. A methodology was also developed for merit assessment of particular classification features in combination with the most promising signal processing algorithms. The protocol also addresses the evaluation of the best combination of features and signal processing algorithms for optimal discrimination. This analysis protocol was applied to several test data sets and the performance of both the feature extraction measures and the signal processing algorithms was studied. Several signal processing methods in the time and frequency domains were found to improve the discrimination of defects.

In-line NDI of Mechanical Dents on Pipelines with Circumferential Guided SH Wave EMAT

---**Xiaoliang Zhao**, Gang Mei, and Bulent Ayhan, Intelligent Automation, Inc., Rockville, MD 20855; Venugopal K. Varma, Oak Ridge National Laboratory, Nuclear Science & Technology Division, Oak Ridge, TN 37831

---Underground pipelines used for transporting natural gas and petroleum fluid are often subject to outside force damages such as third party mechanical damage or earthquakes/floods. Historically, mechanical damage is the single largest cause of pipeline failures. In this paper, circumferentially guided ultrasonic Shear Horizontal (SH) wave Electromagnetic Acoustic Transducer (EMAT) pairs in a through-transmission mode are used for detection and characterization of mechanical dents on the outer surface of a pipe from inside. Safety critical “cup” dents and relatively benign “saucer” dents are created on a 12-inch diameter standard seamless pipe by hydraulically pressing steel balls into the pipe wall. A mobile fixture with a resolver is designed for the EMAT probes so that the sensor positions and waveforms are recorded as the platform goes through the pipe. n1 mode SH wave is directed through and along the wall of the pipe. It can successfully detect mechanical dents of 25% of wall thickness and deeper and pinpoint their axial position in the pipe. The dent features are extracted with a principal component analysis (PCA) technique and classified into “cup” and “saucer” types using a discriminant analysis (DA) algorithm. Dent depth estimation potential is also shown via an amplitude correlation approach.

Measurement of the Properties of Fluids Inside Pipes Using Guided Longitudinal Waves

---**Jian Ma,** Michael J. S. Lowe, and Francesco Simonetti, Mechanical Engineering, Imperial College, London, United Kingdom

---A new technique for measuring the longitudinal bulk velocity and shear viscosity of a fluid contained inside a pipe without a need for extracting a sample from inside of the pipe is presented. It is based on the measurement of the change of the dispersion properties and attenuation of longitudinal guided modes propagating in the pipe due to the presence of the fluid. The technique to extract longitudinal bulk velocity and shear viscosity is discussed and experimentally demonstrated by measuring both low viscosity (distilled water and glycerol) and highly viscous (Cannon viscosity standard VP8400) fluids. The measured properties of glycerol agreed well with conventional methods and literature data for both the longitudinal bulk velocity (within 0.8%) and the viscosity (within 4%). For highly viscous fluid the accuracy of the velocity measurement was found to be reduced slightly (within 1%) while the viscosity measurement became more accurate (within 1%).

Noninvasive Approach for a Pressure Measurement

---**Manton J. Guers**, Daniel R. Zilinskis, and Bernhard R. Tittmann, the Pennsylvania State University, Department of Engineering Science & Mechanics, 212 Earth-Engineering Sciences Building, University Park, PA 16802-6812

---Accurate pressure measurements of the contents in pipes or tanks are useful in several applications. Pressure sensors typically require direct contact with the pressurized media. However, internal measurements may not be permissible in some cases. Internally mounted pressure sensors can also be difficult to service. Therefore, external clamp-on transducers are preferred. Ultrasonic techniques have thus been considered for pressure measurements. Ultrasonic waves are reflected from the interface between the container wall and pressurized media. Variations in the reflected signal have been analyzed for potentially determining pressure. Experimental results have also been compared to one-dimensional simulations. In addition, a resonance measurement has been investigated.

Session 27

SESSION 27

MICROSTRUCTURAL CHARACTERIZATION

P. Panetta, Chairperson
Broadway II

8:30 AM **Ultrasonic Characterization of Texture in Rolled Aluminum in Collaboration with Electron Backscatter Diffraction Measurements**
---**S. D. Essex**, S. M. Dixon, and M. Potter, University of Warwick, Department of Physics, Coventry, United Kingdom

8:50 AM **Inversion of Measured Oblique Incidence Ultrasonic Velocities: A Genetic Algorithm Based Approach**
---V. V. Janapati, C. V. Krishnamurthy, and **K. Balasubramaniam**, Centre for Non Destructive Evaluation (CNDE), Mechanical Engineering Department, IIT Madras, Chennai – 600036, Tamil Nadu, India

9:10 AM **Ultrasonic Characterization of Microstructure Evolution During Processing**
---**L. Yang**, G. Ghoshal, and J. A. Turner, University of Nebraska-Lincoln, Department of Engineering Mechanics, W317.4 Nebraska Hall, Lincoln, NE 68588-0526

9:30 AM **The Influence of Inspection Angle, Wave Type and Beam Shape on Signal-to-Noise Ratios in Ultrasonic Pitch-Catch Inspections**
---**F. J. Margetan**, A. Li, and R. B. Thompson, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

9:50 AM **Correlation Between NDE Measurement of Elongation of Aluminum**
---**R. B. Thompson**, F. J. Margetan, N. Nakagawa, and P. Haldipur, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

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

10:30 AM **Diffuse Ultrasonic Backscatter in Heterogeneous Media**
---**G. Ghoshal** and J. A. Turner, University of Nebraska, Department of Engineering Mechanics, W 317.4 Nebraska Hall, Lincoln, NE 68588-0526; R. L. Weaver, University of Illinois at Urbana-Champaign, Department of Theoretical and Applied Mechanics, 216 Talbot Laboratory, Urbana, IL 61801

10:50 AM **Wave Propagation and Attenuation Mechanisms in Solids and Solid-Liquid Suspensions**
---**P. D. Panetta**, Pacific Northwest National Laboratory, 902 Battelle Boulevard, P. O. Box 999, MSIN K5-26, Richland, WA 99352

11:10 AM **Detection of Proeutectic Cementite in Cast Irons Using Eddy Current Method**
---**T. Uchimoto**, J. Matsukawa, T. Abe, T. Takagi, and T. Sato, Tohoku University, Institute of Fluid Science, Sendai, Miyagi, Japan; H. Ike and T. Takagawa, Iwate Industrial Research Institute, Morioka, Iwate, Japan; N. Horikawa, Hokkaido University, Graduate School of Engineering, Sapporo, Hokkaido, Japan

11:30 AM **Characterization of Microstructure in Heat Treated Titanium Alloys and Maraging Steels Using Eddy Currents**
---B. P. C. Rao, **T. Jayakumar**, B. Sasi, A. Kumar, K. V. Rajkumar, and B. Raj, Indira Gandhi Centre for Atomic Research, Non Destructive Evaluation Division, Kalpakkam, Tamil Nadu, India

11:50 AM ***Lunch***

Ultrasonic Characterization of Texture in Rolled Aluminum in Collaboration with Electron Backscatter Diffraction Measurements

---**Stephen D. Essex**, Steve M. Dixon, and Mark Potter, University of Warwick, Department of Physics, Coventry, United Kingdom

---Electron Backscatter Diffraction (EBSD) is a microscopic technique that provides detailed microstructural and crystallographic orientation information for given samples. It enables the visualization and calculation of important microstructural properties such as grain size and average grain orientations. In order to validate and better understand what information an ultrasonic technique can give us we are correlating the ultrasonic measurements with those from EBSD. It also helps us to appreciate the limitations of each technique and what we can expect each to reasonably deliver. We describe a technique to extrapolate the three independent Orientation Distribution Coefficients (ODCs) W400, W420 and W440 for cubic structures from the Bunge-Euler angle data from EBSD scan data. Preliminary EBSD results for rolled aluminum sheets are discussed and compared to the ODCs obtained using an ultrasonic EMAT-EMAT S0 Lamb wave measurement system.

Inversion of Measured Oblique Incidence Ultrasonic Velocities: A Genetic Algorithm Based Approach

---Vishnu Vardhan Janapati, C. V. Krishnamurthy, and **Krishnan Balasubramaniam**, Centre for Non Destructive Evaluation (CNDE), Mechanical Engineering Department, IIT Madras, Chennai -600036, Tamil Nadu, India

---The determination of material symmetries and principle plane orientations of anisotropic plates, whose planes of symmetries are not known apriori, were calculated using a Genetic Algorithm (GA) based blind inversion method. The ultrasonic phase velocity profiles were used as input data to the inversion. The assumption of a general anisotropy was imposed during the start of each blind inversion. The multi-parameter solution space of the Genetic Algorithm was exploited to identify the “statistically significant” solution sets of elastic constants in the geometric coordinate system of the plate, by thresholding the coefficients-of-variation (Cv). Using these “statistically significant” elastic constants, the unknown material symmetry and the principle planes (angles between the geometrical coordinates and the material symmetry coordinates) were evaluated using the method proposed by Cowin and Mehrabadi. This procedure was verified using simulated ultrasonic velocity data sets on materials with transversely isotropic, orthotropic, and monoclinic symmetries. Experimental validation was also performed on unidirectional Graphite Epoxy [0]7s, and quasi-isotropic Graphite-Epoxy [0/45/90/-45]7s fiber reinforced composite plates.

Ultrasonic Characterization of Microstructure Evolution During Processing

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

---Many cold-working processes for polycrystalline metals cause alignment of the grains with a single symmetry axis. This type of microstructure is called fiber texture. The existence of a preferred orientation of the grains has a big influence on the propagation and scattering of ultrasonic waves, which are often used for material inspection. Knowledge of the wave attenuation of such textured materials is of both theoretical and practical interest to nondestructive testing and materials characterization. In this presentation, the quantitative relations between fiber texture and wave attenuations of hexagonal crystals are presented. The texture is characterized by a Gaussian distribution function that contains a single parameter that governs the transition of the texture from perfectly aligned crystals to statistically isotropic. Under this assumption, the materials of interest have a varying degree of transverse isotropy representative of processing conditions. Simple expressions for the attenuations of the three modes of waves are given in a concise, generalized representation. Example results are presented and discussed in terms of the directional, frequency and texture dependence. Finally, numerical simulation of ultrasonic wave scattering is discussed. The results presented are expected to improve the understanding of the microstructure evolution during thermomechanical processing.---Work supported by DOE.

The Influence of Inspection Angle, Wave Type and Beam Shape on Signal-to-Noise Ratios in Ultrasonic Pitch-Catch Inspections

---**Frank J. Margetan**, Anxiang Li, and R. Bruce Thompson, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

--- For UT inspections of metals, signal-to-noise ratios (S/N) are often used to quantify the extent to which the response from an isolated defect or reference reflector stands out above the competing noise due to scattering of sound by the metal microstructure. Single-scattering grain-noise models have proven useful in understanding and optimizing pulse/echo inspections of jet-engine rotating components. We are working to extend such models to pitch/catch inspections, and this paper reviews recent progress toward that end. Three quantities play key roles in determining S/N for a given pitch/catch inspection: (1) the scattering ability of the defect in question; (2) the capacity of a unit volume of microstructure to generate grain noise; and (3) the volume of insonified microstructure that can produce grain-scattered signals arriving at about the same time as the defect signal.. Each of the three quantities separately, and the resulting S/N ratio itself, depends on the choices made for inspection angles, wave types (longitudinal or shear), and beam sizes and shapes. These dependencies are demonstrated by model calculations for an assumed inspection problem, namely the detection of a small crack located at the center of a Nickel cylinder. We also describe preliminary pitch/catch experiments that are being carried out to measure grain-noise properties and to test noise-model predictions. ---Elements of this work have been supported by Pratt & Whitney, a United Technologies Company, and by the Federal Aviation Administration under Contract #DTFA03-98-D-0008, Delivery Order #0034 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.

Correlation Between NDE Measurements and Elongation of Aluminum

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

---Complex aluminum forgings can have engineering properties which vary with position due to changes in the underlying local metal microstructure. Consequently, the material properties may be in compliance with production requirements in some regions of the forging, but out of compliance in others. One conical Al-7050 forging of interest was found to have elongation properties which failed required tests in certain regions. NDE measurements sensitive to microstructural changes were carried out to search for correlations with elongation properties. Six forging coupons, each measuring approximately 0.5" x 1" x 2", were studied. Elongation testing was not performed on these specific coupons. However, such tests had been performed on coupons in similar regions. Based on those destructive measurements, the coupons examined were thought to span the range of mechanical properties of interest and to include microstructures that produced both failing and passing properties. The results of a set of initial feasibility experiments will be reported. Both ultrasonic and eddy current NDE methods were used, with the goal being to determine which properties were sensitive to the elongation. Ultrasonic testing included the measurement of longitudinal and shear-wave velocity, longitudinal wave attenuation, and longitudinal and shear-wave backscattered grain noise. All tests were performed with the sonic beam entering through the coupon face that would be adjacent to the outer surface of the forging. Only modest differences in wave speed and attenuation values were seen among the suite of coupons, but significant differences were seen in backscattered noise levels. The eddy current measurements were designed to be sensitive to the electrical resistivity. Included were a number of measurement configurations and frequencies, with signals indicating possible correlation with the microstructure. In this paper, the sample history and results of the various measurements are reviewed. Some promising preliminary results are reported.---
This work was supported by the NSF Industry/University Cooperative Research program.

Diffuse Ultrasonic Backscatter in Heterogeneous Media

---**Goutam Ghoshal** and Joseph A. Turner, Department of Engineering Mechanics, W 317.4 Nebraska Hall, University of Nebraska, Lincoln, NE 68588-0526; Richard L. Weaver, Department of Theoretical and Applied Mechanics, 216 Talbot Laboratory, 104 South Wright Street, University of Illinois at Urbana-Champaign, Urbana, IL 61801

---Diffuse ultrasonic backscatter measurements have been especially useful for extracting microstructural information and for detecting flaws in materials. Accurate interpretation of experimental data requires robust scattering models. Quantitative ultrasonic scattering models include components of both transducer beams as well as microstructural scattering information. Here, the Wigner distribution is used in conjunction with a radiative transfer equation (RTE) to model this scattering problem. The Wigner distribution represents a distribution in space and time of spectral energy density as a function of wave vector and frequency. An RTE is derived within the context of the Wigner distribution of Gaussian transducer beam model such that the source and receiver distributions are included in the analysis in a rigorous fashion. The resulting RTE is then simplified in the single-scattering limit typical of many diffuse backscatter experiments. Such experiments, usually done using a modified pulse-echo technique, utilize the variance of the signals in space as the primary measure of microstructure. The resulting backscatter model derived here is compared with previous derivations and experimental backscatter results for materials of common interest. These results are anticipated to impact ultrasonic nondestructive evaluation of polycrystalline and other heterogeneous media.
---Work supported by US DOE.

Wave Propagation and Attenuation Mechanisms in Solids and Solid-Liquid Suspensions

---**P. D. Panetta**, Pacific Northwest National Laboratory, 902 Battelle Boulevard, P. O. Box 999, MSIN K5-26, Richland, WA 99352

---The ultrasonic attenuation is commonly used to characterize the properties of solids and solid-liquid suspension to determine grain morphology for solids and particle size and solids loading for solid liquid suspensions. An ultrasonic field is attenuated by absorption and scattering mechanisms as the field traverses a material. However, the relative strength of the absorption, single scattering and multiple scattering contributions are often unknown. In solids the grain morphology and the dislocation properties are especially important contributions and in solid-liquid suspension the particle size and concentration control the attenuation. This paper will present a study of the attenuation mechanisms in solids and solid-liquid suspensions utilizing traditional attenuation, backscattering, and resonance or diffuse field measurements of the attenuation. The results provide the potential to separate the multiple scattering, single scattering and absorption contribution to the various ultrasonic attenuation measurements. Results for solids and solid-liquid suspensions which elucidate the interrelationship between these energy loss mechanisms will be reported. Where appropriate, the experimental measurements will be compared with theoretical predictions.---
This work was supported by the Department of Energy, Environmental Management Science Program. Pacific Northwest National Laboratory is operated for the U.S. Department of Energy by Battelle under Contract DE-AC06-76RLO18310.

Detection of Proeutectic Cementite in Cast Irons Using Eddy Current Method

---**Tetsuya Uchimoto**, Jun Matsukawa, Toshihiko Abe, Toshiyuki Takagi and Takeshi Sato, Tohoku University, Institute of Fluid Science, Sendai, Miyagi, Japan; Hiroyuki Ike and Takahito Takagawa, Iwate Industrial Research Institute, Morioka, Iwate, Japan; Noritaka Horikawa, Hokkaido University, Graduate School of Engineering, Sapporo, Hokkaido, Japan

---Since electric conductivity and permeability of cast irons depend on their matrices such as ferrite, pearlite and proeutectic cementite, eddy current method can characterize matrices of ductile cast irons. In this study, electromagnetic properties of ductile cast irons were examined in order to discuss the possibility of detection of proeutectoid cementite in ductile and gray cast irons using eddy current method, and consistency between electromagnetic properties and eddy current signals was discussed. For the purpose, gray and ductile cast irons with different cementite contents were prepared. Results of measurement of electromagnetic properties showed that both conductivity and permeability ductile of cast irons decrease as proeutectic cementite content increases, respectively. The eddy current method was applied to characterize specimens of different contents of ferrite, pearlite and proeutectic cementite. It was found that inclusion of proeutectic cementite can be detected through eddy current signals on the complex plane of impedance, in addition to ferrite and pearlite ratio. It is consistent with the results of electromagnetic measurements and support for the fact that the eddy current method has a capability to detect proeutectic cementite nondestructively.

