Abstracts

Review of Progress in Quantitative NDE
Hilton Baltimore
Baltimore, Maryland
July 21 – 26, 2013

Organized by:
Center for Nondestructive Evaluation
Iowa State University

In cooperation with:

Air Force Research Laboratory
American Society for Nondestructive Testing
Ames Laboratory U.S. Department of Energy
Army Research Laboratory
Federal Aviation Administration
National Aeronautics and Space Administration LaRC
National Science Foundation
   Industry/University Cooperative Research Centers

The Center for Nondestructive Evaluation is a member of the ISU Institute for Physical Research and Technology.
### 2013 Review of Progress in Quantitative NDE Program Summary

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<td>35. Thermography/Thermosonics I – KB 12</td>
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<td>24. Sensors, Transducers, &amp; Probes – KB 9</td>
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<td>27. Ultrasonic Methods for Concrete – KB 3</td>
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<td>29. Composites &amp; Laminates – KB 9</td>
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<td>31. Posters: NDE Sensors &amp; Systems, Ultrasonics KB 7, 8</td>
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<td>38. Tomography, Imaging, &amp; Inversion – KB 3</td>
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<td>39. Terahertz NDE – KB 11</td>
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<td>40. Thermography/Thermosonics II – KB 12</td>
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### Conference Details
- **Conference Check-in and Registration**: KB East Foyer, 2:00-6:00 pm and 7:00-9:00 pm
- **Welcome Reception**: KB South Foyer, 7:00-9:00 pm
- **QNDE Conference Dinner**: Eutaw Street (Weather backup location: KB South Foyer)
- Social Reception at 6:30 pm
- Buffet opens at 7:00 pm

**Key:**
- KB = Key Ballroom
- HB = Holiday Ballroom
MONDAY

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  Micromagnetic Testing ............................................ 31
This grid is provided for planning purposes. As you go through your abstract book to decide which talks/sessions you would like to attend, you can mark them on this grid for a one shot look at where you would like to go and when on each day of the conference.

| 1:30 PM | Session 3 Guided Waves I  
| GB 12 | Session 4 Radiography  
| KB 10 | Session 5 Signal Processing  
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MONDAY AFTERNOON, JULY 22, 2013
Plenary Sessions 1 and 2
PROGRAM

Monday, July 22, 2013

PLENARY SESSION 1
Leonard J. Bond, Chairperson
Key Ballroom 1, 2, 5

9:00 AM  Opening Remarks
---Leonard J. Bond, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

9:10 AM  40 Years of Progress in NDT – History as a Guide to the Future
---Mike Farley, ICNDT, c/o BINDT, Newton Building, St. George’s Avenue, Northampton, NN2 6JB, United Kingdom

10:00 AM  NSF Industry-University Cooperative Research Centers
---Rathindra (Babu) DasGupta, National Science Foundation Industry/University Cooperative Research Centers Program, 4201 Wilson Boulevard, Arlington, VA 22230

10:15 AM  Break

PLENARY SESSION 2
Lester W. Schmerr, Jr., Chairperson
Key Ballroom 1, 2, 5

10:30 AM  Nonlinear Ultrasonics for Structural Health Awareness
---Laurence J. Jacobs, College of Engineering, Georgia Institute of Technology, Atlanta, GA 30332-0360

11:20 AM  Through the Looking Glass: The Future for NDE?
---Leonard J. Bond, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

12:10 PM  Lunch

Please Note: The bolded authors throughout this program indicate the presenting author. Also, 40 minute opening presentations are bolded in blue.
9:10 AM

40 Years of Progress in NDT – History as a Guide to the Future
---Mike Farley, ICNDT, c/o BINDT, Newton Building, St George's Avenue, Northampton, NN2 6JB, United Kingdom

---The Keynote Paper by the Chairman of ICNDT (International Committee for NDT) will review progress in NDT/NDE technology over the past 40 years and the developing “state-of-the-art” around the world. There will be a particular emphasis on the energy industries in which the author has worked for almost 40 years. The paper will further consider how other changes over 40 years, including globalization of trade, the emergence of new countries as industrial powers, the ageing of infrastructure, the growing understanding of the importance of NDT and its reliability have impacted the world of NDT and the environment in which ICNDT, its members and groups like those involved in QNDE all work to improve the science and practice of NDT. (ICNDT is an international not-for profit organization, initially founded in 1960, whose members are the NDT societies in more than 60 countries around the world. www.icndt.org).
10:00 AM

NSF Industry-University Cooperative Research Centers
---Rathindra (Babu) DasGupta, National Science Foundation Industry/University Cooperative Research Centers Program, 4201 Wilson Boulevard, Arlington, VA 22230

---The Industry/University Cooperative Research Centers (I/UCRC) program develops long-term partnerships among industry, academe, and government. The centers are catalyzed by a small investment from the National Science Foundation (NSF) and are primarily supported by industry center members, with NSF taking a supporting role in the development and evolution of the center. Each center is established to conduct research that is of interest to both the industry members and the center faculty. An I/UCRC contributes to the Nation's research infrastructure base and enhances the intellectual capacity of the engineering and science workforce through the integration of research and education. Success stories including technology transfer to member organizations, spin-offs from centers, human capital impact and others will be provided in this presentation.
Nonlinear Ultrasonics for Structural Health Awareness
---Laurence Jacobs, College of Engineering, Georgia Institute of Technology, Atlanta, GA 30332-0360

---Predictive health monitoring of structural components will require the development of advanced sensing techniques capable of providing quantitative information on the damage state of structural materials. By focusing on nonlinear acoustic techniques, it is possible to measure absolute, strength based material parameters that can then be coupled with uncertainty models to enable accurate and quantitative life prediction. Starting at the material level, this talk will summarize current research that involves a combination of sensing techniques and physics-based models to characterize damage in both metallic and cement-based materials. In metals, these nonlinear ultrasonic measurements can sense material state, before the formation of micro- and macro-cracks. Typically, cracks of a measurable size appear quite late in a component’s total life, while the material’s integrity in terms of toughness and strength gradually decreases due to the microplasticity (dislocations) and associated change in the material’s microstructure. In cement-based materials, these nonlinear acoustic techniques are a direct measure of the material’s inherent nonlinearity, and are dominated by its hysteretic behavior due to microcracks and other damage. A variety of sensing techniques including second harmonic generation and wave mixing will be considered. Since these nonlinear acoustic techniques are acoustic wave based, component interrogation can be performed with bulk, surface and guided waves using the same underlying material physics; these nonlinear ultrasonic techniques provide results which are independent of the wave type used. Recent physics-based models consider the evolution of damage due to dislocations, slip bands, interstitials, and precipitates in the lattice structure, which can lead to localized damage. The talk will consider applications to characterize fatigue, thermal embrittlement and irradiation damage in nickel-base superalloys, aluminum, steels and stainless steels, as well as alkali silica reaction (ASR) damage in concrete.
Through the Looking Glass: The Future for NDE?
---Leonard J. Bond, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

---The first schemes for detecting underwater objects by echo ranging date from before World War I. In 1912 – just five days after the Titanic hit an iceberg and sank L.F. Richardson filed a patent for echo ranging with airborne sound. A month later he applied for a British patent for its underwater analogue. A Canadian Reginald A. Fessenden patented the first functioning echo-range finder in the United States in 1914. The developments of SONAR, RADAR and other electromagnetic measurements, as well as radiography and pulse-echo ultrasonic inspection moved all forward during World War II. Medical B-scan ultrasonic imaging was featured in Life magazine in September 1954. In the same year (’54) Jaffe discovered new piezoelectric ceramics – Lead titanate-zirconate. NDT started to grow in application. By the 1970’s it was recognized that “there was an inadequate science base for NDT to become quantitative.” The DARPA and Air Force Programs, as well as activities in a range of European countries blossomed. A first meeting was held in November 1973. We are now at the 40th Annual Review of Progress in Quantitative NDE (QNDE), with proceedings that occupy some four meter of shelf space! We have seen various predictions over the years, Unified Life Cycle Engineering, material state awareness, structural health monitoring, Damage Prognostics, on-line monitoring. NDT is now a mature industry with annual global equipment sales close to $2B, and services that have been estimated at anything between five and 10 times this number, when all costs are included. BUT where is NDE, QNDE or whatever it is going to be called moving? NDE remains, and will remain, central to the engineering enterprise. It is moving beyond measurements, it is leveraging advances in computers, data processing, displays and robotics, it is becoming part of the product design optimization process, it is being integrated into manufacturing and much more. The combination of measurements, materials science, modeling and advanced manufacturing that form parts of QNDE all interact with the understanding of material properties. QNDE seeks to assess “features” and give data for the prediction of structural performance, including when using new processes, such as additive manufacturing and many classes of composites. These analyses can provide process signatures and estimates for safe, service and remaining life will all be discussed in this paper. Materials and systems are becoming smart, sensors are, in some cases, becoming part of the structure, wireless networks and distributed computing are all changing the form of systems. We do not yet have the Tricorder, or an NDT car-wash that can fully describe material state and estimate life, under a variety of stressor conditions, but we are moving forward in terms of providing data that let us move from the “find and fix” or workmanship standard approach for NDT of 40 years ago to a more holistic and proactive approach to component design and management and concurrent engineering, or is this simply unified life cycle engineering, being revisited and adopted?
Session 3
### SESSION 3
**GUIDED WAVES I**
Peter Cawley and Ronald A. Roberts, Co-Chairpersons
Key Ballroom 12

1:30 PM  **Guided Waves in NDE and Health Monitoring**
---Peter Cawley, 460B Mechanical Engineering, Imperial College, Exhibition Road, London, SW7 2AZ, United Kingdom