Characterization of Microstructures in Heat Treated Titanium Alloys and Maraging Steels Using Eddy Currents

---Bhagi Purna Chandra Rao, **Tammana Jayakumar**, Balakrishnan Sasi, Anish Kumar, Kesavan Vadivelu Rajkumar, and Baldev Raj, Non Destructive Evaluation Division, Indira Gandhi Centre for Atomic Research, Kalpakkam, Tamil Nadu, India

---Nondestructive characterization of microstructures in metallic materials is important during manufacturing and service life to ensure that there is no undesirable or degradation in microstructures. NDE techniques exploit measurement of changes in physical properties of materials to characterize the microstructural changes. Among others, ultrasonic and eddy current techniques are widely used, because they are sensitive, versatile and field implementable. Ti alloys and Maraging steels are attractive materials in view of their high strength, fracture toughness and corrosion resistance. Solutionizing treatment and thermal ageing change electrical conductivity in non-ferromagnetic Ti alloys and both electrical conductivity and magnetic permeability are altered in Maraging steel. This paper presents results of application of eddy current technique for characterization of ageing behavior of microstructures in heat treated Ti-4.5Al-3Mo-1V (VT 14) alloy and Maraging steel. Capability of eddy current technique for quick assessment of heat treatment adequacy and for field implementation has been studied and the results are compared with ultrasonic measurements, hardness and microscopy. The magnitude and phase of impedance change in VT 14 alloy specimens subjected to solutionizing treatment in the temperature range of 923-1303K, have been correlated with ultrasonic data, hardness and microscopy. Solutionized Maraging steel specimens subjected to heat treatment at 755 K for 0.25, 1, 3, 10, 30, 40, 70 and 100h of duration have been examined. Eddy current response from these specimens indicated that the permeability decreases with increase in ageing duration. This is attributed to (a) intermetallic precipitates (Ni3Ti) and Fe2Mo and (b) reversion of martensite to austenite. These observations are compared with XRD and magnetic Barkhausen emission measurements towards assessing the capability of eddy current technique to quantify the reversion of martensite to austenite.

Session 28

SESSION 28 - POSTERS

MATERIALS AND STRUCTURES, MATERIAL PROPERTIES, NDE TECHNIQUES AND APPLICATIONS, ULTRASONICS AND NONLINEAR ACOUSTICS

Grand Ballroom I

1:30 PM

Materials and Structures

Ultrasonic Guided Wave Imaging of a Composite Plate with Air-Coupled Transducers
---**F. Yan**, E. T. Hauck, and J. L. Rose, The Pennsylvania State University, Department of Engineering Science and Mechanics, 212 EES Building, University Park, PA 16802

Comparison of Millimeter Wave, Shearography and Through-Transmission Ultrasonic Methods for Inspection of Honeycomb Composites
---M. A. Abou-Khousa, A. C. Ryley, S. Kharkovsky, and R. Zoughi, University of Missouri-Rolla, Applied Microwave Nondestructive Testing Laboratory, Electrical and Computer Engineering Department, Rolla, MO 65409; **G. Steffes**, Air Force Research Laboratory (AFRL), Materials and Manufacturing Directorate, Wright Patterson AFB, OH 45433

An Electric Resistance Change Method for Carbon Fiber Reinfored Plastic (CFRP) Inspection
---**X. Zhao**, G. Mei, Z. Ren, T. Qian, and C. Kwan, Intelligent Automation, Inc., 15400 Calhoun Dr. Suite 400, Rockville, MD 20855; A. Todoroki, Tokyo Institute of Technology, Department of Mechanical Sciences and Engineering, Tokyo 1528552, Japan

Feasibility on Ultrasonic Velocity Using Contact with Non-Contact Nondestructive Techniques for Carbon/Carbon Composites
---**K.-H. Im**, M. Chang, and M.-Y. Kim, Woosuk University, Department of Automotive Engineering, 490, Hujung-ri, Samrae-up, Wanju-kun, Chonbuk, 565-701, Korea; D. K. Hsu, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011; S.-J. Song and H. Cho, Sungkyunkwan University, School of Mechanical Engineering, Kyonggi-do, 440-746, Korea; J.-W. Park[1] and I. Y. Yang[2], [1]Department of Naval Architecture and Ocean Engineering, [2]School of Mechanical Engineering, [1,2]Choseun University, 375 Seosuk-dong, Dong-gu, Kwangju 501-759, Korea

A Portable Ultrasonic NDI System for Metal Matrix Composite Track Shoes
---X. Zhao, **B. Mi**, T. Qian, and M. Stevenson, Intelligent Automation, Inc., Rockville, MD 20855; S. Owens and R. Royer Jr., FBS, Inc. State College, PA 16803; B. Tittmann, Pennsylvania State University, Department of Engineering Science and Mechanics, University Park, PA 16802; B. B. Raju, U. S. Army TACOM, Warren, MI 48397

Impedance Method Application for Multi-Layer Structure Testing
---**M. Krishan**, Ma'an College, Al-Balga' Applied University, Ma'an 71111, Jordan

Ultrasonic Inspection of Solid Composite Laminates Using a One-Sided Pitch-Catch Contact Mode
---**D. K. Hsu**[1], D. J. Barnard[1], V. Dayal[1], and K.-H. Im[2], [1]Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011; [2]Department of Mechanical and Automotive Engineering, Woosuk University, Korea

The Effects of Heating Methods on Infrared Thermography
---A. S. Mercer and **P. Klinkhachorn**, West Virginia University, Lane Department of Computer Science and Electrical Engineering, Morgantown, WV 26506-6109; U. B. Halabe and H. V. S. GangaRao, West Virginia University, Department of Civil and Environmental Engineering, Constructed Facilities Center, Morgantown, WV 26506-6103

Array-Based Acoustic Leak Location in Spacecraft Structures
---**R. Roberts**, D. E. Chimenti, and S. Holland, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

Unmanned Ground Vehicle for Autonomous Non-Destructive Testing of FRP Bridge Decks
---**P. Klinkachorn** and A. S. Mercer, West Virginia University, Lane Department of Computer Science and Electrical Engineering, Morgantown, WV 26506-6109; **U. B. Halabe** and H. V. S. GangaRao, West Virginia University, Constructed Facilities Center, Department of Civil and Environmental Engineering, Morgantown, WV 26506-6103

Infrared Thermography Testing of FRP Bridge Decks
---C. L. Hing and **U. B. Halabe**, West Virginia University, Constructed Facilities Center, Department of Civil and Environmental Engineering, Morgantown, WV 26506-6103; P. Klinkhachorn, West Virginia University, Lane Department of Computer Science and Electrical Engineering, Morgantown, WV 26506-6109; H. V. S. GangaRao, West Virginia University, Constructed Facilities Center, Department of Civil and Environment Engineering, Morgantown, WV 26506-6103

3D GPR Imaging of Wooden Logs
---**U. B. Halabe** and S. Pyakurel, Department of Civil and Environmental Engineering, West Virginia University, Morgantown, WV 26506-6103

Material Properties

Increasing SWCNT Buckypaper Strength by Irradiation
---**A. Salmi**[1] and E. Haeggström[2], University of Helsinki, [1]Department of Physical Sciences, [2]Helsinki Institute of Physics, Kustaa Hällströmin kaktu 2, P. O. B. 64, FIN-00014 Helsinki, Finland; K. Arstila, K. Nordlund, and J. Keinonen, Department of Physical Sciences, Accelerator Lab, PB 43, FIN-00014 Helsinki, Finland

P- and S-Wave Velocity in Granite Under Pressure and Heat Load
---**I. Lassila**[1], T. Elbra[1], H. Seppänen[2], J. Haapalainen[1], T. Karppinen[1], E. Haeggström[2], and L. J. Pesonen[1], University of Helsinki, Department of Physical Sciences, P. O. Box 64, FIN-00014, Helsinki, Finland; R. Lehtiniemi, Nokia Research Center, P. O. Box 407, FIN-00045, Helsinki, Finland; [2]Helsinki Institute of Physics, P. O. Box 64, FIN-00014, Finland

Microcrack Detection in Cement-Based Materials Using Nonlinear Ultrasonic Waves
---**X. Chen**, Wuhan University of Technology, School of Transportation, Wuhan, Hubei, P. R. China; J.-Y. Kim, J. Qu, L. J. Jacobs, Georgia Institute of Technology, School of Mechanical Engineering, Atlanta, GA 30332; X. Chen, K. E. Kurtis, L. J. Jacobs, Georgia Institute of Technology, School of Civil & Environmental Engineering, Atlanta, GA 30332

A Theoretical Model for Nondestructive Evaluation of Degradation of Adhesive Joints
---**G. Shui** and Y. Wang, Beijing Jiaotong University, Institute of Engineering Mechanics, Beijing 100044, China; J. Qu, Georgia Institute of Technology, School of Mechanical Engineering, 801 Ferst Drive, Room 4103, Atlanta, GA 30332-0405

New Approaches to Backscattered Rayleigh Wave Signal Analysis for the Evaluation of CVD Diamond Coating Layers
---H.-J. Kim, **W.-W. Wang**, S.-J. Song, Sungkyunkwan University , School of Mechnical Engineering, Suwon, Kyeonggi-do, Korea; D.-J. Yang, Institute of Gas Safety R&D, Korea Gas Safety Corporation, Siheung-si, Kyeonggi-do, Korea; S.-D. Kwon, Andong National University, Department of Physics, Andong, gyeongbuk-do, Korea

Application of Millimeter Wave, Eddy Current and Thermographic Methods for Detection of Corrosion in Aluminum Substrate
---A. C. Ryley, M. T. Ghasr, **S. Kharkovsky**, and R. Zoughi, University of Missouri-Rolla, Electrical and Computer Engineering Department, 214 Emerson Electric Co. Hall, 1870 Miner Circle, Rolla, MO 65409-0040; G. Steffes, Air Force Research Laboratory (AFRL), Materials and Manufacturing Directorate, Wright Patterson AFB, OH 46433-7817

Nondestructive Evaluation of Strain Distribution and Fatigue Distribution from Austenitic Stainless Steel by Using Magnetic Sensors
---**Y. Tsuchida** and M. Enokizono, Oita University, Faculty of Engineering, 700 Dannoharu, Oita 870-1192; M. Oka and T. Yakushiji, Oita National College of Technology, Oita, Japan

Evaluation of Hardening for Carbon Steel by Measuring Magnetic Properties
---Y. Kai, **Y. Tsuchida**, and M. Enokizono, Oita University, Fac. of Eng. Oita 870-1192

A Novel and All-Remote Method for Young's Moduli Determination of Two-Layer Cantilever Beams by Optical Generation and Detection of Resonance Modes
---**D. R. Franca**[1] and A. Blouin, Industrial Materials Institute, National Research Council of Canada, 75 boul. De Mortagne, Boucherville, Québec J4B 6Y4, Canada; [1]Current Address: Department of Electrical Engineering, Faculty of Technology, University of Brasilia, Brasilia, DF 70919-970, Brazil

Monitoring the Integrity of Adhesively Bonded Structures by the Measurement of Acoustic Properties and In-Situ Temperature During Dynamic Loading
---V. Jagasivamani, School of Eng. & Technology, Hampton University, Hampton, VA 23668

NDE Techniques and Applications

Recent Progress in Multi-Channel Quadrature Interferometer: Demonstration of a Compact Fiberized Architecture
---**B. F. Pouet**, S. Breugnot, and P. Clemenceau, Bossa Nova Technologies, Venice, CA 90291; T. Murray; Boston University; Boston, MA

Development of a Synchronized Wireless Eddy Current Inspection Network
---I. Elshafiey and A. Mohra, King Saud University, Electrical Engineering Department, P. O. Box 800, Riyadh 11421, Saudi Arabia; **R. Al-Kahtani**, Saudi Telecommunication Company, P. O. Box 84824, Riyadh 11681, Saudi Arabia

Life Monitoring by Eddy Current Thermography
---**G. Zenzinger** and J. Bamberg, MTU Aero Engines, Munich, Germany

Application of a Novel Multi-Frequency Eddy Current Technique on a Shot Peened Nickel Based Engine-Graded Material
---R. T. Ko, **M. P. Blodgett***, S. Sathish, and T. R. Boehnlein, University of Dayton Research Institute, Structural Integrity Division, 300 College Park Drive, Dayton, OH 45469-0120, *AFRL

Electrostatic-Capacitive Imaging – A New NDE Technique
---**G. Diamond**, D. A. Hutchins, K. K. Leong, and T. H. Gan, University of Warwick, School of Engineering, Coventry CV4 7AL, United Kingdom; M. D. C. Moles, Olympus NDT Canada, 73 Superior Avenue, Toronto, Ontario, Canada M8V 2M7

Development, Field and Beta Tests of a Generic Manual Scanner
---**D. J. Barnard**[1], D. K. Hsu[1], J. J. Peters[2], [1]Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011; [2]Hawaiian Airlines, Honolulu, HI 96822

An Innovative Approach to Online Thickness Measurement of Thermal Spray Coatings
---**M. A. Nadeau**, M. L. Pouliot, M. F. Nadeau, M. J. Blain, M. S. A. Berube, Tecnar Automation Ltd., 1321 Hocquart, Saint-Bruno, Quebec, J3V 6B5, Canada; C. Moreau and M. Lamontagne, Industrial Materials Institute, National Research Council of Canada, Quebec, Canada

Structural Quality Control of Swiss-Type Cheese with Ultrasound
---J. Eskelinen and **E. Haeggström**, University of Helsinki, Department of Physical Sciences, P. O. Box 64, FIN-00014, Helsinki, Finland; A. Alavuotunki and T. Alatossava, University of Helsinki, Department of Food Technology, P. O. Box 66, FIN-00014, Helsinki, Finland

Automated Defect Detection for Pulsed Infrared Thermography
---**S. G. Pickering** and D. P. Almond, University of Bath, RCNDE, Department of Mechanical Engineering, Bath, BA2 7AY, United Kingdom

Visibility of Buried Structures in Atomic Force Acoustic Microscopy
---**B. Koehler**, B. Bendjus, A. Striegler, and N. Pathuri, Fraunhofer IZFP-D, Kruegerstr. 20, 01326 Dresden, Germany

Comparison of SPI and SPSI in Quantitative Measurement of Out-of-Plane Deformation
---**H.-S. Chang**, S.-W. Jung, K.-S. Kim*, and H.-C. Jung, Laser RRC, Chosun University, 375 Seosuk-Dong, Dong-Gu, Gwangju, 501-759, Korea; *Department of Mechanical Design Engineering, Chosun University, 375 Seosuk-Dong, Dong-Gu, Gwangju, 501-759, Korea

Ultrasonics and Nonlinear Acoustics

Excitation and Detection of Guided Waves in Cylindrical Structures for Flaw Inspection
---**K. Takamiya**, Keio University, School of Integrated Design Engineering, Graduate School of Science and Technology, Yokohama, Kanagawa, Japan; T. Sugiura, Keio University, Department of Mechanical Engineering, Faculty of Science and Technology, Yokohama, Kanagawa, Japan

Elastic Body-Oscillator Model for Theoretical Analysis of Nonlinear Ultrasound
---S. Yamamoto, R. Sasaki, Y. Ohara, T. Mihara, and **K. Yamanaka**, Tohoku University, Department of Materials Processing, Sendai, Miyagi, Japan

Nonlinear Dynamics Caused by Incidence of Ultrasonic Waves into a Closed Crack
---**T. Ishikawa** and S. Hirata, School of Integrated Design Engineering, Graduate School of Science and Technology, Keio University, Yokohama, Kanagawa, Japan; T. Sugiura, Department of Mechanical Engineering, Faculty of Science and Technology, Keio University, Yokohama, Kanagawa, Japan

Effect of Contact Nonlinear Acoustics Caused During Incidence of Ultrasonic Wave into a Closed Crack
---**T. Ishikawa** and S. Hirata, Keio University, School of Integrated Design Engineering, Graduate School of Science and Technology, Yokohama, Kanagawa, Japan; T. Sugiura, Keio University, Department of Mechanical Engineering, Faculty of Science and Technology, Yokohama, Kanagawa, Japan

Accurate Simulation of Phased Array Received Signals from Media Containing Arbitrarily Shaped Impedance Discontinuities, with Experimental Validation
---Y.-S. Lai and **V. Lupien,** Acoustic Ideas; W. Abbasi, Siemens Power Generation; W. Hassan, Honeywell Aerospace

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

Ultrasonic Guided Wave Imaging of a Composite Plate with Air-Coupled Transducers

---**Fei Yan**, Eric T. Hauck, and Joseph L. Rose, The Pennsylvania State University, Department of Engineering Science and Mechanics, 212 EES Building, University Park, PA 16802

---In recent years, air-coupled transducers have been widely used for bulk wave C-scan imaging of materials with low acoustic impedances. In this paper, a long range ultrasonic guided wave imaging method using air-coupled transducers is presented to image impact delaminations in a carbon-epoxy composite plate. Two air-coupled transducers were used to generate and receive Lamb waves in the composite plate using through transmission. The Lamb wave mode was controlled by tuning the angle of the incident wave. In the scan processes, two transducers were moved synchronously in the direction perpendicular to the Lamb wave path. The composite plate was scanned in 4 directions (0, 45, 90, and -45 degree with respect to the fiber lay-up). Energy distribution of the Lamb wave ray in each scan direction was studied utilizing a laser vibrometer. The measured energy distribution was combined with the probabilistic damage detection concept for image reconstruction. The impact defects of the composite plate were detected and located in the reconstructed images, and the potential exists to size and determine the severity of these defects.

Comparison of Millimeter Wave, Shearography and Through-Transmission Ultrasonic Methods for Inspection of Honeycomb Composites

---Mohamed A. Abou-Khousa, Adam C. Ryley, Sergey Kharkovsky, and Reza Zoughi, Applied Microwave Nondestructive Testing Laboratory, Electrical and Computer Engineering Department, University of Missouri-Rolla, MO; **Gary Steffes**, Air Force Research Laboratory (AFRL), Materials and Manufacturing Directorate, Wright-Patterson AFB, OH 45433

---Honeycomb composites are increasingly finding utility in a variety of environments and applications, such as structural components, radomes, etc. In-service and environmental stresses can produce unwanted flaws that adversely affect the structural integrity and functionality of these composites. These flaws may be in the forms of disbonds, delaminations, impact damage, crushed honeycomb, moisture intrusion, internal cracks, etc. There are several nondestructive testing (NDT) methods that may be used to inspect these composites for the presence and evaluation of these flaws. Glass fiber-reinforced epoxy skin honeycomb composites are in the family of low permittivity and low loss materials and hence near-field millimeter wave NDT methods are quite suitable for their inspection. These methods are also capable of detecting very thin disbonds, presence of moisture and other intrusive fluids, impact damage, etc. Other NDT methods, such as shearography and ultrasonic testing, may also be used for this purpose particularly if the skin is made of carbon fiber-reinforced epoxy. To this end, two honeycomb composites panels, (1”-thick and 0.5”-thick) each with one side covered with a glass-reinforced epoxy and the other side with carbon fiber-reinforced epoxy skins were produced with several embedded flaws primarily representing planar disbonds at various levels within the thickness of the panels and with different shapes. Near-field millimeter wave NDT techniques in the range of 26-95 GHz, using custom-designed reflectometers, were used to produce images of these panels. The results indicated that at several frequencies, the presence, shape and spatial extent of the disbonds were clearly detected and evaluated. In addition these panels were inspected with shearography and through-transmission ultrasonic methods. This paper presents the results of these investigations and a comparison among the capabilities of these methods.