2:10 PM  **Long Range Guided Wave Defect Monitoring in Rail Track**
---Philip W. Loveday and Craig S. Long, CSIR Material Science and Manufacturing, South Africa

2:30 PM  **1-D Profiling Using Highly Dispersive Guided Waves**
---Arno Volker and Tim van Zon, TNO, Stieltjesweg 1, P. O. Box 155, 2600 AD Delft, The Netherlands

2:50 PM  **Lamb Mode Selection for Accurate Wall Loss Estimation Via Guided Wave Tomography**
---Peter Huthwaite, Remo Ribichini, Michael J. S. Lowe, and Peter Cawley, Imperial College, Mechanical Engineering, London, United Kingdom

3:10 PM  **Break**

3:30 PM  **Recent Developments in Guided Wave Travel Time Tomography**
---Tim van Zon and Arno Volker, TNO, Stieltjesweg 1, P. O. Box 155, 2600 AD Delft, The Netherlands

3:50 PM  **Corrosion Monitoring Using High-Frequency Guided Ultrasonic Waves**
---Paul Fromme, University College London, Department of Mechanical Engineering, London, United Kingdom

4:10 PM  **Topological Imaging of Defects by Inspection of Lamb Waves**
---S. Rodriguez, M. Deschamps, and M. Castaings, University Bordeaux, 12M, UMR-CNRS 5295, F-33400, Talance, France; E. Ducasse, Arts et M_etiers ParisTech, 12M, UMR-CNRS 5295, F-33400, Talance, France

4:30 PM  **Guided Wave Structural Health Monitoring with an Array of Novel Piezoelectric Transducers**
---Aaron M. Lesky, The Pennsylvania State University, The Graduate Program in Acoustics, State College, PA 16802; Clifford J. Lissenden, The Pennsylvania State University, Department of Engineering Science and Mechanics, State College, PA 16802

4:50 PM  **Block-Sparse Lamb Wave Structural Health Monitoring Using Generic Scattering Models**
---Ross M. Levine and Jennifer E. Michaels, Georgia Institute of Technology, School of Electrical and Computer Engineering, 777 Atlantic Drive N.W., Atlanta, GA 30332-0250
1:30 PM

Guided Waves in NDE and Health Monitoring
---Peter Cawley, 460B Mechanical Engineering, Imperial College, Exhibition Road, London SW7 2AZ, United Kingdom

---Guided wave inspection is now used worldwide for the detection of corrosion in pipes; the technique has the advantage that tens of meters of pipe can be screened from a single transducer location and the full volume of the pipe wall is covered. The ability to cover long lengths from a single location is particularly attractive when parts of the pipe are difficult to access such as at road crossings or at wall penetrations, and the technique is also increasingly used on buried lines. There is also great interest in permanently installed sensors to track the condition of a structure and systems are now commercially available. Standard guided wave systems provide rapid screening for the presence of defects but do not give an accurate measurement of defect size; there has been a great deal of research on this topic in recent years without a generally applicable solution being found. This has led to renewed interest in guided wave tomography as a means of obtaining an accurate thickness map over the region enclosed by an array of transducers. This paper will review the current state of the art of guided wave inspection and look at future trends.

2:10 PM

Long Range Guided Wave Defect Monitoring in Rail Track
---Philip W. Loveday and Craig S. Long, CSIR Material Science and Manufacturing, South Africa

---A guided wave ultrasound system was previously developed for monitoring rail track used on heavy duty freight lines. This system operates by transmitting guided waves between permanently installed transmit and receive transducers spaced approximately 1km apart. The system has been proven to reliably detect rail breaks without false alarms. While cracks are sometimes detected there is a tradeoff between detecting cracks and the possibility of false alarms. Adding a pulse-echo mode of operation to the system could provide increased functionality by detecting, locating and possibly monitoring cracks. This would require an array of transducers to control the direction and mode of propagation and it would be necessary to detect cracks up to a range of approximately 0.5 km in both directions along the rail. In this paper, the possibility of adding a pulse-echo mode of operation to the system is explored experimentally. An array of transducers was used along with full matrix capture and subsequent array processing. Lab and field measurement results will be presented.
Corrosion is one of the industries major issues regarding the integrity of assets. Currently inspections are conducted at regular intervals to ensure a sufficient integrity level of these assets. Cost reduction while maintaining a high level of reliability and safety of installations is a major challenge. There are many situations where the actual defect location is not accessible, e.g., a pipe support or a partially buried pipe. Guided wave tomography has been developed to reconstruct the wall thickness. In case of bottom of the line corrosion, i.e., a single corrosion pit, a simpler approach may be followed. Data is collected in a pit-catch configuration at the 12 o'clock position using highly dispersive guided waves. After dispersion correction the data collapses to a short pulse, any residual dispersion indicates wall loss. The phase spectrum is used to invert for a wall thickness profile in the circumferential direction, assuming a Gaussian defect profile. The approach is evaluated on numerically simulated and measured data. The method is intended for rapid semi-quantitative screening of pipes.

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Lamb Mode Selection for Accurate Wall Loss Estimation via Guided Wave Tomography

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Peter Huthwaite, Remo Ribichini, Michael J. S. Lowe, and Peter Cawley, Imperial College, Mechanical Engineering, London, United Kingdom

Guided wave tomography offers a method to accurately quantify wall thickness losses in pipes and vessels caused by corrosion. This is achieved using ultrasonic waves transmitted over distances of approximately 1-2m, which are measured by an array of transducers and then used to reconstruct a map of wall thickness throughout the inspected region. To achieve accurate estimations of remnant wall thickness, it is vital that a suitable Lamb mode is chosen. This talk presents a detailed evaluation of the fundamental S0 and A0 modes, which are of primary interest in guided wave tomography thickness estimates since the higher order modes do not exist at all thicknesses, to compare their performance using both numerical and experimental data while considering a range of challenging phenomena. The study evaluates the sensitivity of each mode to thickness changes as well as comparing the effects of coatings and liquid loadings on the attenuation and phase of the transmitted waves. The expected resolution of the reconstructed thickness maps is also investigated for each of the two modes.
3:30 PM

Recent Developments in Guided Wave Travel Time Tomography
---Tim van Zon and Arno Volker, Stieltjesweg 1, P.O. Box 155, 2600 AD Delft, The Netherlands

---The concept of predictive maintenance using permanent sensors that monitor the integrity of an installation is an interesting addition to the current method of periodic inspections. Guided wave tomography had been developed to map the wall thickness using the travel times of guided waves. It can be used for monitoring or for inspection of pipe-segments that are difficult to access, for instance at the location of pipe-supports. An important outcome of the tomography is the minimum remaining wall thickness, as this is critical in the scheduling of a replacement of the pipe-segment. In order to improve the sizing accuracy we have improved the tomography scheme. A number of major improvements have been realized allowing to extend the application envelope to pipes with a larger wall thickness and to larger distances between the transducer rings. Simulation results indicate that the sizing accuracy has improved and that is now possible to have a spacing of 8 meter between the source-ring and the receiver-ring. Additionally a reduction of the number of sensors required might be possible as well.

3:50 PM

Corrosion Monitoring Using High-Frequency Guided Ultrasonic Waves
---Paul Fromme, University College London, Department of Mechanical Engineering, London, United Kingdom

---Corrosion develops due to adverse environmental conditions during the life cycle of a range of industrial structures, e.g., offshore oil platforms, ships, and desalination plants. Both pitting corrosion and generalized corrosion leading to wall thickness loss can cause the degradation of the structural integrity. The nondestructive detection and monitoring of corrosion damage in difficult to access areas can be achieved using high frequency guided waves propagating along the structure from accessible areas. Using standard ultrasonic transducers with single sided access to the structure, guided wave modes were generated that penetrate through the complete thickness of the structure. The wave propagation and interference of the different guided wave modes depends on the thickness of the structure. Laboratory experiments were conducted and the wall thickness reduced by consecutive milling of the steel structure. Further measurements were conducted using accelerated corrosion in a salt water bath and the damage severity monitored. From the measured signal change due to the wave mode interference the wall thickness reduction was monitored. The high frequency guided waves have the potential for corrosion damage monitoring at critical and difficult to access locations from a stand-off distance.
Topological Imaging of Defects by Inspection of Lamb Waves
---S. Rodriguez, M. Deschamps, and M. Castaings, Univ. Bordeaux, I2M, UMR-CNRS 5295, F-33400 Talence, France; E. Ducasse, Arts Et M_ etiers Paristech, I2M, UMR-CNRS 5295, F-33400 Talence

---Topological imaging is a recent method. So far, it has been applied to bulk waves, and high resolution has been demonstrated for imaging scatterers even with a single ultrasonic insonification of the inspected medium. This method consists in (i) emitting waves and measuring the response of the medium; (ii) solving two propagation problems: the direct problem, where the source is the one used for the insonification, and the adjoint problem, where the source is the time-reversed difference between the wave field measured and that obtained in the direct problem; (iii) computing the image from the two wave fields simply by multiplying both fields in the frequency domain, and integrating over the frequency. The quickness of the method only depends on the cost of the field computations that are performed in the defect-less medium. The present work deals with the application of the topological imaging to guided waves. Combining modal theory and Fourier analysis, the computations are performed in a very short time. The two-dimensional in-plane imaging is based on the propagation of the single S0 Lamb mode. Despite very high dispersion, scatterers are accurately localized and the spatial resolution is equal about one wavelength.