An Electric Resistance Change Method for Carbon Fiber Reinforced Plastic (CFRP) Inspection

---**Xiaoliang Zhao**, Gang Mei, Zhubin Ren, Tao Qian, and Chiman Kwan, Intelligent Automation, Inc., 15400 Calhoun Dr. Suite 400, Rockville, MD 20855; Akira Todoroki, Tokyo Institute of Technology, Department of Mechanical Sciences and Engineering, Tokyo 1528552, Japan

---High strength and low weight carbon fiber reinforce composite materials are widely used in many critical, high-valued systems such as aircraft wing and graphite motor cases. Carbon fibers are intrinsically conductive and they form an impedance network inside the CFRP. This study employs an electric resistance change method for defect identification and localization in a CFRP plate such as delamination and cracks. Experimental study is carried out on 16-ply quasi-isotropic plate type specimens ([(0/45/90/-45)s]2) fabricated with Cytec 977-3 prepreg tapes. On the specimen surface, multiple electrodes are mounted by either co-curing or gluing with conductive epoxy the copper foils to measure electric resistance changes. Dropping weight impact tests are conducted to create a practical delamination crack in the specimen. Quite a number of tests are conducted to obtain a data set for solving inverse problems to estimate delamination location and size from the measured electric resistance changes. Both an artificial neural network and a correlation analysis based statistical approach are employed for a solver of inverse problems. As a result, the method successfully identifies and localizes delamination and cracks for these plate type CFRP specimens.

Feasibility on Ultrasonic Velocity Using Contact with Non-contact Nondestructive Techniques for Carbon/Carbon Composites

---**Kwang-Hee Im**, Ming Chang, and Mi-Youn Kim, Woosuk University, Department of Automotive Engineering, 490, Hujung-ri, Samrae-up, Wanju-kun, Chonbuk, 565-701, Korea; David K. Hsu, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011; Sung-Jin Song and Hyeon Cho, Sungkyunkwan University, School of Mechanical Engineering, Kyonggi-do, 440-746, Korea; Je-Woong Park[1] and In-Young Yang[2], [1]Department of Naval Architecture and Ocean Engineering, [2]School of Mechanical Engineering, [1,2]Choseun University, 375 Seosuk-dong, Dong-gu, Kwangju 501-759, Korea

---Advanced materials are required to have specific functions associated with extremely environments. One of them is carbon/carbon(C/C) composite material, which has obvious advantages over conventional materials. The C/Cs have become to be utilized as parts of aerospace applications and its low density, high thermal conductivity and excellent mechanical properties at elevated temperatures make it an ideal material for aircraft brake disks. Because of permeation of coupling medium such as water, it is desirable to perform contact-less nondestructive evaluation to assess material properties and part homogeneity. In this work, a C/C composite material was characterized with non-contact and contact ultrasonic methods using an acquisition scanner. Also through transmission mode was performed because of the main limitation for air-coupled transducers, which is the acoustic impedance mismatch between most materials and air. Especially ultrasonic images and velocities for C/C composite disk brake was measured and found to be consistent to some degree with the non-contact and contact ultrasonic measurement methods. Low frequency through-transmission scans based on both amplitude and time-of-flight of the ultrasonic pulse were used for mapping out the material property inhomogeneity. Measured results were compared with those obtained by the system with using dry-coupling ultrasonics and through transmission method in immersion. Finally, a feasibility has been found to measure and compare ultrasonic velocities of C/C composites with using the contact/noncontact peak-delay measurement method based on the pulse overlap method.

A Portable Ultrasonic NDI System for Metal Matrix Composite Track Shoes

---Xiaoliang Zhao, **Bao Mi**, Tao Qian, and Mark Stevenson, Intelligent Automation, Inc., Rockville, MD 20855; Steve Owens and Roger Royer Jr., FBS, Inc. State College, PA 16803; Bernhard Tittmann, Pennsylvania State University, Department of Engineering Science and Mechanics, University Park, PA 16802; Basavaraju B. Raju, U. S. Army TACOM, Warren, MI 48397

---Cast aluminum track shoes reinforced with SiCw or metal matrix composite (MMC) inserts at heavy loading area such as the center guide and sprocket windows are light in weight, and can resist high temperature and wear. Various defects such as delaminations at the insert-substrate interface, cracks and porosity in the MMC can be introduced during the manufacturing process and/or in service. Presented in this paper is a portable ultrasonic NDI system to automatically inspect the tank track shoe for disbond, cracks and porosities. Ultrasonic pulse/echo inspection has shown the most reliable result for delamination detection. A prototype clamped-on fixture has been designed to hold an array of four longitudinal transducers for demonstration purpose. It uses 0.5" diameter, 10 MHz transducer probes with a dry couplant pad and applies a same pressure over each transducer to achieve a uniform coupling condition. The entire inspection process is automated with the control of a rugged lunch box computer. A graphical user interface (GUI) is developed with LabVIEW to execute the inspection, extract the defect information, and report the results. The prototype system is tested on both used and brand new track shoes and the results are confirmed with immersion ultrasonic C-scan images.

Impedeance Method Application for Multi-Layer Structure Testing

---**Monzer Krishan**, Ma'an College, Al-Balga' Applied University, Ma'an 71111, Jordan

---Multi-layer materials and structures are widely used in the modern aircraft industry. The main defect of these structures is delamination. The most appropriate method for detection of such kind flaws is the impedance testing method. This paper is devoted to the features of the impedance method for multi-layer panel testing. The theoretical and experimental investigations of mechanical impedance were provided for honeycomb panels. As a result of the theoretical investigation it was obtained the analytic expression which enabled to determine action of such object parameters as honeycomb density and thickness, covering thickness and cylindric rigidity on a test result. The assembly of a combined probe was proposed for experimental investigations of mechanical impedance. An amplitude of the output signal of this probe is depended on the testing object mechanical impedance and flexibility of contact area. Numerical simulation results demonstrate influence of the object parameters on effectiveness of the defect detection in honeycomb structure.

Ultrasonic Inspection of Solid Composite Laminates Using a One-sided Pitch-Catch Contact Mode

---**David K. Hsu**[1], Daniel J. Barnard[1], Vinay Dayal[1], and Kwang-Hee Im[2], [1]Center for NDE, Iowa State University, Ames, IA 50011; [2]Dept. of Mechanical & Automotive Engineering, Woosuk University, Korea

---Ultrasonic NDE of composite laminates is often based on the backwall echoes of the sample. In the inspection of actual composite hardware, the back surface of the part may be curved or contains complex geometry and does not provide a usable backwall echo. In this work, a one-sided pitch-catch setup was used in the detection and evaluation of flaws and material anomalies in solid composite laminates. Two miniature potted Rayleigh wave transducers (for generating surface waves in contact mode on steel) were joined head-to-head and used in the pitch-catch mode on the surface of composites. The pitch-catch signal was found to be more sensitive than normal incidence backwall echo of longitudinal wave to subtle flaw conditions in the composite, including low level porosity, ply waviness, and cracks. The depth of the sampling volume where the pitch-catch signal came from was relatively shallow with the head-to-head miniature Rayleigh probes, but the depth can be increased by increasing the separation distance of the transmitting and receiving probes. With the aid of the generic manual scanner ("GenScan") developed by CNDE at Iowa State University, the one-sided pitch-catch probe may also be used to produce C-scan images.---This material was based upon work supported by the NSF Industry/University Cooperative Research Center for NDE at Iowa State University.

The Effects of Heating Methods on Infrared Thermography

---A. S. Mercer and **Powsiri Klinkhachorn**, West Virginia University, Lane Department of Computer Science and Electrical Engineering, Morgantown, WV 26506-6109; Udaya B. Halabe and Hota V.S. GangaRao, West Virginia University, Department of Civil and Environmental Engineering, Constructed Facilities Center, Morgantown, WV 26506-6103

---Any discontinuity within a structural component changes the transmission of thermal energy through its thickness, which leads to differences in surface temperatures just above the defective and defect-free areas. Infrared Thermography measures the variation in the surface temperatures using an infrared camera and the thermal images (thermograms) are analyzed to locate the presence of subsurface defects such as debonds and delaminations within the structure. Since this technique requires heat to be present in order to produce results, it seems only logical that research should be conducted on the effects that different heating types have on the defect analysis. For this study, various heat sources; such as the sun, a 5000 BTU electric heater, a 9000 BTU propane heater, and a 35000 BTU forced air propane heater, were used to heat up an FRP bridge deck with built-in defects for IR analysis. Different heating times were used to determine how heating time affects the accuracy and the total elapsed time involved in seeing a defect in the resultant IR images. A few methods, such as CO2 cooling, for decreasing the time it takes to see the defect in the image were also explored. Results of this study show that air-filled subsurface defects can be detected accurately in a short amount of time.

Array-Based Acoustic Leak Location in Spacecraft Structures

---**R. Roberts**, D. E. Chimenti, and S. Holland, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---Progress in the development of a method using leak-generated structure-borne noise to locate small air leaks in long-duration spacecraft, such as the International Space Station (ISS) is presented. Space debris and micrometeorites can penetrate the ISS pressure container, causing loss of air. Stopping a small leak is relatively simple, once its location is known. Because rack-mounted equipment and insulation mask the leak location, and because a leak into space vacuum produces almost no airborne ultrasonic noise in the spacecraft interior, a structure-borne noise solution is necessary. Source location using time of flight information contained in structure-borne noise signals has historically performed less-than-robustly due to signal complications introduced by the multi-mode dispersive propagation characteristics of the plate structures. Our work has pursued the use of spatial array detection to rigorously accommodate the complexity multimode signals. Past work has developed integrated array sensors appropriate for in-flight application. The ongoing work summarized in this paper is examining the performance of these sensors when functioning in the presence on non-ideal structural features, such as an integral stiffening pattern machined into the skin of spacecraft structures.

Unmanned Ground Vehicle for Autonomous Non-Destructive Testing of FRP Bridge Decks

---**Powsiri Klinkhachorn** and A. S. Mercer, West Virginia University, Lane Department of Computer Science and Electrical Engineering, Morgantown, WV 26506-6109; **Udaya B. Halabe** and Hota V.S. GangaRao, West Virginia University, Constructed Facilities Center, Department of Civil and Environmental Engineering, Morgantown, WV 26506-6103

---Current non-destructive techniques for analyzing bridge decks have a narrow scope. These techniques are very good at one certain thing but are not robust enough to detect all defects by themselves. For example, infrared analysis can detect air-filled defects and Ground Penetrating Radar (GPR) is good at detecting water-filled ones. These technologies can be combined to create a more robust defect detection scheme. To accomplish this, an Unmanned Ground Vehicle (UGV) has been designed that incorporates both IR analysis and GPR to create a comprehensive defect map of a bridge deck. The UGV autonomously surveys the deck surface and captures data. The UGV has two 1.5 GHz ground coupled GPR antennas that are mounted on the front of the UGV to collect GPR data. It also incorporates an active heating source and a radiometric IR camera to capture IR images of the deck, even in less than ideal weather scenarios such as cold cloudy days. The UGV is designed so that it can collect data in an assembly line fashion. It moves in 1 foot increments. When moving, it collects GPR data from the antenna. When it stops it heats a section of the deck. The next time it stops to heat a section, the IR camera is analyzing the preheated deck section while preparing the next section. Because the data is being continually collected using this method, the UGV can survey the entire bridge deck in a relatively short amount of time.

Infrared Thermography Testing of FRP Bridge Decks

---Cheng L. Hing and **Udaya B. Halabe**, West Virginia University, Constructed Facilities Center, Department of Civil and Environmental Engineering, Morgantown, WV 26506-6103; Powsiri Klinkhachorn, West Virginia University, Lane Department of Computer Science and Electrical Engineering, Morgantown, WV 26506-6109; Hota V. S. GangaRao, West Virginia University, Constructed Facilities Center, Department of Civil and Environmental Engineering, Morgantown, WV 26506-6103

---This paper presents the results from an experimental study that investigated the use of infrared thermography for subsurface defect detection in Fiber Reinforced Polymer (FRP) bridge decks. FRP bridge deck specimens were cast with embedded subsurface defects (air- and water-filled) of varying planar sizes and thicknesses. These decks were tested using infrared thermography under the influence of several heating sources including a quartz heater, heating blanket and solar radiation. The solar radiation test was conducted for a full 24 hour cycle in order to observe both daytime and nighttime surface temperature profiles. While the daytime surface temperature differences between defective and defect-free areas were significant (up to 4 C), it was found that the nighttime temperature differences were less than 0.5 C. The study also compared the results between hot sunny weather and relatively cold weather.

3D GPR Imaging of Wooden Logs

---**Udaya B. Halabe** and Sandeep Pyakurel, Department of Civil and Environmental Engineering, West Virginia University, Morgantown, WV 26506-6103

---There has been a lack of an effective NDE technique to locate internal defects within wooden logs. The few available elastic wave propagation based techniques are limited to predicting E values. Other techniques such as X-rays have not been very successful in detecting internal defects in logs. If defects such as embedded metals could be identified before the sawing process, the saw mills could significantly increase their production by reducing the probability of damage to the saw blade and the associated downtime and the repair cost. Also, if the internal defects such as knots and decayed areas could be identified in logs, the sawing blade can be oriented to exclude the defective portion and optimize the volume of high valued lumber that can be obtained from the logs. In this research, GPR has been successfully used to locate internal defects within the logs. GPR's additional capabilities include the identification of embedded metals and decays within the logs. This paper discusses GPR imaging and mapping of the internal defects using both 2D and 3D interpretation methodology. Several metal pieces were inserted in logs and the reflection patterns from these metals were interpreted in the radargram acquired using 900 MHz antenna. Also, GPR was able to accurately identify the location of the internal defects such as knots and decays. The resolution of the GPR data was further improved using a 1.5GHz frequency antenna. Sawing the top surface of the log and making it flat enabled the antenna to have physical contact with the log and this antenna-log coupling tremendously increased the signal quality and resolution. Scans from several orientations of the log were collected to generate 3D cylindrical volume. The location of the defects showed good correlation with the interpreted defects in the 3D volume. Also, time/depth slices from the 3D cylindrical volume data were useful in understanding the extent of defects inside the log.

Increasing SWCNT Buckypaper Strength by Irradiation

---**Ari Salmi**[1] and Edward Haeggström[2], University of Helsinki, [1]Department of Physical Sciences, [2]Helsinki Institute of Physics, Kustaa Hällströmin katu 2, P.O.B 64, FIN-00014 Helsinki, Finland; Kai Arstila, Kai Nordlund, and Juhani Keinonen, Department of Physical Sciences, Accelerator Lab, PB 43, FIN-00014 Helsinki, Finland

---Single wall nanotube buckypaper is a modern strong light-weight material that could find use in industrial applications. Both shear and elastic moduli are crucial in manufacturing enduring coatings. Simulations have indicated that irradiation might increase the modulus of elasticity of buckypaper. We therefore studied the effects of 12C ion irradiation (ion energy 23 MeV, doses ranging from 1017 to 3•1018 1/m2) on bucky paper (ρ=490±50 kg/m3) comprising of single walled carbon nanotubes (SWCNT). 4 MHz longitudinal and 15 MHz shear ultrasonic signals (80% fractional bandwidth) were transmitted by means of dry-coupled acoustic horns through 40±4 μm thick samples and the time-of-flight (TOF) through the samples was measured. The measurements were conducted under laboratory conditions (RH = 50%, T = 23ºC). From TOF the velocity of the wave was determined and the out-of-plane elastic modulus E = 5.3±1.1 GPa and shear modulus G = 1.9±0.3 GPa were calculated. The velocity anisotropy of the samples was studied by measuring the velocities from several points in the samples. The nonlinearity parameter B/A for the irradiated and reference sample was measured. The results indicated a slight increase (~15%) in both moduli for certain irradiation doses (2•1017 1/m2) as was predicted in earlier simulations. Additional irradiations will be carried out at doses where a larger increase might be possible.

P- and S-wave Velocity in Granite Under Pressure and Heat Load

---**Ilkka Lassila**[1], Tiiu Elbra[1], Henri Seppänen[2], Jonne Haapalainen[1], Timo Karppinen[1], Edward Haeggström[2] and Laui J. Pesonen[1], University of Helsinki, Department of Physical Sciences, P. O. Box 64, FIN-00014, Helsinki, Finland; Reijo Lehtiniemi, Nokia Research Center, P. O. Box 407, FIN-00045, Helsinki, Finland; [2]Helsinki Institute of Physics, P. O. Box 64, FIN-00014, Finland

---The Outokumpu area is economically the most important geological terrain in eastern Finland. Its geologic development is poorly known due to lack of data (e.g. seismic velocity under crustal pressure and temperature conditions). We report on design of an laboratory instrument to estimate seismic P-wave and S-wave velocities of cylindrical core samples (height 22 mm, diameter 25 mm), obtained from the Outokumpu Deep Drilling Project. Thermal- and FEM modeling was used to guide the design. Thermal-, ultrasonic- and pressure engineering considerations are presented as well as preliminary pressure-velocity results. Preliminary P-wave and S-wave velocities of basement granite samples (height 22 mm, diameter 25 mm) from a deep drill core in Outokumpu are reported. The velocities were simultaneously measured using a pitch-catch method with two pairs of 1 MHz Pz27 transducers, one pair for P-wave and the other for S-wave. Fused quartz delay lines were used. The actively heated (24-300 ºC) samples were statically loaded (0-300 MPa) with a hydraulic jack along the acoustic axis during the measurements. These conditions can resemble the crustal conditions down to 15 km. Preliminary results are comparable with literature values for granitic rocks. The instrument can also be used to study acousto-elasticity in rocks.