Guided Wave Structural Health Monitoring with an Array of Novel Piezoelectric Transducers
---Aaron M. Lesky, The Pennsylvania State University, The Graduate Program in Acoustics, State College, PA 16802; Clifford J. Lissenden, The Pennsylvania State University, Department of Engineering Science and Mechanics, State College, PA 16802

---Multi-element, conformable piezoelectric strip transducers have been designed and fabricated for structural health monitoring using ultrasonic guided waves. The piezoelectric fiber composite elements function as a comb transducer to activate a planar wave. A mockup of a storage tank or pressure vessel has been constructed from a steel shell and a hexagonal array of comb transducers. A hot spot to which artificial damage has been induced is monitored with the comb transducers. In addition, conventional piezoelectric disks have also been affixed to the shell in a circular pattern for the purpose of comparison. Different operating conditions are represented by the presence of water inside the shell and temperature variations between 5 and 40°C. The comb transducers have been designed to excite the S1 Lamb wave mode at the longitudinal wave speed, which is oblivious to the presence of liquid loaded boundary conditions. Transmitted and scattered waves are received by the array of strip transducers for each planar wave activated. The circular crested waves activated by each disk transducer are used in a tomography algorithm. Artificial defects simulate a surface breaking fatigue crack and a corrosion pit. Results are presented for baseline and damaged conditions and damage-sensitive signal features are identified.
Block-Sparse Lamb Wave Structural Health Monitoring Using Generic Scattering Models
---Ross M. Levine and Jennifer E. Michaels, Georgia Institute of Technology, School of Electrical and Computer Engineering, 777 Atlantic Drive, NW Atlanta, GA

---A well-known damage detection paradigm is the use of ultrasonic guided waves that are generated and recorded by a spatially-distributed array of piezoelectric transducers. This type of configuration is capable of interrogating a defect from a variety of angles and over a large region of interest by analyzing all pairwise transducer signals. By subtracting prerecorded baseline signals, differential signals are obtained that can be analyzed for the purpose of detecting, locating, and characterizing newly-introduced scatterers. Typical analysis techniques such as delay-and-sum imaging have the ability to detect flaws, but their performance is limited, especially when the potential scatterers may have high directionality or introduce phase shifts. Signal envelopes are frequently used to avoid the problem of unknown phase shifts, which further reduces performance. The sparsity-based technique described here uses a different approach, where each potential damage location has its own generic scattering model that allows for unknown variations in amplitude and phase between each transducer pair. The differential signals are then assumed to be a linear combination of a small number of these models, and an image is generated using a block-sparse reconstruction algorithm that splits the signals into location-based components. Results are presented for both simulated and experimental data. The images exhibit smaller spot size and fewer artifacts than those obtained via delay-and-sum imaging, provided the model is reasonably well-matched to the data.
SESSION 4
RADIOGRAPHY
Uwe Ewert and Joe N. Gray, Co-Chairpersons
Key Ballroom 10

1:30 PM Metrology, Applications and Methods with High Energy CT Systems
---N. Uhlmann, S. Kasperl, M. Karl, M. Salamon, N. Reims, G. Ermann, V. Voland, M. Schmitt, M. Boehnel, and S. Schroepefl, Fraunhofer IIS, Development Center X-Ray Technology EZRT, Furth, Germany; R. Hanke, University of Wurzburg, Lehrstuhl fur Rontgenmikroskopie, Wurzburg, Germany

2:10 PM Strategies for Optimum Calibration of Detector Arrays in Digital Industrial Radiology
---Uwe Zscherpel, Uwe Ewert, and Carsten Bellon, BAM Federal Institute for Materials Research and Testing, Division 8.3, Unterden Eichen 87, D-12205 Berlin, Germany

2:30 PM Spectral Characterization of Storage Phosphor Imaging Plates Using Synchrotron Radiation in the 8-60 keV Energy Range
---Andreas Deresch, Mirko Jechow, and Christian Gollwitzer, Federal Institute for Materials Research and Testing, Non-Destructive Testing, Radiological Methods, Berlin, Germany

2:50 PM Regularization Approach for Tomosynthesis X-Ray Inspection
---Ulf Hassler, Markus Rehak, Konstantinos Tigkos, Wolfgang Holub, Norbert Woerlein, and Ahmad Osman, Fraunhofer Entwicklungszentrum fuer Roentgentechnik, Dept. AMS, D-90762, Fuerth, Germany

3:10 PM Break

3:30 PM X-Ray Tomography of Large Objects with Limited Measurement Angle
---Mikko Vepsalainen, Markku Markkanen, and Pauli Sundberg, Eigenor Corporation, R&D Center, Helsinki, Finland

3:50 PM Experimental Investigation of Iterative Reconstruction Techniques for High Resolution Mammography
---Valeriy Vengrinovich1, Sergei Zolotarev1, and Vladimir Linev2, 1Institute of Applied Physics, Minsk, Belarus; 2Adani Ltd”, Minsk, Belarus

4:10 PM Benchmarking of the Detector Model in Radiographic Simulation
---Uwe Ewert, Andreas Deresch, Carsten Bellon, Gerd-Rudiger Jaenisch, BAM-Federal Institute for Materials Research and Testing, Division 8.3, Unterden Eichen 87, D-12205 Berlin, Germany

4:30 PM X-Ray Source Considerations in Operation of Digital Detector Arrays
---Terrence Jensen and Scott Wendt, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

4:50 PM X-Ray Scattering-Experimental Measures and Models
---Joe Gray and Scott Wendt, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

5:10 PM Feasibility Study for Measurement of Insulation Compaction in the Cryogenic Rocket Fuel Storage Tanks at Kennedy Space Center by Fast/Thermal Neutron Techniques
---Richard A. Livingston and Mohamad Al-Shekhly, University of Maryland, Materials Science & Engineering Department, College Park, MD 20742; Jeffrey S. Schweitzer, University of Connecticut, Physics Department, Storrs, CT; Ann M. Parsons, NASA Goddard Spaceflight Center, Astrochemistry Laboratory, Greenbelt, MD; Ellen E. Arens, John F. Kennedy Space Center, Applied Physics Laboratory, FL
Metrology, Applications and Methods with High Energy CT Systems
---N. Uhlmann, S. Kasperl, M. Karl, M. Salamon, N. Reims, G. Ermann, V. Voland, M. Schmitt, M. Boehnel, and S. Schroepfer, Fraunhofer IIS, Development Center X-ray Technology EZRT, Fürth, Germany; R. Hanke, University of Würzburg, Lehrstuhl für Röntgenmikroskopie, Würzburg, Germany

---The increase of Computed Tomography (CT) as an applicable metrology and Non Destructive Testing (NDT) method raises interest on developing the application fields to larger objects, which were rarely used in the past due to their requirements on the imaging system. Especially the classical X-ray generation techniques based on standard equipment restricted the applications of CT to typical material penetration lengths of only a few cm of steel. Even with accelerator technology that offers a suitable way to overcome these restrictions just the 2D radioscopy technique found a widespread application. Beside the production and detection of photons in the MeV range itself, the achievable image quality is limited using standard detectors due to the dominating absorption effect of Compton Scattering at high energies. Especially for CT reconstruction purposes these effects have to be considered on the development path from 2D to 3D imaging. Most High Energy CT applications are therefore based on line detectors shielding scattered radiation to a maximum with an increase in imaging quality but with time consuming large volume scan capabilities. In this contribution we present the High-Energy X-ray Imaging project at the Fraunhofer Development Centre for X-ray Technology with the characterization and the potential of the CT-system according to metrological and other application capabilities.

Strategies For Optimum Calibration of Detector Arrays In Digital Industrial Radiology
---Uwe Zscherpel, Uwe Ewert, and Carsten Bellon, BAM Federal Institute for Materials Research and Testing, Division 8.3, Unterden Eichen 87, D-12205 Berlin, Germany

---Recent investigations showed that the signal-to-noise ratio (SNR) in dependence of radiation energy and grey value is different for digital detector arrays (DDAs) and imaging plates (IPs). Whereas the image noise of IPs in the NDT dose range is determined by their structural noise, and therefore in a wide range linear dependent on the grey value, the careful calibration of DDAs allows to nearly eliminate structural noise of the detector which leads to a square root behavior of the SNR over grey value. Quantum Noise is here the dominant part. Moreover, the signal (grey value) of the IPs was measured to be independent of the radiation energy and so the SNR as well. Investigations on DDAs showed differences in comparison to IPs. The achievable SNR depends on the detector calibration procedure. So different approached for an optimum detector calibration will be discussed.
2:30 PM

**Spectral Characterization of Storage Phosphor Imaging Plates Using Synchrotron Radiation in the 8-60 keV Energy Range**
---Andreas Deresch, Mirko Jechow, and Christian Gollwitzer, Federal Institute for Materials Research and Testing, Non-Destructive Testing, Radiological Methods, Berlin, Germany

---This work presents attenuation and sensitivity measurements of two types of radiographic imaging plate (IP) using monoenergetic x-rays in the 8-60 keV range. Consistency with measurements using a continuous bremsstrahlung spectrum at higher energies is verified. The measurements are used to validate theoretical predictions made by a detector model, which has been developed for application in simulation of radiographic testing. This model can then be applied over a wider energy range and to other types of detector.

2:50 PM

**Regularization Approach for Tomosynthesis X-Ray Inspection**
---Ulf Hassler, Markus Rehak, Konstantinos Tigkos, Wolfgang Holub, Norbert Woerlein, and Ahmad Osman, Fraunhofer Entwicklungszentrum fuer Roentgentechnik, Dept. AMS, D-90762 Fuerth, Germany

---X-ray inspection is intended to be used as an escalation technique for inspection of carbon fiber reinforced plastics (CFRP) in aerospace applications, especially in case of unclear indications from ultrasonic or other NDT modalities. Due to their large dimensions, most aerospace components cannot be scanned by conventional computed tomography. In such cases, X-ray tomosynthesis may be applied, allowing a quasi-3D slice-by-slice reconstruction of the sample. However, due to the limited angle acquisition geometry, reconstruction artifacts arise, especially at surfaces parallel to the imaging plane. To regularize the tomosynthesis approach, we propose an additional prescan of the object to detect outer sample surfaces. We recommend to use contrasted markers which are temporarily attached to the sample surfaces. The depth position of the markers is derived from that prescan. As long as the sample surface remains simple, few markers are required to fit the respective object surfaces. The knowledge of the surfaces may than be used to regularize the final tomosynthesis reconstruction performed with markerless projections. Eventually, it can also serve as prior information for an ART reconstruction or to register a CAD model of the sample. The presented work is carried out within the European FP7 project QUICOM. We demonstrate the proposed approach within a simulation study of a CFRP application geometry. A practical verification of the approach is planed later in the project.
X-Ray Tomography of Large Objects With Limited Measurement Angle
---Mikko Vepsalainen, Markku Markkanen, and Pauli Sundberg, Eigenor Corporation, R&D Center, Helsinki, Finland

---X-ray computed tomography has proven a valuable tool for determining the three-dimensional inner structure of complex objects. The presence of various internal defects, together with their size, shape and other characteristics, can be reliably detected from computer generated numerical reconstructions. When radiographic projections from all directions (over 180 degrees) are available at dense angular spacing, the method of choice is usually the filtered backprojection (FBP). However, when the data is either sparse or from limited angle, use of FBP produces severe artifacts in reconstruction and cannot be reliably applied. We present an implementation of a novel algorithm based on statistical inversion theory for reconstructing a 3D volume from limited angle data. As a specific use case, we apply the method for detecting structural defects in large composite aerospace components, whose dimensions prevent acquiring measurements over the full circle. In comparison with many other tomographic reconstruction methods that can be applied to the limited angle case, such as tomosynthesis or simultaneous algebraic reconstruction technique (SART), we achieve superior depth resolution, as the algorithm allows incorporating prior information of the measured object into the reconstruction process.

Experimental Investigation of Iterative Reconstruction Techniques for High Resolution Mammography
---Valeriy Vengrinovich¹, Sergei Zolotarev¹, and Vladimir Linev², ¹Institute of Applied Physics, Minsk, Belarus; ²“Adani Ltd.”, Minsk, Belarus

---3D iterative reconstruction techniques, developed in the Institute of Applied Physics, were investigated as to the ability to provide high resolution reconstruction of 2D mammo images from limited projections and limited observation angle within available computational burden. To validate the used techniques real physical mammographic phantoms were used with different inclusions, emulating tissue calcifications of various dimensions, and different types and size of soft tissue pathology. The objectives are further development of the new iterative reconstruction algorithms to improve the three-dimensional breast images quality restored from incomplete and noisy tomosynthesis. The applied iterative methods are the algebraic reconstruction method with simultaneous iterations - SART and the iterative method of statistical reconstruction (Bayesian Image Reconstruction) BIR, which referred here as the preferable iterative methods suitable to improve the image quality. For better processing we use the graphics processor (GPU). Method of minimizing the total variation (TV) is used as a priori support for regularization of iteration process and to reduce the level of noise in the reconstructed image. All presented in this paper results are based on mammograms obtained with mammography Mammoscan. Mammoscan uses scanning technology to produce digital X-ray images. X-ray image of the breast is obtained by scanning of a narrow fan-beam X-rays. X-ray detector, built on the basis of CCD-TDI- matrix, registers projection X-ray image of the scanned area of the breast. The motion detector is synchronized with the movement of X-ray beam. The detector is based on a matrix of photosensitive elements with a scintillation coating. The matrix contains 4096 rows and 128 columns of elements of size 54 x 54 micron. Its length is 221 mm and the width is 7 mm. X-ray projection images are located within the angular range of ± 20 degrees, were collected for the 21st angle with step increments of two degrees. X-ray tube voltage was equal to 35 kVp. In order to quantify the results of the reconstruction, the ratios of the contrast/noise, profiles of the linear attenuation coefficient in the direction crossing the reconstructed heterogeneity, artifact spread function ASF were calculated. For this the value of contrast, the standard deviation of the noise (the root mean-square) RMS, and the ratio of the contrast/noise CNR were determined for selected structural elements, located in the focal plane. Preliminary results with physical phantoms show that all examined methods are capable to reconstruct structures layer-by-layer and to separate layers which images are overlapped in the Z-direction. It was found that the method of traditional shift-and-add tomosynthesis - SAA is worse than iterative methods SART and BIR in terms of suppression of the anatomical noise and image blurring in between the adjacent layers. Despite of the fact that the measured contrast/noise ratio in the presence of low contrast internal structures is higher for the method of tomosynthesis SAA than for SART and BIR methods, its effectiveness in the presence of structured background is rather poor. In our opinion the optimal results can be achieved using Bayesian iterative reconstruction BIR.
Benchmarking of the Detector Model in Radiographic Simulation
---Uwe Ewert, Andreas Deresch, Carsten Bellon, Gerd-Rüdiger Jaenisch, BAM- Federal Institute for Materials Research and Testing, Division 8.3, Unterden Eichen 87, D-12205 Berlin, Germany

---The new standard ISO 17636-2: 2013 “NDT of welds: Radiographic testing — Part 2: X- and gamma ray techniques with digital detectors” describes a complex procedure for film replacement by phosphor imaging plates and digital detector arrays. RT-modeling software should consider these detector types, X-ray film and the standard requirements for image quality. Practitioners expect in the simulated radiographs the same visibility of image quality indicators (IQI) as in the experimental exposures. The proposed benchmark test is based on the comparison of experimental and modeled radiographs. The experimental set up and the determination of the equivalent penetrameter sensitivity (EPS) as described in the procedure of ASTM E 476 is used for quantitative evaluation of the achievable contrast sensitivity for step hole IQIs as considered in Annex B of ISO 17636-2.
Detector data for Computed Radiography (CR) and film systems will be applied on basis of BAM measurements for classification of film systems by ISO 11699-1 and CR systems by ASTM E 2446. The classification of films and digital detectors is based on the measurement of the dose response function, the basic spatial resolution (SRb) of the image and the measured image noise, which depends on the detector efficiency, the quantum statistics and the detector fixed pattern noise.

X-Ray Source Considerations in Operation of Digital Detector Arrays
---Terrence Jensen and Scott Wendt, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---Digital Detector Arrays (DDA) are increasingly replacing film in radiography applications. Standards exist for characterizing the performance of these detectors, and for using them in specific inspections. We have observed that the selection of the x-ray source to use with these detectors can also have a significant influence on the results. We look at differences between standard, and micro-focus x-ray tubes, and end-window vs. side-window micro-focus tubes. We find that for best results, one must calibrate the DDA for the source settings used during an inspection. This is particularly true for variable-focus sources.---This research was funded through the Pratt & Whitney Center of Excellence at ISU.
X-Ray Scattering – Experimental Measures and Models
---Joe Gray and Scott Wendt, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---In x-ray inspections scattering can range from a minor contribution to a dominant one. The larger the scattering component of the radiation reaching a detector, the more it obscures the information content of the images. The interaction producing most scattered radiation is Compton inelastic scattering and as such is influenced by the atomic number of the illuminated material, the energy of the x-ray spectrum and the illumination volume. Distance from the scattering source can have a major effect on the proportion of scatter radiation reaching the detector. The difficulty in measuring scattering effects is that spectra are usually continuous bremsstrahlung spectra with a large range of energies in the make-up. Further the brightness of many industrial sources requires very tight collimation so as to limit saturation effects of energy dispersive detectors. Without this energy dispersive measurement of the sources of scatter, the real impact of many rules of thumb is difficult to evaluate. One thumb rule, for example, is that the scatter radiation is made up of low energy photons that are easily removed by thin lead screens. We present a set of measurements using a high purity germanium detector with very tight collimation – 100 micron OD in a 6.5 mm thick Ta collimator. Measurements from up to 320 KVp will be discussed. Due to the high photon counts observed we developed a high energy stripping function to remove the impact of scatter in the Ge detector. Finally we will present measurements compared to a semi-empirical scatter model developed to include scattering effects in x-ray inspection simulations.---This work was supported by the NSF Industry/University Cooperative Research Program of the Center for Nondestructive Evaluation at Iowa State University.