Microcrack Detection in Cement-Based Materials Using Nonlinear Ultrasonic Waves

---**Xiaojia Chen**, School of Transportation, Wuhan University of Technology, Wuhan, Hubei, P.R. China; Jin-Yeon Kim, Jianmin Qu, Laurence J. Jacobs, School of Mechanical Engineering, Georgia Institute of Technology, Atlanta, GA 30332; Xiaojia Chen, Kimberly E. Kurtis, Laurence J. Jacobs, School of Civil & Environmental Engineering, Georgia Institute of Technology, Atlanta, GA 30332

---Nonlinear ultrasonic techniques have great potential to characterize damage accumulation in cement-based materials. This research uses nonlinear ultrasonic waves to quantify the accumulation of damage, specifically microcracks, in cement-based materials. Multiple one-dimensional, mortar bar specimens are produced using alkali-reactive aggregate and exposed to environmental conditions, following ASTM C 1260, to gradually induce microcracking by alkali-silica reaction (ASR). Nonlinear ultrasonic techniques are then used to incrementally track this damage accumulation. The effectiveness of two complementary nonlinear ultrasonic methods, a nonlinear acoustical modulation (NAM) method and a harmonic amplitude relation (HAR) method, is considered. Both ultrasonic methods give similar results, and can quantitatively track the damage increase in multiple samples. These ultrasonic results show a quantifiable increase in nonlinearity as the ASR expansion (relative increase in length) reaches about 0.05%, which is generally considered to be the strain at which microcracks are initially formed in cement-based materials; this agreement demonstrates that the nonlinear ultrasonic properties are greatly influenced by the formation of these microcracks, and have the potential to be used for early detection of microcracks in cement-based materials. Finally both nonlinear ultrasonic techniques are used to quantitatively track the increase in microcracks as a function of ASR expansion.

A Theoretical Model for Nondestructive Evaluation of Degradation of Adhesive Joints

---**Guoshuang Shui** and Yuesheng Wang, Beijing Jiaotong University, Institute of Engineering Mechanics, Beijing 100044, China; Jianmin Qu, Georgia Institute of Technology, School of Mechanical Engineering, 801 Ferst Drive, Room 4103, Atlanta, GA 30332-0405

---In this paper, a new theoretical model is developed to characterize the damage of the adhesive joint. Generally, damage of the adhesive joint includes debonding, cohesive defects and adhesive defects that are caused at manufacture by curing errors or in service by environmental attack. Considering that the thickness of the adhesive layer is very small, it is reasonable to believe that the damage will decrease the tension modulus of the adhesive joint while the compression modulus will keep unchanged, and therefore the tension and compression modulus of the adhesive joint will be different. This is a nonlinear boundary condition for ultrasonic waves transmitting through the adhesive layer. That is, a purely sine harmonic wave will be distorted when passing through the adhesive joint, and higher order harmonics will be generated. Using integral method, we solve the associated boundary value problem to obtain the nonlinear ultrasonic wave forms passing through the adhesive layer that has different tension and compression modulus. Defining a nonlinear coefficient that is related to the amplitude of the transmitted waves, we can therefore correlate this nonlinear coefficient with the damage variable that is related to the tension and compression modulus of the adhesive layer. The results show that this nonlinearity coefficient is quite sensitive to the damage variable of the adhesive joint. With the relation between nonlinear coefficient and damage variable, we can thus learn the materials damage state, and we believe that this method can be effectively used to characterize the in-service state and predict fatigue life of the adhesive layer. Furthermore, we can also make some assessment to the total number of microcracks per unit area nondestructively through the nonlinear coefficient by assuming the existence of the microcracks only influences the tension modulus of the adhesive layer.

New Approaches to Backscattered Rayleigh Wave Signal Analysis for the Evaluation of CVD Diamond Coating Layers

---Hak-Joon Kim, **Wen-Wu Wang**, and Sung-Jin Song, Sungkyunkwan University, School of Mechanical Engineering, Suwon, 440-746, Korea; Dong-Ju Yang, Institute of Gas Safety R&D, Korea Gas Safety Corporation, Siheung-si, Kyeonggi-do, Korea; Sung-Duk Kwon, Department of Physics, Andong National University, Andong, gyeongbuk-do, Korea

---Nondestructive evaluation of chemical vapor deposit (CVD) diamond coating layers has to be performed since delamination between the CVD diamond coating layer and the silicon substrate occurs frequently due to a large difference in material properties. The backscattered Rayleigh waves have been applied previously, however, since the thickness of CVD diamond coating layer is only a few micrometers. The time trace angular scan (TTAS) and the frequency spectrum angular scan (FSAS) methods have been proposed and showed a high possibility of the proposed methods as tools for evaluation of the bonding quality of the diamond coating layer. Even though those signal analysis methods have demonstrated their high potentials, it is necessary to develop more precise and quantitative methods that are based on sound understanding of underlying physics. To address such a need, in this study, we propose three new signal analysis tools; “Specular profile”, “Energy profile” and “Time-Frequency windowed profile”. These approaches are based on propagation and scattering characteristics of the Rayleigh surface wave. Using the proposed methods, we will also evaluate the bonding quality of CVD coating layers. In this presentation, the concept of these three profiles and the initial experimental results will be presented.

Application of Millimeter Wave, Eddy Current and Thermographic Methods for Detection of Corrosion in Aluminum Substrate

---Adam C. Ryley, Mohammad T. Ghasr, **Sergey Kharkovsky**, and Reza Zoughi, University of Missouri-Rolla, Electrical and Computer Engineering Department, 214 Emerson Electric Co. Hall, 1870 Miner Circle, Rolla, MO 65409-0040; Gary Steffes, Air Force Research Laboratory (AFRL), Materials and Manufacturing Directorate, Wright-Patterson AFB, OH 46433-7817

---Aluminum structures exposed to the elements are susceptible to corrosion. Corrosion may cause various mechanical and structural deficiencies such as wall thinning. It is desirable to rapidly detect and evaluate the properties of an aluminum substrate early in the corrosion process to avoid costly maintenance actions. Millimeter wave nondestructive inspection techniques have shown great potential for this purpose due to their high spatial resolution. This is particularly true for structures covered with dielectric coatings (e.g., appliqué), in which millimeter wave signals can easily penetrate through the coating and expose the presence of corrosion. This paper presents the results of an extensive investigation by comparing the nondestructive evaluation c-scan imaging results of millimeter wave, conventional eddy current, and flash thermography techniques. The millimeter wave analysis involved using single and differential probes at frequency ranges from 30-70 GHz. The conventional eddy current analysis was completed at low frequencies, and the flash thermography imaging was taken at various times using a whole field technique.

Nondestructive Evaluation of Strain Distribution and Fatigue Distribution from Austenitic Stainless Steel by Using Magnetic Sensors

---**Yuji Tsuchida** and Masato Enokizono, Oita University, Faculty of Engineering, 700 Dannoharu, Oita 870-1192; Mohachiro Oka and Terutoshi Yakushiji, Oita National College of Technology, Oita, Japan

---Austenitic stainless steel is usually classified as a nonmagnetic material. However, applying stress transforms the plastic part of it into a martensitic crystal structure, from an austenitic crystal structure and it becomes magnetized. Strain evaluation and fatigue evaluation can be performed by measuring the leakage magnetic flux density of remanent magnetization after applying strain and fatigue to austenitic stainless steels. This paper describes the measurement of leakage magnetic flux density of remanent magnetization by a typical Hall element sensor for SUS304 and SUS304L and by a high-sensitivity thin-film flux-gate magnetic sensor for SUS316 and SUS316L.

Evaluation of Hardening for Carbon Steel by Measuring Magnetic Properties

---Yuichiro Kai, **Yuji Tsuchida**, and Masato Enokizono, Oita University, Faculty of Engineering, 700 Dannoharu, Oita 890-1192

---High strength steel is desired by many structural buildings and parts for machines in manufacturing industry. Therefore, industrial products which require high strength are hardened using induction heating. However, it is very difficult to control hardening depth and hardness for steel. And the hardening method can increase the hardness of steel at the risk of increasing its brittleness. Therefore, measurement and evaluation of hardness and hardening depth is very important. We propose to evaluate the hardening depth by using electromagnetic method instead of mechanical tests. Therefore, it is very important to make clear the change of material characteristics of the hardened steels. In this paper, magnetic properties of the hardened carbon steel are measured and the evaluation of hardening is carried out from the measured results of magnetic properties.

A Novel and All-Remote Method for Young's Moduli Determination of Two-Layer Cantilever Beams by Optical Generation and Detection of Resonance Modes

---**D. R. Franca**[1] and A. Blouin, Industrial Materials Institute, National Research Council of Canada, 75 boul. De Mortagne, Boucherville, Québec J4B 6Y4, Canada; [1]Current Address: Department of Electrical Engineering, Faculty of Technology, University of Brasilia, Brasilia, DF 70919-970, Brazil

---Microstructures made of cantilever beams are important for designing a number of practical devices. Proper design requires that the Young´s moduli of the cantilever's thin layers be accurately known. The resonance method is an elegant approach for determining the Young´s moduli in the thin layers domain. Through this method, Young´s moduli of the layers are correlated to modal resonant frequencies of the microstructures. Here, a novel, simple and effective method of exciting resonance modes in microstructures is proposed. A laser pulse is pointed to arbitrary locations over the surface of the test structure (in this case, a MEMS board containing an array of cantilever beams). Elastic excitation of the whole board then forces the cantilevers to vibrate effectively, as a variety of resonance modes is simultaneously excited. The method is nondestructive, remote and totally free of sample preparation. In addition, no precise alignment of the generation laser beam with respect to the board is required. A broadband homodyne Michelson interferometer is implemented for vibration detection, making the inspection technique totally non-contact. Using the first mode resonance frequency together with the cantilever´s *Q* factor, an analytical procedure leading to the Young´s moduli determination of thin layers of two-layer cantilever beams is derived. The procedure works under the assumption that air damping is the dominant loss mechanism acting on the cantilevers. Results are in good agreement with published values.

Monitoring the Integrity of Adhesively Bonded Structures by the Measurement of Acoustic Properties and In-Situ Temperature During Dynamic Loading

---Vadivel Jagasivamani, School of Engineering & Technology, Hampton University, Hampton, VA 23668

---Adhesive bonding methods are useful in reengineering of legacy systems, to reduce the cost of remanufacturing, especially in small quantities. Two major limitations associated in employing bonding methods are assuring the structural integrity and ensuring the structures to stay within the permissible range of temperatures. The elastic properties, density, and linear dimensions in the bonded region are temperature sensitive. The stresses associated with the bonding layer will influence the elastic properties of the bond. During dynamic loading the temperature in the bondline region increases due to the process of relaxation of the adhesives. The present work attempts to correlate the dynamic change in the temperature and acoustic properties to the status of the bondline on test samples subjected to dynamic loading. Measurements of time of flight, absorption coefficient and in-situ temperatures have been carried out during dynamic loading of bonded structure. The test results have been correlated to the integrity of bonding and the onset of deterioration of the bonding. The current work discusses the principles and applications of the technique in assessing the integrity of bonded structures.

Recent Progress in Multi-Channel Quadrature Interferometer: Demonstration of a Compact Fiberized Architecture
---**Bruno F. Pouet**, Sebastien Breugnot, and Philippe Clemenceau, Bossa Nova Technologies, Venice, CA 90291; T. Murray; Boston University; Boston, MA

---Laser-ultrasonics has now become a recognized NDE technique for use in industrial environment. The field of industrial application is further broadening as the cost of laser-ultrasonics equipment decreases and becomes simpler to use and to maintain. We previously demonstrated that a highly sensitive, robust and cost effective interferometer for remote detection of ultrasound can be achieved with a multi-channel quadrature interferometer. This architecture takes advantage of the random distribution of speckled light in order to introduce a random quadrature. Multi-channel detection is achieved with photodiodes arrays combined with parallel processing electronic circuitry. Summing the independent signals leads to a stable output signal independently of the environment. This interferometric scheme is well suited for use with optical fiber delivery. We will demonstrate that the optical design of the random quadrature interferometer can be further simplified using optical fiber delivery, increasing its robustness without degrading its performances. In this case, we take advantage of the partial reflection at the fiber end for generating the reference beam and the interferences are produced through mode coupling in the fiber. A breadboard prototype will be displayed and demonstration will be carried out with the measurement of ultrasounds on unprepared, rough sample surfaces.

Development of a Synchronized Wireless Eddy Current Inspection Network
---I. Elshafiey and A. Mohra, King Saud University, Electrical Engineering Department, P. O. Box 800, Riyadh 11421, Saudi Arabia; **R. Al-Kahtani**, Saudi Telecommunication Company, P. O. Box 84824, Riyadh 11681, Saudi Arabia

---A new system is proposed based on a wireless network of eddy-current probes for detecting subsurface cracks and anomalies. Excitation in each node is performed using a meander type-planar coil, while detection of the magnetic field is done using data fusion of signals acquired from a giant magnetoresistive GMR sensor and a mesh-type planar coil. Three dimensional computational modeling is developed to characterize the probe interaction with structure at various frequencies and enhance the design. Combined with wireless sensor network technology, an array of such probe could be used in inspecting large structures. A synchronization technique is presented to enhance the fusion of data acquired from a number of distributed probes. Results show that this technique has the advantages of robustness, scalability and low complexity. With the miniaturization of probe design, development of a scalable synchronization technique, and the adoption of emerging wireless network standards, a distributed eddy current inspection network could prove effective in inspecting large size structures such as pipelines and storage tanks.

Life Monitoring by Eddy Current Thermography

---**Guenter Zenzinger** and Joachim Bamberg, MTU Aero Engines, Munich, Germany

---Eddy Current Thermography is a new crack inspection technique for electrical conducting materials. The component to be inspected is heated by a short induction current and the resulting temperature profile on the surface of the component is recorded by an infrared camera. Cracks cause to a local change in this temperature profile and are detectable with high lateral resolution. Especially for the detection of closed cracks and cracks under the surface which are not accessible for fluorescent penetrant inspection Eddy Current Thermography is well suited. One application of this technique is therefore the life monitoring during component testing. As an example, an aero engine compressor drum spin test was investigated by Eddy Current Thermography. The early detection of crack initiation and the monitoring of the crack growth are presented.

Application of a Novel Multi-frequency Eddy Current Technique on a Shot Peened Nickel Based Engine-graded Material

---Ray T. Ko, **Mark P. Blodgett**, Shamachary Sathish, and Thomas R. Boehnlein, University of Dayton Research Institute, Structural Integrity Division, 300 College Park Drive, Dayton, OH 45469-0120

---The shot peening conditions of a nickel based engine-graded material were evaluated using a novel multi-frequency eddy current measurement technique. With this technique, a frequency shift was found to be dependent on the conductivity of different materials. This paper describes the application of this technique on a shot peened nickel based engine-graded material. At high frequencies, the surface conditions were easily distinguishable using the frequency shift measurement. At low frequencies, the frequency shift diminished for different surface conditions, but it still varied with different materials. The resulting frequency shifts due to shot peening conditions on a nickel based engine-graded material as well as the effect of liftoff on the sensitivity of the measurement technique will be presented.

Electrostatic-Capacitive Imaging - A New NDE Technique

---**G. Diamond**, D. A. Hutchins, K. K. Leong, and T. H. Gan, School of Engineering, University of Warwick, Coventry CV4 7AL, United Kingdom; M. D. C. Moles, Olympus NDT Canada, 73 Superior Avenue, Toronto, Ontario, Canada M8V 2M7

---A new technique for NDE has been developed which is capable of imaging a wide range of materials and structures, ranging from insulators to metallic conductors. The approach, known as Electrostatic -Capacitive Imaging (ECI), uses electrode arrays in air to produce an AC electric field distribution within the material. Scanning the electrodes over the material causes a change in the field distribution, and hence changes in output voltage. Capacitive coupling allows the technique to work on a wide variety of material conductivities and permittivities, without the disadvantages associated with conventional eddy current and potential drop methods and can even be used in non-contact mode while under water. Images are presented of carbon fiber composite materials, concrete, Plexiglas and metals, illustrating the range of application in NDE. The effect of electrode shape and excitation frequency will be discussed in terms of image resolution and depth of penetration.

Development, Field and Beta Tests of a Generic Manual Scanner

---**D. J. Barnard**[1], D. K. Hsu[1], J. J. Peters[2], [1]Center for NDE, Iowa State University, Ames, IA 50011; [2]Hawaiian Airlines, Honolulu, HI 96822

---A novel Generic Manual Scanner has been developed that combines simple and inexpensive position encoding hardware, hand-held inspection instruments and a pc computer and software, enabling the production of C-Scan images. A core concept of this development is to use NDT/I equipment already in use by and familiar to inspectors, with no change in procedures. A minimal selection of scan sizes and data collection settings are utilized to minimize the training required to operate the unit. The manual scanner system is undergoing field and beta test to evaluate system performance and reliability, with units at the Air Force Research Lab (Dayton, OH), NavAir (Pax River), United Airlines (SFO), Cessna Aircraft Co. (Wichita, KS), as well as other locations. The users have provided valuable feedback on the operation of the system, suggested adding new or deleting unused features as well as reporting of bugs/problems with the C-scan software interface. Reported here are the results of these tests as well as intended future work. - This material is based upon work supported by the Federal Aviation Administration under Contract #DTFA03-98-D00008, the Air Force Research Lab, and NavAir STTR N05-T004 Phase I. The FAA technical monitor is Paul Swindell.

An Innovative Approach to Online Thickness Measurement of Thermal Spray Coatings

---**M. Alexandre Nadeau**, M. Luc Pouliot, M. Francois Nadeau, M. Jacques Blain, M. Simon Alex Berube, Tecnar automation Ltd., 1321 Hocquart, Saint-Bruno, Quebec, J3V 6B5, Canada; Christian Moreau and Mario Lamontagne, Industrial Materials Institute, National Research Council of Canada, Quebec, Canada

---In the past ten years, tremendous advancements have been made in the field of advanced sensors for the particle spray plume characterization. However, to this point, there exist very few commercially available technologies allowing for online characterization of the as-deposited coating. It is known for a fact that coating thickness is one of the most important parameter to monitor and control. The current methods to measure thickness are still destructive tests or direct mechanical measurements that translate into significant production time losses. Furthermore, those methods are rather limited in terms of precision. A novel industrial technology has been developed that enables online, real-time and non-contact measurement of the individual spray pass thickness as they are being deposited. Micron-level resolution has been achieved independently from: (a) the nature of the sprayed material (b) the nature of the substrate (c) the surface roughness (4) the thermal expansion of the part. In this paper, the prototype is described. Then, results obtained on typical HVOF and plasma sprayed coatings are presented. Finally, current fields of application and future developments are discussed.