Feasibility Study for Measurement of Insulation Compaction in the Cryogenic Rocket Fuel Storage Tanks at Kennedy Space Center by Fast/Thermal Neutron Techniques
---Richard A. Livingston and Mohamad Al-Shekhly, University of Maryland, Materials Science & Engineering Department, College Park, MD 20742; Jeffrey S. Schweitzer, University of Connecticut, Physics Department, Storrs, CT; Ann M. Parsons, NASA Goddard Spaceflight Center, Astrochemistry Laboratory, Greenbelt, MD; Ellen E. Arens, John F. Kennedy Space Center, Applied Physics Laboratory, FL

---The liquid hydrogen and oxygen cryogenic storage tanks at John F. Kennedy Space Center (KSC) use expanded perlite as thermal insulation. Some of the perlite may have compacted over time, compromising the thermal performance and also the structural integrity of the tanks. Neutrons can readily penetrate through the 1.75 cm outer steel shell and through the entire 120 cm thick perlite zone. Neutrons interactions with materials produce characteristic gamma rays which are then detected. In compacted perlite the count rates in the individual peaks in the gamma ray spectrum will increase. Portable neutron generators can produce neutron simultaneous fluxes in two energy ranges: fast (14 MeV) and thermal (25 meV). Fast neutrons produce gamma rays by inelastic scattering which is sensitive to Si, Al, Fe and O. Thermal neutrons produce gamma rays by radiative capture in prompt gamma neutron activation (PGNA), which is sensitive to Si, Al, Na, K and H among others. The results of computer simulations using the software MCNP and measurements on a test article suggest that the most promising approach would be to operate the system in time-of-flight mode by pulsing the neutron generator and observing the subsequent die away curve in the PGNA signal.
Session 5
Monday, July 22, 2013

SESSION 5
SIGNAL PROCESSING
Aleksandar Dogandzic and Lalita Udpa, Co-Chairpersons
Key Ballroom 11

1:30 PM  Improved Ultrasonic SAFT Imaging of Flaws in Structures with Curved Surfaces
Sohichi Hirose, Seitaro Nishimoto, and Taizo Maruyama, Tokyo Institute of Technology, Department of Mechanical and Environmental Informatics, Meguro, Tokyo, Japan; Yasuaki Nagata, Nippon Steel & Sumitomo Metal Co., Process Research Laboratories, Futtsu, Chiba, Japan

1:50 PM  Application of 3-D FFT in Laser Ultrasonic NDT Technique
Lei Yang and I. Charles Ume, Georgia Institute of Technology, G. W. Woodruff School of Mechanical Engineering, 813 Ferst Drive N.W., Atlanta, GA 30332-0405

2:10 PM  Automated Processing of Ultrasonic B-Scans for Composite Ply Distortion Analysis
Jason Wu and Hong Tat, Boeing Research & Technology, Seattle, WA 98124

2:30 PM  3D Assisted Defect Recognition for the Ultrasonic Waveform Inspection of Titanium Components
Andrew F. Ferro and Patrick J. Howard, GE Aviation, Manufacturing Engineering, One Neumann Way, MD-Q8, Cincinnati, OH 45215-6301

2:50 PM  Improving the Reliability of Automated Non-Destructive Inspection
Nicholas Brierley, Trevor Tippetts, and Peter Cawley, Imperial College, 682 Mechanical Engineering, Exhibition Road, London, SW7 2AZ, United Kingdom

3:10 PM  Break

3:30 PM  Study on the Ultrasonic Inspection Method Using the Full Matrix Capture for the In-Service Railway Wheel
J. Peng, L. Wang, Y. Zhang, X. Gao, and C. Peng, NDT Research Center, College of Physical Science and Technology, Southwest Jiaotong University, Chengdu, China

3:50 PM  Progress on the Development of Automated Data Analysis Algorithms and Software for Ultrasonic Inspection of Composites
John C. Aldrin, Computational Tools, 7275 Chatham Avenue, Gurnee, IL 60031; Chris Coughlin and David S. Forsyth, TRI/Austin, Austin, TX; John T. Welter, Air Force Research Laboratory (AFRL/RXCA), Wright Patterson AFB, OH 45433

S. Safdarnejad, L. Udpa, and S. S. Udpa, Michigan State University, Electrical and Computer Engineering Department, East Lansing, MI 48824; J. Knopp, G. Steffes, C. Buynak, and E. Lindgren, Wright Patterson AFB, OH 45433

4:30 PM  Acoustic Emission Signal Classification for Detection of Early Stages of Cracks in Rotating Gearbox Components
Wei Chu and Dan Xiang, X-wave Innovations, Inc., Gaithersburg, MD 20878
1:30 PM

**Improved Ultrasonic SAFT Imaging of Flaws in Structures with Curved Surfaces**

---Sohichi Hirose, Seitaro Nishimoto, and Taizo Maruyama, Tokyo Institute of Technology, Department of Mechanical and Environmental Informatics, Meguro, Tokyo, Japan; Yasuaki Nagata, Nippon Steel & Sumitomo Metal Co., Process Research Laboratories, Futtsu, Chiba, Japan

---A time domain SAFT in ultrasonic nondestructive testing is a well-known signal processing technology to obtain flaw images in structures. The underlying fundamental algorithm of the SAFT coherently superimposes A-scan waveforms measured along an aperture to each element of the image. Majority of conventional SAFT implementations is, however, based on a very simplified model of the imaging system that has been used in radar applications. When those algorithms are applied in ultrasonic NDT, diffraction effects of the transducer and geometrical configurations of structures may deteriorate the quality of flaw images. In our research, a time domain SAFT for flaws in immersed structures with curved surfaces is improved in conjunction with approximate wave solutions, which were obtained in an explicit form by Schmerr (1998). In the improved SAFT, the approximate solutions are used to normalize A-scan waveforms and then the normalized waveforms are superimposed to obtain images with high contrast for flaws in structures in curved surfaces. As examples, the proposed SAFT is applied to data for a defect in an immersed round bar, obtained in simulation and experiment.

1:50 PM

**Application of 3-D FFT in Laser Ultrasonic NDT Technique**

---Lei Yang and I. Charles Ume, Georgia Institute of Technology, G.W. Woodruff School of Mechanical Engineering, 813 Ferst Drive NW, Atlanta, GA 30332-0405

---Laser ultrasonic NDT technique has drawn a lot of interests recently in various application areas. All advantages of traditional ultrasonic technique are inherited with additional non-contact and broadband generation characteristics. The principle of this NDT technique is using laser to generate broadband ultrasonics and then investigating the effect of any structural feature under inspection on the ultrasonic wave propagation. However, there are various structural features present in the sample, which will cause reflections of ultrasounds from different directions. Another important source of reflection is the sample boundaries. These reflections, usually not directly related to the structural feature under inspection, will obscure the interactions with the real structural feature of interest. In order to highlight the most informative components in the received signals, it is desirable to remove useless reflection signals in the signal processing phase. This work proposed a 3-D fast Fourier transform (FFT) based algorithm to effectively remove useless reflection components in laser ultrasonic signals. The application of this algorithm was investigated in different scenarios. The implementation of the algorithm was demonstrated by processing an imaging signal from inspecting a ball grid array (BGA) chip solder bump quality using laser ultrasonic technique. The small chip dimension led to quick and strong reflections from four boundaries in acquired signals, which were not informative in terms of inspecting the solder bump quality. The proposed method was proven to be able to effectively remove reflections from all four boundaries and make the direct incident waves standing out in the signals, which would make it easy to investigate the interaction between ultrasonic wave propagation and potential solder bump defects. The proposed method is a general signal processing method, which is not limited to the laser ultrasonic NDT technique.
**Automated Processing of Ultrasonic B-scans for Composite Ply Distortion Analysis**
---Jason Wu and Hong Tat, Boeing Research & Technology, Seattle, WA 98124

---Ply distortion in carbon fiber reinforced plastic (CFRP) composite structures can result in performance knockdowns. The performance impact of the ply distortion can depend on many factors, but two commonly desired parameters are the distortion height and width. An ultrasonic B-scan can reveal the ply distortion; however, visual interpretation of the B-scan can vary when done manually. An automated method to analyze the B-scan for the ply distortions is desirable to provide consistency of measurement. This paper will present two algorithms to process the B-scans for measuring the height and width of a composite ply distortion.

**3D Assisted Defect Recognition for the Ultrasonic Waveform Inspection of Titanium Components**
---Andrew F. Ferro and Patrick J. Howard, GE Aviation, Manufacturing Engineering, One Neumann Way, MD-Q8, Cincinnati, OH 45215-6301

---Titanium aircraft engine forgings are inspected at all material depths using the ultrasonic testing (UT) process called multizone inspection. This process creates a raster array of 1D A-scan signals that image the material's underlying characteristics, which in the case of forged titanium, result in highly variable noise. The 3D volume is analyzed as a stack of 2D depth slices that are gated into C-Scans. The intention is to accept or reject the part by examining for the presence of small anomalies in these images in terms of their signal to noise ratio (SNR). Ultrasonic testing inspectors determine that rejection decision by using specialized image software and a 2D assisted defect recognition (ADR) algorithm. This approach for calculating SNR greatly reduces inspector subjectivity compared to a manual approach, but in 2D, not all available information is used to determine a true detection. Enabling ADR to use the 3D volume for the forging inspection, an automated SNR calculation has been extended to address these issues. The 3D ADR algorithm's life cycle from design to validation will be discussed. Validation testing results have shown that 3D ADR significantly increases probability of detection compared to 2D ADR while also reducing its false positive rate.
2:50 PM

Improving the Reliability of Automated Non-Destructive Inspection
---Nicholas Brierley, Trevor Tippetts, and Peter Cawley, Imperial College, 682 Mechanical Engineering, Exhibition Road, London SW7 2AZ, United Kingdom

---In automated NDE a region of an inspected component is typically interrogated several times, be it within a single data channel, across multiple channels or over the course of repeated inspections. The systematic combination of these diverse readings is recognized to provide a means to improve the reliability of the inspection, for example by enabling noise suppression. Specifically, such data fusion makes it possible to declare regions of the component defect-free to a very high probability whilst readily identifying indications. Registration, aligning input datasets to a common coordinate system, is a critical pre-computation before meaningful data fusion takes place. A novel scheme based on a multi-objective optimization with advanced biased sampling is described. The developed data fusion framework, that is able to identify and rate possible indications in the dataset probabilistically, based on local data statistics, is outlined. Large datasets from the industrial ultrasonic testing of power station rotors and aerospace turbine disks serve as test inputs. Results thus obtained, for both the registration and subsequent fusion processing stages, are presented.