Structural Quality Control of Swiss-type Cheese with Ultrasound

---Joona Eskelinen and **Edward Hæggström**, Department of Physical Sciences, University of Helsinki, PO Box 64, FIN-00014, Helsinki, Finland; Antti Alavuotunki and Tapio Alatossava, Department of Food Technology, University of Helsinki, PO Box 66, FIN-00014, Helsinki, Finland

---We present non-destructive evaluation (NDE) of Swiss-type cheese using a 2MHz ultrasonic pulse-echo-method (PE). Our goal was to prove feasibility for ultrasonic characterization of cheese-eye size/distribution and ripening induced cracks. The study is conducted in co-operation with a major dairy company. Due to access restrictions we selected a water-coupled contact PE approach to test packaged cheese blocks (~80kg). This approach relies on the large acoustic impedance difference between carbon dioxide and bulk cheese. To illustrate the sensitivity of our approach, we performed a single-transducer scan of a block to obtain a 3D image that was compared to dissection images of the cheese block. Comparison of ultrasonic images and cheese dissections showed the feasibility of the proposed method. The method sensitivity exceeds industry demands and defect recognition shows good potential. Image analysis (IA) can provide a quantitative quality parameter describing the size and distribution of cheese-eyes (eyes and cracks up from mm-range can be detected). IA combined with reflection pattern analysis provides means to enhance the defect monitoring. Quality assurance, e.g. ripening stage monitoring and foreign body detection can be appended into a single inexpensive, fast and low-complex on-line monitoring device for cheese-blocks.

Automated Defect Detection for Pulsed Infrared Thermography

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

---Transient thermography involves the generation of a transient heat flux inside the test sample using flash lamp surface excitation. Subsurface defects produce anomalies in the surface cooling characteristics captured by an infrared camera. The interpretation of infrared camera image sequences can require significant time and the judgment of an experienced operator due to the problems that can be caused by non-uniform heating and emissivity. There is a need to deskill thermographic NDE to make the interpretation of thermographic data faster and more reliable. The work presented in this poster evaluates a number of methods used to automate the defect detection process. One technique consists automatically evaluating the shape of thermal contrast curves to produce a binary defect image. Other techniques are based on curve fitting temperature-time data to test for deviations from the 1/root time thermal decay characteristic of defect free material. However, it has been found that this ideal behavior is not a reliable feature of the characteristics obtained from all samples using standard pulse thermography equipment.

Visibility of Buried Structures in Atomic Force Acoustic Microscopy

---**Bernd Koehler**, Beatrice Bendjus, André Striegler, and Naganami Pathuri, Fraunhofer, IZFP-D, Kruegerstr. 20, 01326 Dresden, Germany

---Advanced Scanning Probe Microscopy (SPM) modes such as Atomic Force Acoustic Microscopy (AFAM) and Ultrasonic Force Microscopy (UFM) combine Atomic Force Microscopy (AFM) with an excitation of the sample or cantilever by ultrasound. These techniques become increasingly powerful tools for the determination of material properties on nanoscale. Nondestructive evaluation of subsurface and buried structures is getting more and more important in semiconductor industries and electronics system integration technology. Existing methods that allow subsurface measurements with high local resolution are mostly based on destructive concepts as surface ablation by Focused Ion Beam (FIB) devices. It is widely discussed in literature that AFAM and UFM techniques should have the capability to detect subsurface features. But direct proofs of this capability are hard to find. The difficulty comes from the point that in UFM and AFAM images besides elastic contrast also topological contrast is mixed in. So, for a direct proof samples are needed which (a) show subsurface contrast and (b) having definitely no surface topology correlated with the subsurface feature in question. These samples are not so easy to obtain. An appropriate sample fabrication technology was developed based on the focussed ion beam technique. Using the machined samples the buried structure visibility for the AFAM technique could be proved uniquely. The results are compared with conclusions from modelling.

Comparison of SPI and SPSI in Quantitative Measurement of Out-of-Plane Deformation

---**Ho-Seob Chang**[1], Sung-Wook Jung[1], Kyoung-Suk Kim[2], and Hyun-Chul Jung[1], [1]Laser RRC, Chosun University, 375 Seosuk-Dong, Dong-Gu, Gwangju, 501-759, Korea; [2]Dept. of Mechanical Design Engineering, Chosun University, 375 Seosuk-Dong, Dong-Gu, Gwangju, 501-759, Korea

---Speckle Pattern Interferometry(SPI) is a common method for measuring out-of-plane deformation and in-plane deformation and applied for vibration analysis and strain/stress analysis. However, SPI is sensitive to environmental disturbance, which provide the limitation of industrial application. On the other hand, Speckle Pattern Shearing Interferometry (SPSI) which is insensitive to external disturbance can directly measure the gradient of out-of-plane deformation. In this paper, a technique that extracts out-of-plane deformation from results of SPSI by numerical processing is proposed and measurement results of SPI and Shearoraphy are compared quantitatively.

Excitation and Detection of Guided Waves in Cylindrical Structures for Flaw Inspection

---**Katsuhito Takamiya**, School of Integrated Design Engineering, Graduate School of Science and Technology, Keio University, Yokohama, Kanagawa, Japan; Toshihiko Sugiura, Department of Mechanical Engineering, Faculty of Science and Technology, Keio University, Yokohama, Kanagawa, Japan

---Inspection techniques such as visual inspection or a magnetic flux leakage testing used in long cylindrical structures including a steel pole or a wire rope require great time for inspecting their whole surfaces. Therefore, there have been increasing researches on a more efficient method utilizing guided waves. However, guided waves usually consist of several modes, and it is quite difficult to extract effect of each mode from received signals. This research investigates excitation and detection of wave modes for a thin metallic rod by using ultrasonic transducers or electromagnetic acoustic transducers through experiments and numerical analyses. Effects of a defect in the rod on received signals are also discussed.

Elastic Body-Oscillator Model for Theoretical Analysis of Nonlinear Ultrasound

---Setsu Yamamoto, Ryota Sasaki, Yoshikazu Ohara, Tsuyoshi Mihara, and **Kazushi Yamanaka,** Department of Materials Processing, Tohoku University, Sendai, Miyagi, Japan

---Nonlinear ultrasound, i.e. higher harmonics (2f) and subharmonics (f/2), has been expected as a most promising approach to detect closed cracks which are invisible by linear ultrasound. Among them, subharmonics has a great selectivity and sensitivity for closed cracks. However, the mechanism of subharmonic generation in closed cracks has yet to be elucidated. To clarify it, we constructed an elastic body-oscillator model where the object including the input crack face is an elastic body which can support both incident and reflected waves, whereas that including the output crack face is an oscillator with a mass and a spring which naturally provides the resonance characteristics essential for the subharmonics. A force function works between both faces depending on a crack opening displacement. For a quantitative comparison between the theoretical analysis and an experiment which was conducted in well-defined closed cracks in an aluminum alloy (Al7075), we assigned real parameters, i.e. input frequency, displacement amplitude of input wave, elastic modulus and density, to the constructed model. As a result, we succeeded to quantitatively reproduce subharmonic waveforms and also obtained a remarkably good agreement in the closure stress dependence of its intensity. Furthermore, a requirement for subharmonic generation can be defined by using a balance between the force function and the spring constant of the oscillator in a quasi-static condition.

Nonlinear Dynamics Caused by Incidence of Ultrasonic Waves into a Closed Crack

---**Tamaki Ishikawa** and Sohshu Hirata, School of Integrated Design Engineering, Graduate School of Science and Technology, Keio University, Yokohama, Kanagawa, Japan; Toshihiko Sugiura, Department of Mechanical Engineering, Faculty of Science and Technology, Keio University, Yokohama, Kanagawa, Japan

---A nondestructive evaluation technique based on nonlinear acoustics has been recently expected as a potential method of detecting a closed crack such as a failure of joining and a fatigue crack caused by residual stress. This research investigates nonlinearity coming from collisions between two faces of a closed crack caused by incident ultrasonic waves. According to our theoretical analysis of nonlinear dynamics shown by a simple mass-spring model hitting against a sinusoidally excited base, qualitative changes in vibration of the mass occur and superharmonics or subharmonics appear, depending on parameters such as the input frequency or the initial compressive force between the mass and the base. Numerical analyses and experiments were also carried out, by using a model of two solid blocks in contact. Obtained results show tendency similar to that of the above theoretical result. Furthermore, subharmonics detected in received signals are much larger than superharmonics.

Effect of Contact Nonlinear Acoustics Caused During Incidence of Ultrasonic Wave into a Closed Crack

---**Tamaki Ishikawa** and Sohshu Hirata, School of Integrated Design Engineering, Graduate School of Science and Technology, Keio University, Yokohama, Kanagawa, Japan; Toshihiko Sugiura, Department of Mechanical Engineering, Faculty of Science and Technology, Keio University, Yokohama, Kanagawa, Japan

---A nondestructive evaluation technique based on nonlinear acoustics has been recently expected as a potential method of detecting a closed crack such as a failure of joining and a fatigue crack caused by residual stress. This research investigates nonlinearity coming from collisions between two faces of a closed crack caused by incident ultrasonic waves. According to our theoretical analysis of nonlinear dynamics shown by a simple mass-spring model hitting against a sinusoidally excited base, qualitative changes in vibration of the mass occur and superharmonics or subharmonics appear, depending on parameters such as the input frequency or the initial compressive force between the mass and the base. Numerical analyses and experiments were also carried out, by using a model of two solid blocks in contact. Obtained results show tendency similar to that of the above theoretical result. Furthermore, subharmonics detected in received signals are much larger than superharmonics.

Accurate Simulation of Phased Array Received Signals from Media Containing Arbitrarily Shaped Impedance Discontinuities, with Experimental Validation

---Yi-San Lai and **Vincent Lupien**, Acoustic Ideas; Waheed Abbasi, Siemens Power Generation; Waled Hassan, Honeywell Aerospace

---Computational ultrasonic models with focal law calculation and ultrasonic beam modeling capabilities accelerate phased array ultrasonic application development. It may be useful to simulate the actual A, B, C, D and S-scan responses received by a proposed phased array transducer and inspection technique, in the presence or absence of defects, to aid in assessing the adequacy of the resolution and sensitivity of the inspection. The usefulness of such simulations depends on the accuracy of the computational models which handle the propagation of waves and their interaction with scattering boundaries. Accurate computation of wave propagation is already possible in tools such as Continuum Ultrasonic Modeler™. In an effort to provide highly accurate received responses, we have been working on developing a scattering model to handle both reflection-like discontinuities, such as those adequately represented by a Kirchhoff approximation, and diffraction-like discontinuities, such as sharp edges. The superposition of both phenomena should be sufficiently general to handle the modeling of arbitrarily shaped voids, inclusions, cracks, delaminations, and rough interfaces. In this paper we concentrate on comparisons of our scattering model with experimental results for spherical and plane discontinuities. We also present a comparison of the computed responses with those of at least one other commercially available ultrasonic phased array modeling tool.

Session 29

SESSION 29

Pavilion East

3:30 PM **Emerging Issues in NDE Engineering: Coupling Research, Technology Transfer and Education**

---As NDE matures as a discipline, a set of measurement techniques of ever increasing sophistication are emerging. The need for these new techniques is driven by a number of factors, including economic pressures to operate closer to safety margins and to extend lives for longer periods, and the techniques are enabled by advances in sensor technology, imaging devices, and information handling. Examples include ultrasonic and eddy current array technologies, a variety of digital x-ray techniques as well as emerging tools and strategies such as VibroThermography, Terahertz Imaging and Health Monitoring/Prognosis. This increasing technique sophistication places new demands on the technology transfer and education processes. The transfer of the technique can involve more subtleties and the education required to deal with them may need to be at a higher level. This session will explore these links. A series of short presentations by OEMs, equipment developers, inspection providers, government agencies and educators will provide an overview of the issues as seen from different perspectives. This will be followed by a general discussion by the audience of needed future steps.

FRIDAY

Session 30

SESSION 30

UT TRANSDUCERS, FIELDS, AND ARRAYS
Broadway I

8:30 AM **Effect of Mass Damping and Stiffness Damping in Micromachined Air-Coupled Capacitance Transducer**
---**M. K. KM**, S. Goravar, and V. Kommareddy, General Electric Global Research, Bangalore, India; J. Barshinger, A. May, Y. Fan, W.-C. Tian, and X. Wang, General Electric Global Research, Niskayuna, NY 12309

8:50 AM **Generating the Gaussian Basis Functions for Multi-Gaussian Beam Models**
---**L. W. Schmerr, Jr.**[1,2] and A. Lopez-Sanchez[1,2], [1]Center for NDE and the [2]Department of Aerospace Engineering, Iowa State University, Ames, IA 50011

9:10 AM **Application and Validation of the Gaussian Beam Superposition Technique to Simulate the Inspection of Aero Engine Components**
---**M. Spies**, Physical Basics Department, Fraunhofer-Institute for Nondestructive Testing IZFP, 66123 Saarbrücken, Germany; Wolf-Dieter Feist, MTU Aero Engines GmbH, 80995 München, Germany

9:30 AM **Ultrasonic Surface Wave Propagation and Interaction with Surface Defects**
---**Y. Fan**, S. Dixon, R. S. Edwards, and X. Jian, University of Warwick, Department of Physics, Coventry, CV4 7AL, United Kingdom

9:50 AM **Ultrasonic Beam Modeling for Wave Propagation in Dissimilar Metal Pipe Welds**
---**H. Jeong**, Wonkwang University, Division of Mechanical and Automobile Engineering, Iksan, Jeonbuk 570-749, Korea; L. W. Schmerr, Jr., Center for NDE and Department of Aerospace Engineeering, Iowa State University, Ames, IA 50011

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

10:30 AM **Numerical Simulation of Scattered Wave from Flaws for Ultrasonic Array Transducer**
---**S. Hirose**, Tokyo Institute of Technology, Department of Mechanical and Environmental Informatics, Meguro, Tokyo, Japan; N. Kono, Hitachi, Ltd., Power and Industrial System R&D Laboratory, Hitachi, Ibaraki, Japan; K. Nakahata, Ehime University, Department of Civil and Environmental Engineering, Matsuyama, Ehime, Japan

10:50 AM **Generation of Wavelength-Matched Guided Wave in Tube by Ring-Arrayed Laser Illumination**
---**K.-Y. Jhang**, Hanyang University, School of Mechanical Engineering, Seongdong-Gu, Seoul 133-791, Korea; B.-O. Lim, Hanyang University, Graduate School, Seoul 133-791, Korea; I. K. Park, Department of Mechanical Engineering, Seoul National University of Technology

11:10 AM **A Study on the Time Reversal Method for Focusing Ultrasonic Guided Waves Using Array Transducers**
---H.-J. Kim, **J.-H. Seo**, and S.-J. Song, Sungkyunkwan University, School of Mechanical Engineering, Suwon, 440-746, Korea; J.-H. Kim and H.-S. Eom, Korea Atomic Energy Research Institute, Daejon, 305-353, Korea

11:30 AM **A New Multi-Gaussian Beam Model for Phased Array Transducers**
---**R. Huang** and L. W. Schmerr, Jr.[1,2], Iowa State University, [1]Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011; [2]Department of Aerospace Engineering, Iowa State University; A. Sedov, Lakehead University, Department of Mechanical Engineering, Thunder Bay, Ontario, Canada

11:50 AM ***Adjourn***

Effect of Mass Damping and Stiffness Damping in Micromachined Air-Coupled Capacitance Transducer

---**Manoj Kumar KM**, Shivappa Goravar, and Vamshi Kommareddy, General Electric Global Research, Bangalore, India; James Barshinger, Andrew May, Ying Fan, Wei-Cheng Tian, and Xuefeng Wang, General Electric Global Research, Niskayuna, NY 12309

---Performance of MEMS devices relies largely on the interaction between solids and fluids. When optimizing the design it is important to consider the general characteristics of this fluid-structure interaction. Finite Element approach is used to study the effect of mass damping and stiffness damping arising due to micro fluid layers in Micromachined Air-coupled Capacitance transducer. Transient dynamics of these systems are completely driven by this fluid-structure interaction. The aim of this paper is to understand the variations in mass and stiffness damping with frequency of operation. Furthermore, the effect of the mass and stiffness damping with geometrical parameters and transient behavior of the system are discussed.

Generating the Gaussian Basis Functions for Multi-Gaussian Beam Models

---**Lester W. Schmerr, Jr**.[1,2] and Ana Lopez-Sanchez[1,2], [1]Center for NDE and the [2]Department of Aerospace Engineering, Iowa State University, Ames, IA 50011

---In a multi-Gaussian beam model, a small number of Gaussians are superimposed to accurately simulate the wave field of a piston transducer. Originally, these Gaussians were obtained by a very computationally intensive non-linear least squares approach. However, an alternate method to generate these Gaussian basis functions has been proposed using Prony's method. Since Prony's method only involves finding a set of roots and solving linear equations, it is very fast. However, there are sampling and stability issues also associated with this method. Here, we will examine those issues and demonstrate the overall capabilities of Prony's method to generate the wave fields of planar and focused transducers.---This work was supported by the NSF Industry/University Cooperative Research Center at Iowa State University.

Application and Validation of the Gaussian Beam Superposition Technique to Simulate the Inspection of Aero Engine Components

---**Martin Spies,** Physical Basics Department, Fraunhofer-Institute for Nondestructive Testing IZFP, 66123 Saarbrücken, Germany; Wolf-Dieter Feist, MTU Aero Engines GmbH, 80995 München, Germany

---The use of high-performance components in aeronautics increases the need for advanced inspection techniques. This especially holds for ultrasonic NDT of complex components which generally suffers from loss of sensitivity, beam distortions and beam disorientations, if the transducer is not perfectly matched to the inspection conditions. The use of respective simulation tools is therefore essential for the improvement of currently applied techniques and the development of new approaches. Within the European research project VERDICT, the Gaussian beam superposition technique has been specifically refined to meet the simulation needs of European engine manufacturers. Testing and validation of the refined method have been performed with respect to an experimental calibration set-up, routinely applied at MTU. Experiments have been performed on a curved test block, where 0.2 mm and 0.3 mm flat-bottomed holes (FBH) have been manufactured under depths from 3 mm to 15 mm, and from 12 mm to 40 mm. These model defects have been interrogated using a spherically focusing and a cylindrically focusing commercial probe, respectively. To perform realistic simulations, the two transducers have been characterized by individual sets of Gaussian beam coefficients, based on experimental beam field data. A variety of simulation results, covering beam fields in water as well as C-scans obtained on the FBHs, will be shown in comparison with experimental data; excellent agreement has been obtained.---This work has been funded by the European Commission under Contract No. G4RD-CT-2002-00860, which is gratefully acknowledged.