3:30 PM

Study on the Ultrasonic Inspection Method Using the Full Matrix Capture for the In Service Railway Wheel
---J. Peng, L. Wang, Y. Zhang, X. Gao, and C. Peng, NDT Research Center, College of Physical Science and Technology, Southwest Jiaotong University, Chengdu, China

---The quality of wheel is especially important for the safety of high speed railway. In this paper, a new ultrasonic array inspection method, the Full Matrix Capture (FMC) and Total Focus Method (TFM), has been studied and applied to the high speed railway wheel inspection, especially in the wheel web from the tread. Firstly, it describes the conventional UT and phased array UT to inspection the wheel rim and web, discusses the ultrasonic resolution and SNR in the wheel web as far field. Secondly, the principle of FMC and TFM algorithm is discussed and applied to railway wheel inspection. An experiment has been built with a railway wheel which has been manufactured different artificial defects in the wheel web to testing the performance of FMC and TFM. Thirdly, the inspection result, such as the reliable detection, SNR and image resolution, has been analyzed according to the different active aperture size based the TFM algorithm, comparison to the conventional phased array UT. It is demonstrated that this TFM algorithm is with good potential for the wheel inspection.
Progress on the Development of Automated Data Analysis Algorithms and Software for Ultrasonic Inspection of Composites
--- John C. Aldrin, Computational Tools, 7275 Chatham Avenue, Gurnee, IL 60031; Chris Coughlin and David S. Forsyth, TRI/Austin, Austin, TX; John T. Welter, Air Force Research Laboratory (AFRL/RXCA), Wright-Patterson AFB, OH

---The ultrasonic inspection of large composite structures requires significant manpower and production time. To address this burden and ideally increase inspection reliability, the development and implementation of automated data analysis (ADA) software are proposed. ADA software are computer algorithms combined with a graphical user interface that process NDE data, perform quantitative evaluations of material conditions, and present indications with quantitative measures to the operator. Progress is presented on the development of ADA software to make calls on anomalous indications, such as inserted materials, porosity, resin rich regions, ply drop gaps, overlaps and wrinkles, while minimizing false calls due to part features, resin bleed out, scanning artifacts or rework areas. The data analysis task follows standard procedures for analyzing signals for time-of-flight indications and backwall amplitude dropout. Adaptive gates are leveraged to compensate for ply drop and panel curvature variation. Once part boundaries and transitions are identified, feature extraction algorithms are applied to through-thickness and backwall C-scan images based on amplitude and size criteria. Shape and orientation measures are also evaluated in order to better distinguish real indication from other likely false calls. ADA processing results are presented for a variety of test specimens that include inserted materials and discontinuities produced under poor manufacturing conditions.

--- S. Safdarnejad, L. Udpa, and S. S. Udpa, Michigan State University, Electrical and Computer Engineering Department, East Lansing, MI 48824; J. Knopp, G. Steffes, C. Buynak, and E. Lindgren, WPAFB, OH 45433

---Accuracy of models utilized in statistical analysis of eddy current signals plays a significant role in the analysis performance. While many studies focus on development of accurate models for different eddy current probe signals, noise is commonly modeled using simplistic Gaussian models. Accurate noise model is as significant as the signal model in detection and classification tasks. In this paper, accurate statistical models for representation and synthesis of eddy current measurement noise are developed. Noise can be periodic noise, spatially correlated noise, and random noise generated by lift-off variations and electronic circuits. Considering eddy current signals as complex signals, random noise is modeled in the complex plane using Gaussian Mixture Models (GMM). Analysis results show that GMM along with models for other types of noise enhance parametric analysis of noisy eddy current signals. Proposed noise models also may be utilized for generation of realistic noisy data from simulated eddy current signal by injecting controlled amount of noise to the signal. The noisy signal can be useful in development of robust signal analysis tools and also for training analysts in eddy current inspection.
4:30 PM

Acoustic Emission Signal Classification for Detection of Early Stages of Cracks in Rotating Gearbox Components
---Wei Chu and Dan Xiang, X-wave Innovations, Inc., Gaithersburg, MD 20878

---Many critical, highly loaded rotating gearbox components have fast crack propagation rates. Early detection of cracks in gearbox is critical to mitigating the risk of catastrophic failure. Acoustic Emission (AE) techniques have proven to be capable of continuously monitoring the crack initiation and propagation. Due to the long distance of AE signal propagation from the AE sources to the sensors installed in the housing, the AE signal suffers from severe attenuation and noises. Accurate AE signal classification technology that is capable of extracting the true AE signal out of background noises generated by the surrounding environment of a gearbox is desired. In this paper, an innovative feature extraction and analysis based AE signal classification technology is developed to address this issue. Potential AE signals are first pulled out of the noisy background in real-time through a set of automated AE detection algorithms. Then features including count, energy, duration, amplitude, rise time, amplitude rise time ratio, etc. are extracted and analyzed. Through the comparison and correlation of features extracted from signals recorded by multiple AE sensors, respective feature thresholds are determined to distinguish noises from real AE signal. The classification results are experimentally validated through fatigue tests.
Session 6
Monday, July 22, 2013

SESSION 6
MATERIALS CHARACTERIZATION
K. Elliott Cramer, Chairperson
Key Ballroom 3

1:30 PM Quantification of Residual Stress from Photonic Signatures of Fused Silica
---K. Elliott Cramer, NASA Langley Research Center, NDE Sciences Branch, MS 231, Hampton, VA 23681; Maurice E. Hayward, College of William and Mary, Williamsburg, VA 23187

1:50 PM High Accuracy Wall Thickness Loss Monitoring
---Attila Gajdacsi and Frederic Cegla, Imperial College, Mechanical Engineering, London, United Kingdom

2:10 PM Estimation of Thermal Cracking Stress During Spraying of Thermal Barrier Coatings by Laser AE Method
---Kaita Ito, Hitoshi Kuriki, and Manabu Enoki, The University of Tokyo, Department of Materials Engineering, Tokyo, Japan; Hiroshi Araki and Seiji Kuroda, National Institute for Materials Science, High Temperature Materials Unit

2:30 PM AE Sources of a Droplet Stress Corrosion Cracking Testing in Type 304 Stainless Steel
---Mitsuharu Shiwa, Hiroyuki Masuda, and Hisashi Yamawaki, National Institute for Materials Science, Materials Reliability Unit, Tsukuba, Japan; Kaita Ito and Manabu Enoki, The University of Tokyo, Department of Materials Engineering, School of Engineering, Tokyo, Japan

2:50 PM Electrochemical Behavior of Cold-Rolled Casing and Tubing Steels in Sweet Environment

3:10 PM Break

3:30 PM Characterization of Magnesium Alloy for Oral & Maxillofacial Reconstruction Prosthesis Applications
---Shaily M. Bhola, Brajendra Mishra, and David L. Olson, Colorado School of Mines, Metallurgical & Materials Engineering, 1500 Illinois Street, Golden, CO 80401

3:50 PM Nonlinear Free Vibration of a Beam with Hysteretic Damage
---Daniel Mendelsohn, Ohio State University, Department of Mechanical and Aerospace Engineering, Columbus, OH 43210; Claudio Pecorari, Hesjakollen 111 A, Bergen, Norway

4:10 PM 2D Stochastic-Integral Models for Characterizing Random Grain Noise in Titanium Alloys
---Harold A. Sabbagh, R. Kim Murphy, and Elias H. Sabbagh, Victor Technologies, LLC, Bloomington, IN 47407-7706; Matthew Cherry, University of Dayton Research Institute, Dayton, OH 45469; Adam Pilchak, Air Force Research Laboratory (AFRL/RXCM), Wright Patterson AFB, OH 45433; John C. Aldrin, Computational Tools, Gurnee, IL 60031; Charles Annis, Statistical Engineering, Palm Beach Gardens, FL 33418

4:30 PM Characterization of Degradation Using Reflectance Spectroscopy

4:50 PM Non-Local Modeling and Simulation of Wave Propagation and Crack Growth
---Massimo Ruzzene, Georgia Institute of Technology, D. Guggenheim School of Aerospace Engineering, G. W. Woodruff School of Mechanical Engineering, Atlanta, GA; Adam Martowicz and Wieslaw J. Staszewski, AGH University of Science and Technology, Department of Robotics and Mechatronics, Krakow, 30-059, Poland

5:10 PM Characterization of Annealing in Polycrystalline Copper Using Harmonic Generation Technique
---R. S. Mini, Krishnan Balasubramaniam, and Parag Ravindran, Indian Institute of Technology Madras, Department of Mechanical Engineering, Chennai, Tamilnadu, India
1:30 PM

Quantification of Residual Stress from Photonic Signatures of Fused Silica

---K. Elliott Cramer, NASA Langley Research Center, Nondestructive Evaluation Sciences Branch, MS 231, Hampton, VA 23681; Maurice E. Hayward, College of William and Mary, Williamsburg, VA 23187

---A commercially available grey-field polariscope (GFP) instrument for photoelastic examination is used to assess impact damage inflicted upon the outer-most pane of Space Shuttle windows made from fused silica. A method and apparatus for calibration of the stress optic coefficient using four-point bending is discussed. The results are validated on known material (plexiglass) and are found to agree with literature values to within 6%. The calibration procedure is then applied to fused-silica specimens and the stress optic coefficient is determined to be $2.41 \pm 0.54 \times 10^{-12} \text{ pa}^{-1}$. Fused silica specimens containing impacts artificially made at the Hypervelocity Impact Technology Facility (HIT-F) to simulate damage typical during space flight are examined. The damage sites are cored from fused silica window carcasses and examined with the GFP. The calibrated GFP measurements of residual stress patterns surrounding the damage sites are presented.