Ultrasonic Surface Wave Propagation and Interaction with Surface Defects

---**Yichao Fan**, S. Dixon, R. S. Edwards, and X. Jian, University of Warwick, Department of Physics, Coventry, CV4 7AL, United Kingdom

---Electromagnetic Acoustic Transducers (EMATs) are non-contact ultrasonic transducers capable of generating wideband surface waves on metallic samples. We describe some lab based ultrasonic measurements using EMATs to generate wideband, low frequency (approximately 50-500kHz) ultrasonic surface waves on a number of samples including aluminum billets and sections of rail track that contain simulated defects. A stabilized Michelson interferometer has been used to measure accurately the absolute out-of-plane displacement of the ultrasonic waves generated on the sample, which propagate along the sample to interact with a simulated surface breaking defect. Transient finite element analysis has been used to model the ultrasonic wave propagation on the sample and the interaction of these waves with surface breaking defects. These simulations compare very favorably with the experimental results obtained using the Michelson interferometer. We describe different approaches that can be used to determine the depth and presence of the crack. The non-contact nature of EMATs and the pitch-catch test geometry that we propose to use for testing make them especially suitable for online detection and depth gauging of surface breaking cracks at high inspection speeds.

Ultrasonic Beam Modeling for Wave Propagation in Dissimilar Metal Pipe Welds
---**Hyunjo Jeong**, Division of Mechanical and Automobile Engineering, Wonkwang University, Iksan, Jeonbuk 570-749, Korea; Lester W. Schmerr, Jr., Center for NDE and Department of Aerospace Engineering, Iowa State University, Ames, IA 50011

---Recently the modular form of multi-Gaussian beam (MMGB) model has been developed that can be efficiently used to simulate ultrasound propagation in multi-layered anisotropic materials with arbitrary interface curvatures. This model was successfully applied in the past to simulate the beam propagation in isotropic material systems where multiple interfaces are involved. In this paper, we consider this model for the dissimilar metal pipe welds in nuclear power plants. Their representative structure is comprised of stainless steel pipe - high Nickel alloy buttering - high Nickel alloy weld metal - carbon nozzle with stainless steel cladding. Some components of the MMGB model such as slowness surface curvature approximation and transmission between general anisotropic materials are calculated and used in the model. Simulation results for different testing configurations are presented.

Numerical Simulation of Scattered Wave from Flaws for Ultrasonic Array Transducer
---**Sohichi Hirose**, Dept. of Mechanical and Environmental Informatics, Tokyo Institute of Technology, Meguro, Tokyo, Japan; Naoyuki Kono, Power and Industrial System R&D Laboratory, Hitachi, Ltd., Hitachi, Ibaraki, Japan; Kazuyuki Nakahata, Dept. of Civil and Environmental Engineering, Ehime University, Matsuyama, Ehime, Japan

---NDT techniques based on the ultrasonic phased array technology are applied in various industrial contexts. For the effective use of phased array techniques, it is essential to have well knowledge on the characteristics of radiated beam profile by array transducer and beam propagation in the test material. This study shows mathematical model of the phased array transducer and numerical simulation of the scattered wave from flaw (flaw echo) which is received at the phased array transducer. Here we focus on analyses of the transient wave by means of the fast multipole BEM (FMBEM). In numerical simulations, the pulse shaped waves are used and wave fields are visualized to understand the feature of the flaw echo.

Generation of Wavelength-Matched Guided Wave in Tube by Ring-Arrayed Laser Illumination

---**Kyung-Young Jhang**, Hanyang University, School of Mechanical Engineering, Seongdong-Gu, Seoul 133-791, Korea; Byung-Ok Lim, Hanyang University, Graduate School, Seoul 133-791, Korea; I. K. Park, Department of Mechanical Engineering, Seoul National University of Technology

---The laser ultrasonic technique has been considered as a useful non-contact method to generate the ultrasonic guided wave in tube. In practical applications of the guided wave technique, however, it is very important, though often difficult, to identify propagating modes. Thus, it is more preferred when it comes to generating and detecting a single or less number of modes. In this paper, we propose a wavelength-matched method using the ring-arrayed laser illumination that enables to generate only the specific longitudinal mode of which wavelength is determined by the array spacing. In order to test the performance, the experimental system including optics to produce the ring-arrayed beam pattern is constructed, and tube specimens are tested. The laser source is Nd:YAG and the detector is the air-coupled transducer that is able to detect only a single mode by tuning its detection angle. Experimental results show that the predicted mode is clearly generated and detected. The proposed technique is fully non-contact, and it also has the advantage of greatly enhanced mode selectivity. This advantage makes it possible to avoid complication in the detected wave signal.

A Study on the Time Reversal Method for Focusing Ultrasonic Guided Waves Using Array Transducers

---Hak-Joon Kim, **Jong-Ho Seo**, and Sung-Jin Song, Sungkyunkwan University, School of Mechanical Engineering, Suwon, 440-746, Korea; Jae-Hee Kim and Heung-Sup Eom, Korea Atomic Energy Research Institute, Daejon, 305-353, Korea

---For the long range inspection of ultrasonic guided waves using array transducers, phase tuning methods are quite often adopted to generate ultrasonic guided waves of particular modes. The phase tuning method is able to control wave modes but not to focus waves on the defects under interrogation. Thus, a robust tool that can control not only generated wave modes but also focusing the guided waves on the flaws is strongly desired. To address such a need, in this study, we will adopt the time reversal technique to focus ultrasonic guided waves generated by array transducers on the defects since the time reversal technique can provide proper time delays for focusing on the defect and tuning wave modes. For investigation and verification of the time reversal method, we simulate ultrasonic guided waves propagation to and scattering from artificial defects without time delay using a numerical simulation tool. Then, based on the simulation result, we determine the appreciate time delay using the time reversal technique and re-generate ultrasonic guided waves with the calculated time delay. In this paper, comparison of the simulation results obtained by the time reversal technique to those by a conventional phase tuning method will be presented. Furthermore, we also present experimental results acquired by an array ultrasonic guided wave system with time delays calculated by time reversal techniques.

A New Multi-Gaussian Beam Model for Phased Array Transducers

---**Ruiju Huang** and Lester W. Schmerr Jr., Center for NDE, Iowa State University, Ames, IA, 50011; Lester W. Schmerr Jr., Dept. of Aerospace Eng., Iowa State University, Ames, IA, 50011; Alexander Sedov, Dept. of Mechanical Eng., Lakehead University, Thunder Bay, Ontario, Canada

---Phased array transducers have received much attention in recent two decades since no mechanical movement of the transducer is required to scan an object. This attractive feature is obtained by electrically adjusting the time delay of each element to attain the appropriate beam steering and focusing. Modeling the radiation of a phased array transducer is very challenging. In this work, a new linear-phased multi-Gaussian beam model is developed to simulate the wave fields generated by a phased array transducer. Simulation results show that the piecewise linear phasing required for the multi-Gaussian model produces a radiated wave field similar to piecewise constant phasing used in actual phased array transducers. This model is not limited to beam steering angles exceeding the paraxial approximation limits of about 20-30 degrees where the ordinary multi-Gaussian beam model is not available. With the help of this new beam model, a steered beam from a phased transducer can be predicted efficiently.

Session 31

SESSION 31

NDE RELIABILITY AND POD
Broadway II

8:30 AM **NDT Comparisons of In-service Cracks, Manufactured Cracks and EDM Notches**
---D. Piotrowski, Delta Air Lines, Technical Operations, Atlanta, GA 30320; **M. D. Bode**, Sandia National Laboratories, FAA Airworthiness Assurance NDI Validation Center (AANC), Albuquerque, NM 87106

8:50 AM **Estimating the Distribution of the Sizes of Flaws Remaining After an Inspection**
---**P. W. Hovey**, University of Dayton, Department of Mathematics, Dayton, OH 45469; A. P. Berens, Consultant, Dayton, OH 45469

9:10 AM **X-Ray POD Model and Validation**
---**J. Gray**, [1]I. Gray, and J. Zhang, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011; [1]NDE Technologies, Inc., Charlottesville, VA 22911

9:30 AM **Systematic Approach for Validation of X-Ray Automatic Defect Recognition Systems**
---M. Navalgund, R. Venkatachalam, P. MC, M. Asati, and **M. Venugopal**, John F. Welch Technology Centre, GE Global Research Centre, Bangalore, India

9:50 AM **Reliability Assessment by Simulation for High Energy Radiography**
---**G.-R. Jaenisch**, C. Bellon, and U. Ewert, Federal Institute for Materials Research and Testing, Division VIII.3, Unter den Eichen 87, 12205 Berlin, Germany

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

10:30 AM **Ultrasonic Modelling Tools Developed in the VERDICT European Project for the NDT of Engine Components**
---**L. Le Ber**, DRT/LIST/DETECS/SYSSC/LVT, Commissariat à l'Energie Atomique, 91191 GIF SUR YVETTE, France; M. Spies, Fraunhofer-Institut Zerstörungsfreie Prüfverfahren (IZFP), 66123 Saarbrücken, Germany; R. Stacey, City University, London EC1V OHB, United Kingdom; R. Coulette, Snecma Moteurs, 91003 Evry Cedex, France

10:50 AM **Production of UT Reference Blocks Containing Artifically Introduced Defects**
---**A. A. Kaya** and S. Ucuncuoglu, Materials Institute, TUBITAK Marmara Research Center, Gebze/Kocaeli, Turkey; N. Kurkcu, A. Kandemir, and H. Arsian, General Electric Marmara Technology Center, gebze/Kocaeli, Turkey

11:10 AM **Evaluation of Ultrasonic Scattering at LCF Crakcs Including Optically Measured, Real Roughness Profiles**
---W. Satzger and J. Bamberg, MTU Aero Engines GmbH, 80995 München, Germany; **M. Spies**, University of Saarland, Physical Basics Department, Fraunhofer Institute for Nondestructive Tesitng IZFP, Bldg. E3.1, 66123 Saarbruecken, Germany

11:30 AM **Progress on POD for Friction Stir Welds**
---**T. A. Gray**[1], T. C. Jensen[1], R. B. Thompson[1], K. Chimbli[2], D. J. Medlin[2], C. Allen[2], and W. J. Arbegast[2], [1]Center for Nondestructive Evaluation, Iowa State University, Ames, IA 50011; [2]Center for Friction Stir Processing, South Dakota School of Mines and Technology, Rapid City, SD 57701

11:50 AM **Reliability of the Ultrasonic Technique Applied to Detection of Pipe Weld Defects**
---**J. Rebello** and A. Carvalho, Federal University of Rio de Janeiro, Metallurgy and Materials Department, Rio de Janeiro, Brazil; L. Sagrilo, Federal University of Rio de Janeiro, Civil Department, Rio de Janeiro, Brazil

12:10 PM ***Adjourn***

NDT Comparisons of In-service Cracks, Manufactured Cracks and EDM Notches

---David Piotrowski, Technical Operations, Delta Air Lines, Atlanta, GA 30320; **Michel D. Bode**, FAA Airworthiness Assurance NDI Validation Center (AANC), Sandia National Laboratories, Albuquerque, NM 87106

---NDT reliability is an increasingly important component of today's damage tolerant maintenance programs, particularly in the area of aging aircraft. Typically, Probability of Detection (POD) studies are conducted and the results fed into engineering analyses which determine inspection interval and inspection threshold. However, these POD studies can be conducted on EDM notches, "manufactured" crack specimens, or actual in-service crack specimens. The purpose of this paper is the education of the aerospace community in the subtle differences and benefits of using EDM notches, "manufactured" cracks, and real cracks as POD specimens. Previous POD studies are compared to an actual teardown of a retired passenger aircraft, resulting in vast sums of data, including NDT signal response, fractographic analysis, and POD data. Careful analysis of this data reveals that not all POD studies are created equal. Additionally, the paper provides an awareness of the assumptions used in each type of POD study, and potential consequences of violating such assumptions.

Estimating the Distribution of the Sizes of Flaws Remaining After an Inspection

---**Peter W. Hovey**, Department of Mathematics, University of Dayton, Dayton, OH 45469; Alan P. Berens, Consultant, Dayton, OH 45469

---The U.S. Air Force plans for maintenance and retirement of aircraft based in part on fatigue crack growth models. Periodic inspections are used to help assess airworthiness and plan for future inspections. Nondestructive inspections are not perfect so some cracks are missed and the likelihood that an individual crack is detected is a function of the size of the crack when inspected. Additionally, the crack size distribution is related to the number of flight hours the aircraft has experienced, so not all inspection results come from the same distribution. Several models are compared that utilize the capability of the inspection system and the variation between aircraft and times of inspections to estimate the distribution of sizes of cracks that were missed during the inspection.

X-Ray POD Model and Validation

---**J. Gray**[1], I. Gray[2], and J. Zhang[3], [1]Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011; [2]NDE Technologies, 1785 Sourwood Place, Charlottesville, VA 22911; [3]University of Bristol, Department of Mechanical Engineering, Queen's Building, University Walk, Bristol B58 ITR, United Kingdom

---The development of effective POD models based on two-dimensional data is a significant extension over the threshold-based methods often used for single point measurements data. The application of a simple threshold criteria is very conservative when the additional measurements and spatial correlation of a single is available in 2D data. The reason for this conservative estimate is that the function that converts a noisy 2D image signal to a scalar does not perform anywhere near the level of the human eye in picking out defect signals in images. The histogram of the noise and the signal for easily detectable defects has an almost complete overlap. An alternative approach is to use the additional information afforded by a 2D image and determine the probability that all of the pixel values in a local image area all fluctuate the same direction, the same amount is due to noise. The resulting scalar is a much closer measure of the eye's ability to pick out signals in very noisy image data. As is hinted at in the pervious discussion, the resolution limits of the eye, both the spatial and contrast sensitivity, play an important role in determining an accurate POD measure. Finally the role of lighting and pseudocolor mapping also play an important role in the eyes perception of the signal. We discuss an hypothesis test method for determining a detectable signal and to apply physiological limits as recorded in the extensive medical literature to develop a robust 2D POD model suitable for X-ray images and any other image type data.

Systematic Approach for Validation of X-Ray Automatic Defect Recognition Systems

---Megha Navalgund, Rajashekar Venkatachalam, Prakash MC, Mahesh Asati, and **Manoharan Venugopal,** John F. Welch Technology Centre, GE Global Research Centre, Bangalore, India

---With the advent of digital radiography, there has been a gradual shift from operators viewing images to find defects to totally automated defect recognition (ADR) systems. This has resulted in reduced operator subjectivity, reduced operator fatigue, and increased productivity. These automated defect recognition solutions are based on reference or non-reference based approach or a combination of both. There exists some amount of uncertainty or reluctance to accept automated systems in view of no systematic quantified metrics available on performance of these ADR systems in comparison to human operators. This paper describes the metrics that one could follow to quantify the performance of ADR systems such as detectability for different defect types and sizes, accuracy, false call rate, robustness to various noise levels etc., As it might be difficult to have images with defects of various sizes, shapes, contrast and noise levels, a methodology to generate images with simulated defects with variability's in parameters such as size, shape, contrast to noise ratio etc., is demonstrated. This can be used to generate probability of detection estimates for different defect types and geometries. This will result in establishing confidence limits for ADR systems and can be used to judge if it would meet specific customer requirement. This would facilitate increase in the acceptability of ADR systems over current manual defect recognition systems for applications in various industries such as Castings, Oil and Gas, Aviation etc.

Reliability Assessment by Simulation for High Energy Radiography

---**Gerd-Ruediger Jaenisch**, Carsten Bellon, and Uwe Ewert, Federal Institute for Materials Research and Testing, Division VIII.3, Unter den Eichen 87, 12205 Berlin, Germany

---Efficient and reliable nondestructive evaluation techniques are necessary to ensure the safe operation of complex parts and construction in an industrial environment. Radiography is one of the classical nondestructive testing techniques widely applied in industry. Over the years modeling became more and more important in modern NDE. It is increasingly used to optimize techniques for complex applications and to support the preparation of written procedures. Hence, computer modeling has to be able to handle all significant properties of a NDE system with sufficient accuracy. In case of radiographic applications the model includes the radiation source, the interaction of radiation with material, the detection process, and the geometrical description of the part or the construction. As known from practice the last can be very complex and requires a description that allows the handling of arbitrary geometries. The link between NDE models and CAD provides the ability to quantitatively evaluate complex inspection procedures. Depending on the formulated inspection problem or the influencing factors that should be accessed by modeling an appropriate physical model has to be chosen to describe the underlying interaction mechanisms. For high energy applications the description of the radiation source, like the spectrum of a LINAC, becomes essentially difficult. An approach is discussed to overcome this difficulty. The developed simulation capabilities are used to assess the reliability of the radiographic inspection of thick section welds for a special application.

Ultrasonic Modelling Tools Developed in the VERDICT European Project for the NDT of Engine Components

---**Laurent Le Ber**, DRT/LIST/DETECS, SYSSC/LVT, Commissariat à l'Energie Atomique, 91191 GIF SUR YVETTE, France; Martin Spies, Fraunhofer-Institut Zerstörungsfreie Prüfverfahren (IZFP), 66123 Saarbrücken, Germany; Richard Stacey, City University, London EC1V OHB, United Kingdom; Richard Coulette, Snecma Moteurs, 91003 Evry Cedex, France

---The European VERDICT project (2003-6) addressed the improvement of the aerospace engine component inspection. Its remit covered the four major NDT techniques: X-rays, Ultrasonics, Eddy Currents and Infrared Thermography. Regarding Ultrasonic techniques, the major aim of the VERDICT programme was to provide designers and inspectors with a set of tools that could provide more accurate and efficient simulation of ultrasonic testings of realistic engine components. To facilitate the simulation of the various NDT configurations of the engine components new software tools - mainly CAD and imaging tools - have been developed. In addition a great deal of work has been done to improve the modelling used in the calculations. This has meant taking existing ultrasonic models, improving them, and integrating them within the CIVA platform. The models involved are the Finite Difference Modelling (FDM) approach developed by City University, the Gaussian Beam (GB) model developed by IZFP, and the semi-analytical pencil approach of CEA. In this communication we describe these models, indicate how they have been improved under VERDICT, and give some examples of applications.---This work has been funded by the European Commission under Contract No. G4RD-CT-2002-00860, which is gratefully acknowledged.

Production of UT Reference Blocks Containing Artificially Introduced Defects

---**Ali A. Kaya** and Selda Ucuncuoglu, Materials Institute, TUBITAK Marmara Research Center, Gebze/Kocaeli, Turkey; Nihat Kurkcu, Ayse Kandemir, and Hulya Arslan, General Electric Marmara Technology Center, Gebze/Kocaeli, Turkey

---Probability of Detection (POD) estimation curves for ultrasonic inspection are difficult to establish and their confidence intervals quite large restricting their use for applications in aircraft engine part productions due to the limited sampling size of natural defects that may be gathered from the production processes. In order to achieve a sufficient sampling size, metallic blocks of steel, Inconel 718 and Ti-6Al-4V alloys containing artificially introduced defects of known type, size, shape and location were prepared to serve as references in ultrasonic inspection. The synthetic defects employed were all pertinent to the specific alloy systems used in each case, that is, the defects were either of the type actually likely to be found in the alloy, or at least relative in terms of their sound reflectivity; thus compositional defects named ‘dirty white’ and ‘freckle’ for Inconel-718; ‘hard-alpha’ and voids for titanium alloy; and voids, oxides and carbides for steel and Inconel-718 were used. The spherical and cylindrical defects ranged in size from 12mils to 80mils in diameter. The scope of the study entailed both the determination of POD curves of various ultrasonic inspection set-ups and the correct parameters for manufacturing processes involved. C-scan results and metallographic examinations on cut-up sections have been interpreted, and the effect of the grain sizes of matrix materials and defects incorporated into the assessments.

Evaluation of Ultrasonic Scattering at LCF Cracks Including Optically Measured, Real Roughness Profiles

---Wilhelm Satzger and Joachim Bamberg, MTU Aero Engines GmbH, 80995 München, Germany; **Martin Spies**, Physical Basics Department, Fraunhofer Institute for Nondestructive Testing IZFP, University of Saarland, Bldg. E3.1, 66123 Saarbruecken, Germany

---All real crack surfaces are rough and this affects the wave scattering behavior, as has been the topic of numerous studies. In ultrasonic nondestructive testing this is of special interest, since as the surface roughness increases the scattered energy distribution changes dramatically. Increasing roughness leads to a reduction of the initially strong specular field and the appearance of a widely spread diffuse field, accordingly affecting the reliability of ultrasonic sizing techniques. In this contribution, an approach is presented to theoretically study the effect of surface roughness of real defects on ultrasonic wave scattering. Using an optical roughness measurement system, real roughness profiles are recorded for cracks generated during low cycle fatigue (LCF) testing. These measured profiles are then discretized and used as input for the theoretical model, which has been presented by Ogilvy in the late 1980s. Having obtained realistic input data to characterize the crack surface roughness, it is possible to evaluate the scattered energy distribution in dependence of frequency, angle of insonification and wave type. With this new approach respective optimizations can be performed, which is particularly interesting for complex three-dimensional crack geometries. Several evaluation examples for real LCF cracks will be presented. In view of an improvement of the sizing accuracy of rough cracks, this new approach is not only of interest for aero engine components, but may also be applied to the problem of stress corrosion cracking which occurs in the heat affected zone of weldments in austenitic stainless steels.

Progress on POD for Friction Stir Welds

---**T. A. Gray**[1], T. C. Jensen[1], R. B. Thompson[1], K. Chimbli[2], D. J. Medlin[2], C. Allen[2], and W. J. Arbegast[2], [1]Center for Nondestructive Evaluation, Iowa State University, Ames, Iowa 50011; [2]Center for Friction Stir Processing, South Dakota School of Mines and Technology, Rapid City, SD 57701

--- An NSF TIE Project between the Center for Nondestructive Evaluation (CNDE) and the Center for Friction Stir Processing (CFSP) began in 2005 to assess the effects of defects in friction stir welds (FSW). A key element in this assessment is determination of the probability of detection (POD) of discontinuities typical to FSW. Studies in the first year of the TIE Project are focusing on wormholes in FSW butt welded aluminum plates. Both ultrasonic (UT) and x-ray radiographic (XR) inspection methods are being used. In initial work, FSW samples containing wormholes of varying degrees of severity were fabricated at CFSP. Preliminary UT and XR measurements at CNDE are being used to define a new control set of FSW samples for POD analysis. The NDE results from the preliminary samples, as well as any available data from the new POD set, will be presented.---
This work was supported by the NSF Industry/University Cooperative Center for Nondestructive Evaluation at Iowa State University and Center for Friction Stir Processing at South Dakota School of Mines and Technology.

Reliability of the Ultrasonic Technique Applied to Detection of Pipe Weld Defects

---**J. Rebello** and A. Carvalho, Metallurgy and Materials Department, Federal University of Rio de Janeiro, Rio de Janeiro, Brazil; L. Sagrilo, Civil Department, Federal University of Rio de Janeiro, Rio de Janeiro, Brazil

---The objective of this work is to evaluate the reliability of the ultrasonic nondestructive test technique (NDT), for specific test conditions, using POD (probability of detection) curves developed by experimental procedures. The majority of the works, published on these areas of research, evaluate the reliability of the NDT techniques using POD curves simulated on computational algorithms that do not reflect, necessarily, the real inspection conditions, since the main factor of uncertainty in the inspection is the human factor, which is difficult to take into account. Two classes of defects, lack of penetration and lack of fusion were intentionally inserted in 24 weld beads manufactured from pipeline of API X70 steel with an outer diameter of 254mm and wall thickness of 19.05mm. These specimens were inspected using manual and automatic ultrasonic techniques. The inspection using the ultrasonic pulse echo manual technique was carried out by six (6) qualified and certified inspectors. Additionally automatic inspections were carried out using the pulse echo and the TOFD (Time of Flight Diffraction) techniques. The results, besides producing real POD curves, showed the superiority of the automatic techniques over the manual test in the probability of detection of these two classes of defects.

Session 32

SESSION 32

NDE FOR MATERIALS CHARACTERIZATION
Pavilion East

8:30 AM **Improved Material Characterization Using Classifier-Based Data Fusion**
---J. Dion, **M. Kumar**, and P. Ramuhalli, Michigan State University, Department of Electrical and Computer Engineering, Nondestructive Evaluation Laboratory, East Lansing, MI 48824

8:50 AM **Determination of Gruneisen Constant from Elevated Temperature Rayleigh Velocities**
---M. A. Doxbeck and **M. A. Hussain**, Launcher Technology, Benet Laboratories, 1 Buffington Street, Watervliet, NY 12189-4050

9:10 AM **Characterization of Hydrogen Concentration Profiles in Zircaloy Cladding Tubes with Laser Ultrasound Technique**
---Y.-A. Lai and **C.-H. Yang**, Chang Gung University, Department of Mechanical Engineering, 239 Wen-Hua 1st Road, Kwei-Shan, Taoyuan, Taiwan, R.O.C., China (ROC)

9:30 AM **Enhancements of Microwave Anisotropy Measurement Technique**
---**S. Predak** and G. Busse, University of Stuttgart, Institute of Polymer Testing and Polymer Science, Department of Non-Destructive Testing (ZfP), Stuttgart, Germany

9:50 AM **Considerations for Measuring Acoustic Birefringence in Thin Sheets Using Electromagnetic Acoustic Transducers (EMATs)**
---M. P. Fletcher and **S. Dixon**, University of Warwick, Department of Physics, Coventry, Warwickshire, CV4 7AL, United Kingdom

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

10:30 AM **Nondestructive Case Depth Measurements on Induction Hardened Steels Using a Model-Based Magnetic Hysteresis Technique**
---**C. C. H. Lo**, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

10:50 AM **Development of a System to Measure Austenite Grain Size of Plate Steel Using Laser-Based Ultrasonics**
---**C. S. Lim**, J. K. Yi, S. T. Hong, S. G. Choi, and K. J. Oh, POSLAB, POSCO, Instrumentation Research Group, 1, Goedong-dong, Pohang, Gyeongbuk, 790-785, Korea; Y. Nagata, H. Yamada, and N. Hamada, Nippon Steel Corporation

11:10 AM **Ultrasonic Porosity Estimation of Low-Porosity Ceramic Samples**
---J. Eskelinen, H. Hoffrén, T. Kohout, **E. Haeggström**, and L. J. Pesonen, University of Helsinki, Department of Physical Sciences, P. O. Box 64, FIN-00014, Helsinki, Finland; E. Haeggström, Helsinki Institute of Physics, P. O. Box 64, FIN-00014, Finland

11:30 AM **Effect of Temperature Gradient on Ultrasound Wave Propagation in Fluids – A FE Simulation Study**
---**M. K. KM**, S. Jeyaraman, and B. Ganesan, GE-Global Bangalore, Karnataka, India 560066; T. J. Batzinger, GE-Global Research, Nishkayuna, NY 12309; S. Ao and J. Tilden, GE-Infrastructure (Sensing), Billerica, MA 01821

11:50 AM **Noninvasive Ultrasonic Approach to Fluid Level Measurement and the Potential for Fluid Identification**
---D. R. Zilinskis, **M. J. Guers**, and B. R. Tittmann, The Pennsylvania State University, Department of Engineering Science & Mechanics, 212 Earth-Engineering Sciences Building, University Park, PA 16802-6812

12:10 PM ***Adjourn***

Improved Material Characterization Using Classifier-Based Data Fusion

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

---The nondestructive evaluation of the condition of materials subjected to heat treatment and varying stress levels is of importance in several applications, including the nuclear power industry. Typically, the material under test is inspected using one or more NDE techniques and the data is analyzed to evaluate the condition of the material. However, it has been observed that measurement data obtained by different inspection techniques are often complementary in nature. Therefore, higher accuracy can be achieved by fusing information provided by the different inspection modes. This paper proposes a classifier-fusion based approach to combine multifrequency eddy current and ultrasound data for material characterization applications. The proposed approach combines data from two inspection modes (ultrasound and eddy current) to determine the condition of the material. In particular, several classifiers are designed to classify the material under test into different classes. The proposed algorithm uses a hierarchy of classifiers to determine the material state/treatment (e.g. stress, heat treatment etc.) and level of exposure to this condition. Separate classifiers are designed for the different modes of inspection, and a weighted majority-voting rule is then used to combine classifiers for achieving higher accuracy. In addition, at select levels on the classifier hierarchy, features from multiple inspection modes are also used to design a single classifier for optimal performance. The proposed algorithm was applied on Inconel 600 samples that were exposed to several treatment modes (stress, heat treatment, corrosion and cracking), with different levels of exposure to each treatment mode. Classifiers in the proposed hierarchy were designed using a training data set and their accuracies were predicted using a separate test data set. Initial results indicate that the classifier fusion provides better result as compared to the single classifier approach for this problem.

Determination of Gruneisen Constant from Elevated Temperature Rayleigh Velocities

---Mark A. Doxbeck and **Moayyed A. Hussain**, Launcher Technology, Benet Laboratories, 1 Buffington Street, Watervliet, NY 12189-4050

---By exploiting finite deformation theory, we calculate implicit expressions for the change in longitudinal and transverse velocities of a material at elevated temperatures as a function of a uniform deformation parameter. We match the theoretical and experimental data with a least-squares fit to obtain the 3rd order elastic constants, and hence the Gruneisen parameter. The experimental data was collected with a laser ultrasonic system at temperatures ranging from 20 - 300 C. This approach was used on samples of aluminum and coated specimen of tantalum on steel and chromium on steel.

Characterization of Hydrogen Concentration Profiles in Zircaloy Cladding Tubes with Laser Ultrasound Technique

---Yu-An Lai and **Che-Hua Yang**, Chang Gung University, Department of Mechanical Engineering, 239 Wen-Hua 1st Rd., Kwei-Shan, Taoyuan, Taiwan, R.O.C., China (ROC)

---This research is focused on the characterization of material properties (MP) in hydrogen-charged Zircaloy cladding tubes with hydride precipitation distributed across the thickness in a continuous way. The material characterization processes combines a theoretical model, an ultrasound measurement technique and an inversion algorism. A theoretical model based on a global matrix method is used to model the dispersion curves of longitudinal modes propagating in a tube with an arbitrary number of layers. A laser ultrasound technique (LUT) is used to measure dispersion curves of guided waves propagating in the tubes. An inversion calculation based on simplex algorism is used to determine the MP from the measured dispersion data. With this material characterization process, material properties, including elastic moduli and thicknesses for two-layered tubes, are determined and verified with independent measurements. Furthermore, the proposed characterization processes is used to characterize MP profiles of tubes with their MP changing continuously across the thickness. The current result provides useful information for quantitative nondestructive inspection of Zircaloy cladding tubes with hydride precipitation distributed across the thickness in various profiles.

Enhancements of Microwave Anisotropy Measurement Technique

---**Sabine Predak** and Gerd Busse, Institute of Polymer Testing and Polymer Science, Department of Non-Destructive Testing (ZfP), University of Stuttgart, Stuttgart, Germany

---Wave propagation in birefringent material depends on the polarization direction. In anisotropic material, different phase velocities are observed along and perpendicular to the main orientation direction. For measurement of anisotropy (like fiber orientations in injection molded material) the sample is placed in an open resonator system. Length of resonator or frequency can be tuned while the intensity of the reflected microwave signal is recorded. By rotating the orientation of the linearly polarized microwave source, the resonator is operated at different angles between polarization and fiber direction. During this rotation the resonator length needs to be correspondingly readjusted in a feedback circuitry so that the observed length (or frequency) is an indicator of microwave refraction index. This way both the direction and the degree of anisotropy are determined. Combining the procedure with a positioning table, raster scans can be performed to determine the fiber orientation field in the sample. As the detector signal depends on material parameters and sample positioning, the conditions of wave propagation in the open resonator setup were analyzed and compared to corresponding measurements. As a result it is possible to enhance the reliability of the system by optimizing the sample position. Thus the determination of the degree of anisotropy or fiber content can be improved.

Considerations for Measuring Acoustic Birefringence in Thin Sheets Using Electromagnetic Acoustic Transducers (EMATs)

---**Marc P. Fletcher,** Department of Physics, University of Warwick, Coventry, Lincs, United Kingdom

---In aluminum or steel sheets it is generally accepted that the energy of through thickness shear waves is steered into two orthogonal polarizations, parallel and perpendicular to the rolling direction, of the sheet. Ultrasonic velocity measurements used to determine the orientation distribution coefficients (ODCs) in thin sheets can be obtained from the time domain waveform or its corresponding FFT. In the case of thin birefringent samples, data from radially polarized shear waves can be analyzed in the frequency domain allowing peaks to be resolved that correspond to the slightly different velocities associated with each shear waves polarization. By rotating a linearly polarized EMAT through 360° in small increments it is observed that the calculated velocities are not constant and are dependant on the signal processing used with the FFT. Further investigation using simulated waveforms show that this inconsistency in calculated velocity is an artifact of the data analysis itself.

Nondestructive Case Depth Measurements on Induction Hardened Steels Using a Model-Based Magnetic Hysteresis Technique

---**Chester C.H. Lo,** Iowa State University, Center for Nondestructive Evaluation, Applied Sciences Complex II, 1915 Scholl Road, Ames, Iowa 50011

---Magnetic hysteresis measurements offer realistic prospects for nondestructive case depth measurements on surface hardened steels because of the high sensitivities of magnetic properties to microstructure such as phase composition and dislocation density. Our recent studies of induction hardened steels with a range of case depths have shown strong correlations between the depth profiles of hardness and magnetic properties. In order to exploit these correlations for quantitative case depth measurements, we have developed a model-based approach for determining case depths from experimental hysteresis loops. An extended hysteresis model was developed to simulate the measured hysteresis loops, which exhibit two abrupt magnetization changes at low reverse field and at the knees of the loop. These changes arise from the magnetization reversal processes which take place first in the core and then in the case under a higher applied field. The case depths were estimated by modeling hysteresis loop as a weighed sum of signals from the case and the core. The estimated case depths were found to agree with the values obtained from the measured hardness depth profiles, demonstrating the potential of the magnetic hysteresis technique for case depth measurements.---This work was supported by the NSF sponsored Industry/University Cooperative Research Program of the Center for Nondestructive Evaluation at Iowa State University.

Development of a System to Measure Austenite Grain Size of Plate Steel Using Laser-Based Ultrasonics

---**Choong Soo Lim**, Jae Kyung Yi, Soon Taik Hong, Seung Gap Choi, and Ki Jang Oh, POSLAB, POSCO, Instrumentation Research Group, 1, Goedong-dong, Pohang, Gyeongbuk, 790-785, Korea; Yasuaki Nagata, Hirohisa Yamada, Naoya Hamada, Nippon Steel Corporation

---A measurement system for material properties of plate steel using laser-based ultrasonics has been developed. The system consists of pulsed Nd:YAG laser for ultrasonic generation, CW single frequency laser and confocal Fabry-Perot interferometer for ultrasonic detection. Additionally, fiber delivery technique of high power pulsed laser beam was also developed, since the goal of this study is to measure austenite grain size in hot-rolling process in real production line. At first, the relationship between the ultrasonic attenuation coefficients using longitudinal waves and austenite grain size of samples was investigated in the laboratory experiments. The samples heated up to 1,200„aC were quenched just after ultrasonic measurement and austenite grain sizes were analyzed by the conventional microscopic method. According to the experimental results, the ultrasonic attenuation coefficients showed a good correlation with actual austenite grain sizes. For the next step, the system was installed in a hot rolling pilot plant of plate steel, and it was verified that the austenite grain size could be measured even in the environment of a hot rolling pilot plant. In the experiments, it was also confirmed that the fiber delivery system could deliver Nd:YAG laser beam of 810 mJ/pulse and ultrasonic signals could be obtained successfully.