1:50 PM

High Accuracy Wall Thickness Loss Monitoring

---Attila Gajdacsi and Frederic Cegla, Imperial College, Mechanical Engineering, London, United Kingdom

---Ultrasonic inspection of wall thickness in pipes is a standard technique applied widely in the petrochemical industry. The potential precision of repeat measurements with permanently installed ultrasonic sensors however significantly surpasses that of handheld sensors as uncertainties associated with coupling fluids and positional offsets are eliminated. With permanently installed sensors the precise evaluation of very small wall loss rates becomes feasible in a matter of hours. The improved accuracy and speed of wall loss rates measurements can be used to evaluate and develop more effective mitigation strategies. This paper presents an overview of factors causing variability in the ultrasonic measurements which are then systematically addressed and an experimental setup with the best achievable stability based on these considerations is presented. In the experimental setup galvanic corrosion is used to induce predictable and very small wall thickness loss. Furthermore, it is shown that the experimental measurements can be used to assess the effect of reduced wall loss that is produced by the injection of corrosion inhibitor. The measurements show an estimated standard deviation of less than 100 nanometers, which in turn allows us to evaluate the effect and behavior of corrosion inhibitors within just a few hours.
Estimation of Thermal Cracking Stress during Spraying of Thermal Barrier Coatings by Laser AE Method

---Kaita Ito, Hitoshi Kuriki, and Manabu Enoki, The University of Tokyo, Department of Materials Engineering, Tokyo, Tokyo, Japan; Hiroshi Araki and Seiji Kuroda, National Institute for Materials Science, High Temperature Materials Unit

---Thermal barrier coatings (TBCs) system, which is deposited by plasma spray method usually contain a number of cracks. These cracks can be classified into vertical and horizontal cracks and certainly affect the performance of TBCs. A monitoring method to detect the crack generation and propagation during plasma spraying is significantly required. In this study, a laser AE technique which enables in-situ and non-contact monitoring during spraying process was developed to study the cracking phenomena in TBC. A new scanning pattern of the plasma torch was successfully applied to introduce only vertical cracks into the top coat. More number of AE events could be obtained by applying an improved noise filtering and multiple-threshold event detection procedures. A temperature history during spraying was also measured and used for thermal stress simulation by FEM analyses. A relationship between cracking and thermal stress in the top coat was established based on the results of AE monitoring and FEM simulation.

AE Sources of a Droplet Stress Corrosion Cracking Testing in Type 304 Stainless Steel

---Mitsuharu Shiwa, Hiroyuki Masuda, and Hisashi Yamawaki, National Institute for Materials Science, Materials Reliability Unit, Tsukuba, Japan; Kaita Ito and Manabu Enoki, The University of Tokyo, Department of Materials Engineering, School of Engineering, Tokyo, Japan

---Acoustic emission and optical video microscope (VMS) monitoring was proposed to investigate the stress corrosion cracking of type 304 stainless steels of work-hardened (Type I) and solution heat treatment (Type II) specimen caused by a small magnesium-chloride droplet. The crack propagation length could measure clearly under the droplet with coved glass by VMS. The cracks velocity of Type I were 3.2-4.7 x 10^{-6} m/ks and it propagated almost continuously. That of Type II were 2.1-3.8 x 10^{-6} m/ks and it propagated similar to Type I. AE signals were generated at early stage of SCC testing, after that they were generated discontinuously in Type I. None of AE signals were detected in Type II. The detected AE signals were synchronized with small bubbling on the crack in a droplet observed by high magnification VMS. With the cross-section SEM observations, covered pitting under the crack was observed at the bubbling position. It could be concluded that the detected AE signals were mainly attributed to the bubbling from the covered pitting.
2:50 PM

Electrochemical Behavior of Cold-Rolled Casing and Tubing Steels in Sweet Environment

---This paper discusses the effect of cold rolling on the corrosion behavior of casing and tubing steels; i.e., N80 and P110. The steels are cold rolled to 10%, 20% and 30%. Synthetic formation water purged with CO2 gas was used as an electrolyte. The corrosion behavior was studied through electrochemistry techniques; linear polarization resistance (LPR) and electrochemical impedance spectroscopy (EIS) were applied to assess the corrosion rate and evolution of atomic processes and interfacial phenomena. Corrosion product morphology, structure and composition were evaluated using field emission scanning electron microscopy (FESEM) coupled with energy dispersive spectroscopy (EDS). When the amount of cold work was increased, N80 grade steel experienced an increased corrosion rate while P110 steel showed a decreased corrosion rate. EIS modeling showed a one-time constant for N80 steel and a two-time constant for P110 steel which suggest a scale formation.

3:30 PM

Characterization of Magnesium Alloy for Oral & Maxillofacial Reconstruction Prosthesis Applications
---Shaily M. Bhola, Brajendra Mishra, David L. Olson, Colorado School of Mines, Metallurgical & Materials Engineering, 1500 Illinois Street, Golden, CO 80401

---Magnesium and its alloys are potential candidates for degradable maxillofacial reconstruction implant materials. However, their limitations are localized severe corrosion, high corrosion rates and the formation of subcutaneous hydrogen pockets. The intent of this research is to evaluate the microstructure, tensile properties and corrosion behavior of the formed magnesium alloy (AZ91D) using high pressure casting as an industrial production process. The as cast material has a controlled microstructure of α-Mg phase and eutectic mixture of alternating α'-Mg and β phase and a tensile strength of 191 MPa. The corrosion rate in the alloy system is close to 0.02 mm/year which is thought to be acceptable for oral & maxillofacial reconstruction implant applications in terms of producing hydrogen gas at a rate that could be easily absorbed by surrounding human tissues without accumulating as bubbles in human body.
3:50 PM

Nonlinear Free Vibration of a Beam with Hysteretic Damage
---Daniel Mendelsohn, Ohio State University, Department of Mechanical and Aerospace Engineering, Columbus, OH 43210; Claudio Pecorari, Hesjakollen 111 A, Bergen, Norway

---We present an asymptotic analysis of nonlinear free vibration of a beam with a damage plane represented by nonlinear hysteretic bending and shear springs. The perturbation parameter is the product of the ratio of the nonlinear to linear parts of the stiffness times the amplitude of the free vibration. The loss of energy due to hysteresis and ensuing damping in time is accounted for by reducing the amplitude of vibration after each cycle by an amount such that the loss in total system energy equals the work done to traverse the hysteresis loop. A new Fourier representation for each cycle of the hysteresis and the deflection solution is used for this purpose and leads to higher harmonics, an evolving complex stiffness and corrected natural frequency. The frequency increases to its linear value from an initially reduced value. The damage parameter, frequency shift and fundamental amplitudes are presented as functions of the initial damage parameter and time (cycles of vibration). Many of the results exhibit sufficient sensitivity with respect to the damage parameter that they should be able to be used to characterize the damage.

4:10 PM

2D Stochastic-Integral Models for Characterizing Random Grain Noise in Titanium Alloys
---Harold A. Sabbagh, R. Kim Murphy, and Elias H. Sabbagh, Victor Technologies, LLC, Bloomington, IN 47407-7706; Matthew Cherry, University of Dayton Research Institute, Dayton, OH 45469; Adam Pilchak, Air Force Research Laboratory(AFRL/RXCM), Wright-Patterson AFB, OH; John C. Aldrin, Computational Tools, Gurnee, IL 60031; Charles Annis, Statistical Engineering, Palm Beach Gardens, FL 33418

---We extend our previous work, in which we applied high-dimensional model representation (HDMR) and analysis of variance (ANOVA) concepts to the characterization of a metallic surface that has undergone a shot-peening treatment to reduce residual stresses, and has, therefore, become a random conductivity field. That example was treated as a one-dimensional problem, because those were the only data available. In this study, we develop a more rigorous two-dimensional model for characterizing random, anisotropic grain noise in titanium alloys. Such a model is necessary if we are to accurately capture the ‘clumping’ of crystallites into long chains that appear during the processing of the metal into a finished product. The mathematical model starts with an application of the Karhunen-Loeve (K-L) expansion for the random Euler angles that characterize the orientation of each crystallite in the sample. The random orientation of each crystallite then defines the stochastic nature of the electrical conductivity tensor of the metal. We study two possible covariances, Gaussian and double-exponential, which are the kernel of the K-L integral equation, and find that the double-exponential appears to satisfy measurements more closely of the two. Results based on data from a Ti-7Al sample will be given, and further applications of HDMR and ANOVA will be discussed.
4:30 PM

**Characterization of Degradation Using Reflectance Spectroscopy**


---A semi-classical model of the reflectance of a complex material is modeled. Model selection techniques using this reflectance model are developed to detect molecular vibration modes measured using infrared spectroscopy. An inverse problem methodology is then used to ascertain the underlying vibrational modes associated with varying concentrations of different chemical species. These two techniques are developed to characterize the extent of material degradation through the detection of spectra associated with the chemical processes underlying the degradation process. These methods are validated using data from samples of ceramic matrix composites. The samples considered were exposed to varying amounts of thermal cycling to ascertain the effectiveness of these methods to detect degradation.