Ultrasonic Porosity Estimation of Low-porosity Ceramic Samples

---Joona Eskelinen, Hannu Hoffrén, Tomas Kohout, **Edward Hæggström**, and Lauri J. Pesonen, Department of Physical Sciences, University of Helsinki, PO Box 64, FIN-00014, Helsinki, Finland; Edward Hæggström, Helsinki Institute of Physics, PO Box 64, FIN-00014, Finland

---We report on efforts to extend the applicability of an airborne ultrasonic burst-reflection method (UBR) towards lower porosities. *UBR* can characterize highly porous (ø>80%) foams and glass bead packings (ø≈50%). We validated our method with plastic foams (ø≈32%–64%). *UBR* measures sample surface reflectivity at two or more incidence angles. We used low porosity (ø≈5%–30%) ceramic samples (30% Kaolin Grolleg-ECC, 20% Ball Clay Hyplas-64, 40% Feldspar FFF-K7, 10% Quartz-FFQ) to evaluate the feasibility of extending the *UBR* porosity range. We also investigated the applicable frequency range (0.1-2 MHz) that depends on the sample's pore and grain size distribution. Preliminary results indicate that *UBR* estimates correlate with estimates obtained by a water immersion method. A slight porosity underestimation can be explained by differences between the two methods. *UBR* estimates depend on pore size distribution as predicted by the theoretical boundary conditions of the used high-frequency approximation. This problem can be alleviated by using suitable measurement frequencies. The current setup and available airborne frequencies allows porosity evaluation within um-mm range pore sizes. *UBR* Porosity estimation range extension was feasible. Developing of a field-device for wide-range porosity measurements should be possible if pore size distribution is accounted for.

Effect of Temperature Gradient on Ultrasound Wave Propagation in Fluids – A FE Simulation Study

---**M. K. KM**, Satheesh Jeyaraman, and Baskaran Ganesan, GE-Global Bangalore, Karnataka, India-560066; Thomas J. Batzinger, GE-Global Research, Nishkayuna, NY 12309; Shirlely Ao and Jeffrey Tilden, GE-Infrastructure (Sensing), Billerica, MA 01821

---In this paper, we implement a weak formulation of the wave equation for a varying sound speed due to temperature gradient in a given medium. The temperature gradient, both linear and non-linear, is a spatial function mapped over a given region. The speed of sound as a function of temperature is governed by a relationship obtained by J. Lubbers and R. Graff. The resulting PDE is implemented and solved in FEMLAB. Multiple interfaces were modelled as a change in material properties. Effect of a temperature gradient on the refraction angle between interfaces was inspected. Results based on time of flight for linear and non-linear temperature profile is presented for some commonly used industrial materials.

Noninvasive Ultrasonic Approach to Fluid Level Measurement and the Potential for Fluid Identification

---Daniel R. Zilinskis, **Manton J. Guers**, and Bernhard R. Tittmann, The Pennsylvania State University, Department of Engineering Science & Mechanics, 212 Earth-Engineering Sciences Building, University Park, PA 16802-6812

---Analyzing low impedance fluids inside sealed containment vessels often presents a challenge. Common measurement strategies include wetted transducers and specially designed waveguides placed inside the vessel. However, such approaches may not be suitable for certain applications. Therefore, the potential for interrogating fluids inside a vessel with external clamp-on piezoelectric transducers has been investigated. The impedance of the fluid influences the signal reflection at the interior surface of the vessel wall. Using pulse-echo measurements, the attenuation characteristics of these reflections were used to distinguish fluid level and potentially identify fluids as well. In addition, reflections from the opposite sidewall of the vessel were observed. This second measurement was then be used to provide additional sound wave velocity information. Results suggest that both measurements can be utilized for effective measurements of fluid characteristics. The experimental data has also been compared to one-dimensional simulations.

Session 33

SESSION 33

NDE DEVICES AND SYSTEMS
Pavilion West

8:30 AM **A High-Resolution Real-Time Ultrasonic Imaging System for NDI Applications**
---**Y. Zhou**, G. Petculescu, I. Komsky, and S. Krishnaswamy, Northwestern University, Center for Quality Engineering and Failure Prevention, Evanston, IL 60208

8:50 AM **A Variable Pitch Comb Fixture for Rayleigh Wave Generation**
---**D. J. Barnard**, Materials and Engineering Physics Program, Ames Laboratory, USDOE, Ames, IA 50011

9:10 AM **SFD, A Novel Industrial System Flaw Detector for Rapid Online Monitoring of Defects in Metal Tubes**
---**P. Marty**, C. Brotherwood, N. Hankinson, and T. Marshall, NDT Solutions Ltd., Dunston Innovation Centre, Dunston Road, Chesterfield, S41 8NG, United Kingdom

9:30 AM **Development of a System to Measure Recrystallization Ratio of Plate Steel Using Laser-Based Ultrasonics**
---**Y. Nagata**, H. Yamada, and N. Hamada, Nippon Steel Corporation, Environment & Process Technology Center, Futtu Chiba, Japan; C. S. Lim, J. K. Yi, S. T. Hong, S. G. Choi, and K. J. Oh, POSLAB, POSCO, 1 Goedong-dong, Nam-gu, Pohang, Gyeongbuk, Korea

9:50 AM **Phased Array Ultrasonic Inspection of Titanium Forgings**
---**P. Howard**, R. Klaassen, and N. Kurkcu, GE Aviation, One Neumann Way, Mail Drop Q45, Cincinnati, OH 45215; J. Barshinger, C. Chalek, E. Nieters, and Z. Sun, GE Global Research, Niskayuna, NY 12309; F. de Fromont, GE Inspection Technologies, Lewistown, PA 17044

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

10:30 AM **Development of Eddy Current Techniques for the Detection of Stress Corrosion Cracking in Space Shuttle Primary Reaction Control Thrusters**
---**R. A. Wincheski**, NASA Langley Research Center, Nondestructive Evaluation Sciences Branch, Hampton, VA 23681; J. W. Simpson, Lockheed Martin, Hampton, VA 23681

10:50 AM **Industrial Applications of Confocal Microscopy**
---**M. A. Sala**, Corning Incorporated, Advanced Engineering, Corning, NY 14831

11:10 AM **A Borescope Based Optical Surface Scanner**
---**F. Inanc**, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

11:30 AM **Active Thermography for the Detection of Defects in Powder Metallurgy Compacts**
---**S. Benzerrouk**, D. Apelian, and R. Ludwig, Worcester Polytechnic Institute, Metal Processing Institute, Worcester, MA 01609; S. Benzerrouk and R. Ludwig, Worcester Polytechnic Institute, Electrical and Computer Engineering Department, Worcester, MA 01609

11:50 AM **The Design of a Multi-Agent NDE Inspection Qualification System**
---**N. McLean**, J. McKenna, A. Gachagan, S. McArthur, and G. Hayward, University of Strathclyde, Department of Electronic and Electrical Engineering, 204 George Street, Glasgow, G1 1XW, Scotland, United Kingdom

12:10 PM ***Adjourn***

A High-Resolution Real-Time Ultrasonic Imaging System for NDI Applications

---**Yi Zhou**, Gabriela Petculescu, Igor Komsky, and Sridhar Krishnaswamy, Center for Quality Engineering and Failure Prevention, Northwestern University, Evanston, IL 60208

---Ultrasonic NDI methods have an impressive record of applications on metallic and composite structures. However, the need for a wet couplant between the specimen and the transducer and the rather long inspection times necessitated by point-by-point scanning of large structures limits their applications. To overcome these constraints, a dry-contact large-area ultrasonic imaging system is being developed for real-time high-resolution NDI applications. The system consists of a large ultrasonic source, either piezoelectric or laser-based, a polymer dry-couplant, and a commercially available real-time ultrasonic CCD camera which displays easy-to-interpret images. Applications of this real-time high-resolution ultrasonic imaging system on metallic and composite structures are presented using either PZT or laser-based ultrasound generation as the source of the ultrasound. Aluminum and unidirectional and woven composites have been investigated in both through-transmission and pulse-echo modes. Images of artificial defects of different types and shapes in the investigated materials are demonstrated. The latest configuration of the imaging system working in pitch-catch mode is also reported. This configuration enables a one-sided ultrasounic inspection. Moreover, it does not require the narrowband beamsplitter which is necessary in pulse-echo mode. Therefore, this configuration substantially improves the system’s bandwidth, spatial resolution, and image quality.

A Variable Pitch Comb Fixture for Rayleigh Wave Generation

---**D. J. Barnard**, Materials and Engineering Physics Program, Ames Laboratory, USDOE, Ames, IA 50011

---Several methods are available for the generation of Rayleigh waves on a substrate surface. A so-called "comb" is one method, where the comb elements (fingers) contact the surface, with spacing between adjacent fingers equal to the Rayleigh wavelength of the substrate for a given frequency. Although efficient and simple, a comb with fixed finger spacing will generate only a fixed frequency Rayleigh wave on a particular substrate. A simple fixture has been developed whereas the pitch of the fingers can be varied over a range of spacings, allowing the fixture to be used on a wider range of materials and/or over a range of frequencies on the same substrate. The fixture allows the use of commercial contact transducers for Rayleigh wave generation. Elements of the fixture and tests results of the fixtures used for generating Rayleigh waves on aluminum and steel substrates will be demonstrated.---The Ames Laboratory is operated for the USDOE by Iowa State University under contract W-7405-ENG-82. This work was supported by the Office of Energy Research, Office of Basic Energy Sciences.

SFD, A Novel Industrial System Flaw Detector for Rapid Online Monitoring of Defects in Metal Tubes

---**P. Marty**, C. Brotherwood, N. Hankinson, and T. Marshall, NDT Solutions Ltd, Dunston Innovation Centre, Dunston Road, Chesterfield, S41 8NG, United Kingdom

---The new NDT Solutions equipment, SFD-100, is a flexible single or multiple channel ultrasonic systems instrument suited for automated inspections. It is the ideal tool for integrating into existing industrial scanning systems UT with fully integrated motor control. All components of the SFD-100 instrument have been designed to be flexible and easily configurable to provide the optimal solution for multiple transducer inspections. The instrument interface has been constructed using Inspection Ware scanning software from UTEX Scientific at its core, providing the flexibility for integration into existing systems as an upgrade rather than requiring a full replacement, and support for complete scanning system with motor control capability. It offers extensive range of signal processing, evaluation tools and alarms for flaw detection and materials characterization. The combination of two high specification PCI cards, (pulser-receiver, data capture) allows the product to be packaged into a single rugged embedded unit, rackmounted or portable. The pulser-receiver and data capture PCI cards are both of outstanding specification providing the best available hardware as a basis for the system and the software can be customized to suit the requirements of the inspection. After presentation of the instruments, application examples for on-line tube testing will be presented.

Development of a System to Measure Recrystallization Ratio of Plate Steel Using Laser-based Ultrasonics

---**Yasuaki Nagata**, Hirohisa Yamada, and Naoya Hamada, Environment & Process Technology Center, Nippon Steel Corporation, Futtu Chiba, Japan; Choong Soo Lim, Jae Kyung Yi, Soon Taik Hong, Seung Gap Choi, Ki Jang Oh, POSLAB, POSCO, 1 Goedong-dong, Nam-gu, Pohang, Gyeongbuk, Korea

---In this study, a material property measurement system for plate steel using laser-based ultrasonics has been developed. The system consists of pulsed Nd:YAG laser for ultrasonic generation, CW single frequency laser and Fabry-Perot interferometer for ultrasonic detection. The system generates and detects shear waves and precisely calculates anisotropy parameter values of shear wave velocities of test samples. At first, the relationship between anisotropy parameter and recrystallization ratio was investigated in the laboratory experiments. Quenching the test samples just after the ultrasonic measurement, recrystallization ratio values were measured by the conventional microscopic method. According to the experimental results, the anisotropy parameter values showed a good correlation with actual recrystallization ratio values. To evaluate the applicability of the system to real steel production line, the system was installed in a hot rolling pilot plant of plate steel. As the results, it was demonstrated that the system could measure the recrystallization ratio using the anisotropy parameter values of shear wave velocities, even in the environment of a hot rolling pilot plant.

Phased Array Ultrasonic Inspection of Titanium Forgings

---**Patrick Howard**, Richard Klaassen, and Nihat Kurkcu, GE Aviation, One Neumann Way, Mail Drop Q45, Cincinnati, OH 45215; James Barshinger, Carl Chalek, Edward Nieters and Zongqui Sun, GE Global Research, Niskayuna, NY; Francois de Fromont, GE Inspection Technologies, Lewistown, PA 17044

---In an effort to improve the detection of low-reflectivity flaws in large-grained alloys such as titanium, the aerospace industry implements high sensitivity ultrasonic inspection methods for disk forgings. These methods typically use multiple, subsurface-focused sound beams in combination with digital C-scan image acquisition and display. The methods are based on the principle that the signal-to-noise ratio of flaw echoes is improved by limiting the volume of material interacting with the ultrasonic pulse at any given point in time. Traditionally, forging inspections have been performed using multiple single element, fixed focused transducers. Recent advances in phased array technology have made it possible to perform an equivalent inspection using a single phased array transducer. General Electric has developed a system to perform titanium forging inspection based on medical phased array technology and advanced image processing techniques. The components of that system and system performance for titanium inspection will be discussed.

Development of Eddy Current Techniques for the Detection of Stress Corrosion Cracking in Space Shuttle Primary Reaction Control Thrusters

---**Russell A. Wincheski**, Nondestructive Evaluation Sciences Branch, NASA Langley Research Center, Hampton, VA 23681; John W. Simpson, Lockheed Martin, Hampton, VA 23681

---A recent identification of stress corrosion cracking in the Space Shuttle Primary Reaction Control System (PRCS) Thrusters triggered an extensive nondestructive evaluation effort to develop techniques capable of identifying such damage on installed shuttle hardware. As a part of this effort, specially designed eddy current probes inserted into the acoustic cavity were explored for the detection of such flaws and for evaluation of the remaining material between the crack tip and acoustic cavity. The technique utilizes two orthogonal eddy current probes which are scanned under stepper motor control in the acoustic cavity to identify cracks hidden with as much as 0.060” remaining wall thickness to the cavity. As crack growth rates in this area have been determined to be very slow, such an inspection provides a large safety margin for continued operation of the critical shuttle hardware. Testing has been performed on as manufactured and flown thruster components with both actual and fabricated defects. This presentation will review the design and performance of the developed eddy current inspection system. Detection of flaws as a function of remaining wall thickness, orientation angle, and initiation location with respect to the acoustic cavity will be presented along with the proposed system configuration for depot level or on vehicle inspection capabilities.

Industrial Applications of Confocal Microscopy

---**Martin A. Sala**, Advanced Engineering, Corning Incorporated, Corning, NY 14831

---Scanning Confocal Microscopy is a powerful tool in the biology investigator's kit providing an ability to produce 3-D images of microscopic specimens as well as fluorescent imaging of specifically tagged objects. Providing resolutions into the 100's of nm, this technique is allowing new insights for Corning Incorporated's materials based divisions including Life Science's Projects, post mortem analyses of Display Products, porosity of Cellular Substrates and added understanding of glass compositions used in fiber, astronomy and the development of new products.

A Borescope Based Optical Surface Scanner

--- **Feyzi Inanc**, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---The surface characterization is one of the areas where the optical methods play a significant role and there are many different methodologies and techniques available for such characterization studies. Illumination of the target surface area and transmitting the optical signal back to the detector is one of the crucial steps in optical characterization techniques and access to the target area restricts the implementation of optical techniques. In the previous years, we reported on using a borescope based approach for scanning surfaces that are not easily accessible. The method has used triangulation principle for characterizing the surface topology. In those reports, we have shown the principle of proof, introduced the equipment and test setup and demonstrated some of the approaches used for image distortions that are at the significant levels when borescopes are used for transmitting and receiving optical signals. In this study, we will report on the final form of the borescope based optical scanner and provide some results obtained through this scanner. The results from the scanner will be compared to the results obtained through a standard laser profilemeter and we will discuss scan resolution, accuracy and speed issues by using those comparative benchmarking.---This material is based on work supported by NASA under award NNL05AA19G.

Active Thermography For The Detection of Defects in Powder Metallurgy Compacts

---**S. Benzerrouk**, D. Apelian, and R. Ludwig, Metal Processing Institute, Worcester Polytechnic Institute, Worcester, MA 01609; S. Benzerrouk and R. Ludwig, Electrical and Computer Engineering Department, Worcester Polytechnic Institute, Worcester, MA 01609

---Active thermography is an established NDE technique that has become the method of choice in many industrial applications which require non-contact access to the parts under test. However, when conducting on-line infrared inspection of powder metallic compacts, complications can arise due the generally low emissivity of metals and the thermally noisy environment in manufacturing plants. In this paper we present results of an investigation that tests the suitability of active IR imaging of powder metallurgy compacts for the detection of surface and sub-surface defects in the pre-sinter state in an on-line manufacturing environment to ensure hundred percent quality assurances. Additional off-line tests are carried out for a statistical quality analysis. Specifically, the IR imaging of sub-surface defects is based on a transient instrumentation approach that relies on an electric control system that synchronizes and monitors the thermal response due to an electrically generated heat source. Preliminary testing reveals that this newly developed pulsed thermography system can be employed to detect subsurface defects in green-state parts. Practical measurements agree well with theoretical predictions. The inspection approach being developed targets the testing of all green-state compacts as they exit the compaction press at speeds of up to 1,000 parts per hour.

The Design of a Multi-Agent NDE Inspection Qualification System

---**Neil McLean**, James McKenna, Anthony Gachagan, Stephen McArthur, Gordon Hayward, University of Strathclyde, Department of Electronic and Electrical Engineering, 204 George Street, Glasgow, G1 1XW, Scotland, United Kingdom

---Design and qualification of ultrasonic NDE inspection procedures can be costly and time consuming tasks. While a number of software tools have been developed to aid the process, including mathematical models for flaw-response simulation and expert systems for data manipulation, the heterogeneous nature of these systems mean that in practice their use requires extensive interpretation and manipulation of data by an experienced engineer. A novel Multi-Agent system (MAS) for NDE inspection qualification is being developed to facilitate a scalable environment allowing integration and automation of new and existing inspection qualification tools. This paper discusses the advantages of using a MAS approach to integrate the large number of disparate NDE software tools. The design and implementation of the system architecture is presented, including the development of an ontology to describe the NDE domain. The process of converting existing systems to agents is discussed, in particular the development of agents to facilitate provision of component geometry; ray tracing and coverage mapping services; and GTD and Kirchhoff flaw-response models. In addition, the development of a new agent for the prediction of ‘least-detectable’ defects for a given inspection specification will be presented.

AUTHORS INDEX

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AUTHORS INDEX

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