4:50 PM

**Non-Local Modeling and Simulation of Wave Propagation and Crack Growth**

---Massimo Ruzzene, Georgia Institute of Technology, D. Guggenheim School of Aerospace Engineering, GW. Woodruff School of Mechanical Engineering, Atlanta, GA; Adam Martowicz and Wieslaw J. Staszewski, AGH University of Science and Technology, Department of Robotics and Mechatronics, Krakow, 30-059 Poland

---The paper presents the results of numerical analyses carried out for 2D models of aluminum plates undergoing crack propagation. Different types of numerical analyses were performed to show the area of applicability for NDE of a non-local discrete formulation of mechanical continua. The authors’ interests dealt with: the phenomenon of clapping, higher harmonics generation, acoustic emission and Lamb wave propagation. The above cases were discussed in terms of efficient modeling and detection of spontaneously propagating crack. In-plane components of the nodal displacements were considered for the first 3 cases. In the last case a 2D model allowed to find the nodal displacement for the vertical cross-section along the direction of wave propagation and therefore assess its disturbance when introducing a notch. The results from the non-local numerical technique were discussed in terms of solution accuracy and computational effort. Apart from theoretical aspects of the presented work, the obtained results seem to be of great importance for improvement of NDE experiments in terms of sensor distribution and required accuracy.
Characterization of Annealing in Polycrystalline Copper Using Harmonic Generation Technique
---R. S. Mini, Krishnan Balasubramaniam, and Parag Ravindran, Indian Institute of Technology Madras, Department of Mechanical Engineering, Chennai, Tamilnadu, India

---Sensitivity of Non-linear Ultrasonic method to annealing treatment in pure copper is considered in this study. Recovery, recrystallization and grain growth associated with annealing has profound influence on nonlinearity parameter. Presence of precipitates and secondary phase particles, and its effect on nonlinearity parameter was considered by many authors. Influence of grain growth on nonlinearity parameter is the focus of this study. Variation of non-linearity parameter, $\beta$, with different holding durations and for different temperatures of holding was analyzed. The samples were all annealed at a temperature above its recrystallization temperature. Microstructural studies as well as hardness measurements were performed to understand the relationship between the microstructure changes caused by the annealing heat treatment process and the ultrasonic non-linear parameter. Increase in grain size with holding time, results in a decrease in nonlinearity parameter.
Session 7
Monday, July 22, 2013

SESSION 7

ICBM-BARKHAUSEN NOISE AND MICROMAGNETIC TESTING

Robert Fix, Chairperson
Key Ballroom 9

1:30 PM  The Barkhausen Effect: Modeling and Application to NDE of Stress
David C. Jiles, Iowa State University, Department of Electrical and Computer Engineering, Center for NDE, and Ames Laboratory, U. S. Department of Energy, Ames, IA 50011

2:10 PM  Residual Fatigue Life Assessment of Shot Peened 12% Martensitic Stainless Steel Components Using Barkhausen Noise Measurements for Surface Stress Monitoring
Gajanana V. Prabhu-Gaunkar, Department of Met. Eng. & Mat. Sci., Indian Institute of Technology, Powai, Mumbai 400 076

2:30 PM  Characterization of Material Deformation at the Crack Tip of a Carbon Steel Feeder Piping Using Barkhausen Noise Analysis
H. N. Singh, R. S. Sripastav, V. P. Jathar, Anil Bhandekar, J. L. Singh, and S. Anantharaman, Post Irradiation Examination Division, Bhabha Atomic Research Centre, Mumbai-400085, India

2:50 PM  Insight on the Inconsistencies of Barkhausen Signal Measurements for Radiation Damage on Nuclear Reactor Steel
Soraia Pirfo Barroso, Michael E. Fitzpatrick, Ferenc Gillemot, Marta Horváth, Ákos. Horváth, Szekely Richard, Materials Engineering, The Open University, Walton Hall, Milton Keynes, MK7 6AA, United Kingdom; Hungarian Academy of Sciences-KFKI Energy Research Institute (EKI), P. O. Box 49 H-1525, Budapest 114, Hungary

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3:30 PM  Evaluation of Magnetic Barkhausen Noise for the Measurement of Stress in HY-80 Submarine-Hull Steel Using Flux-Control
Arash A. Samimi and Lynann Clapham, Applied Magnetics Group, Department of Physics, Queen's University, Kingston, Ontario, Canada; Arash A. Samimi and Thomas W. Krause, NDE Lab, Department of Physics, Royal Military College of Canada, Kingston, Ontario, Canada

3:50 PM  New Approaches to Bi-Axial Stress and Fatigue Degradation Estimates Via Barkhausen Noise
Valeriy Vengrinovich, Valeriy Busko, Dmitriy Dmitrovich, and Dmitriy Vintov, Institute of Applied Physics, Minsk, Belarus

4:10 PM  MBN Techniques for Quantitative Determination of Stress
Yevgen Melikhov and Lukasz Mierczak, Wolfson Centre for Magnetics, Cardiff University, Cardiff, United Kingdom; David Jiles, Department of Electrical and Computer Engineering, Iowa State University, Ames, IA 50011

4:30 PM  Auto-Calibration Principles for Two-Dimensional Residual Stress Measurements by Barkhausen Noise Technique
Ualana Cikalova, Jürgen Schreiber, Susanne Hillmann, and Norbert Meyendorf, Fraunhofer IZFP Dresden, Maria-Reiche-Str. 2, 01109 Dresden, Germany

4:50 PM  Calculation of a Universal Stress-Depth Calibration Profile Using a White Noise Approximation to the Magnetic Barkhausen Noise Spectrum
Orfeas Kypris, Ikenna C. Nlebedim, and David C. Jiles*, Iowa State University, Department of Electrical and Computer Engineering, Ames, IA 50011; *U.S. Department of Energy, Ames Laboratory, Ames, IA 50011
1:30 PM

The Barkhausen Effect: Modeling and Application to NDE of Stress
---D. C. Jiles, Department of Electrical and Computer Engineering and Center for Nondestructive Evaluation and Ames Laboratory, U.S. Department of Energy, Iowa State University, Ames, IA 50011-3060

---The Barkhausen effect consists of sudden discontinuous changes in magnetization in a magnetic material that occur when the applied magnetic field is changing continuously. The development of a theoretical model has been crucial to the understanding of the complex relationships between magnetic measurements and materials condition. The Barkhausen effect model has been extended to deal with more advanced stochastic domain wall dynamics and the dependence on stress. Model equations of the magnetomechanical effect have been improved for better description of the effects of stress on magnetic properties and this has been extended to include description of the stochastic process aspects of the Barkhausen effect. In this way has it been possible to make serious advances in the interpretation of Barkhausen effect measurements and their practical application. This improved understanding has resulted in the construction of equipment for assessment of surface stress condition based on the detection and analysis of Barkhausen emissions.

2:10 PM

Residual Fatigue Life Assessment of Shot Peened 12% Martensitic Stainless Steel Components Using Barkhausen Noise Measurements for Surface Stress Monitoring
---Gajanana V. Prabhu-Gaunkar, Dept. of Met. Eng. & Mat. Sc., Indian Institute of Technology, Powai, Mumbai 400 076

---One of the key measures for preventing mechanical fatigue failures of equipment is to monitor cumulative damage due to exposure of components to fluctuating stresses and relate this to their performance. Fatigue life depends on the nucleation and growth of cracks which generally originate on a surface. Accumulation of fatigue damage gives rise to the formation of crack nuclei. In this work shot peening have been employed to study delay the onset of fatigue cracks by inducting compressive surface stresses. In this presentation we discuss the observations on the role of surface stresses on fatigue life of a 12% Cr martensitic stainless steel. Desired residual surface stress levels were achieved by controlled shot peening. Laboratory tests were carried out on flat specimens to determine fatigue life in relation to residual surface stress levels measured using X-ray diffraction and Barkhausen noise measurements. A relationship has been established between surface residual stress and fatigue life for the material. A model has been proposed and applied to examine performance of steam turbine rotor blades using Barkhausen Noise measurements for in-situ stress measurements.
Characterization of Material Deformation at the Crack Tip of a Carbon Steel Feeder Piping Using Barkhausen Noise Analysis

---H. N. Singh, R. S. Sridasav, V. P. Jathar, Anil Bhandekar, J. L. Singh, and S. Anantharaman, Post Irradiation Examination Division, Bhabha Atomic Research Centre, Mumbai-400085, India

---Various industrial process plants, including nuclear reactors, use carbon steel piping in their fluid and heat transport circuit. The feeder pipes of Pressurized Heavy Water Reactors (PHWRs) perform a vital function as they carry the primary coolant required to cool the nuclear fuel. Each feeder is configured with a combination of bends of various degrees. The bending process creates thinning at extrados and thickening around intrados resulting in an uneven residual tensile hoop stress distribution. Structural integrity of these pipings is of vital importance to the safe operation of the reactors. Stress and plastic deformation generate characteristic Magnetic Barkhausen Noise (MBN) signals in ferromagnetic materials, which can be used for assessing the condition of material. The feeder pipes removed from PHWR reactors were subjected to burst test and MBN signatures were collected along the line of crack and at both sides of the cracked region. Residual stress measurement was also carried out on a number of points along the line of cracked tip using X-ray diffraction technique which corresponded to MBN measurements. The MBN parameters were plotted using 3D imaging software and compared with the MBN values of undeformed regions. The drop in RMS value of MBN was observed around the crack tip where plastic deformation had taken place. After MBN measurements on the feeder pipe, a section of 50 mm axial length of the deformed tube from crack tip to undeformed region was cut diametrically using diamond cut off wheel. The sectioned pipe was ground and polished on both sides for evaluation of other mechanical properties using Ball Indentation Test (BIT) technique. This paper presents details of experimental set-up and measurement carried out in relationship with plastic deformation in the material. The result showed that there were good relations between plastic deformation and measured Magnetic Barkhausen Noise parameters.

Insight on the Inconsistencies of Barkhausen Signal Measurements for Radiation Damage on Nuclear Reactor Steel

---Soraia Pirfo Barroso1, Michael E. Fitzpatrick1, Ferenc Gillemot2, Marta Horváth2, Ákos Horváth2 and Szekely Richard2, 1 Materials Engineering, The Open University, Walton Hall, Milton Keynes, MK7 6AA, United Kingdom; 2 Hungarian Academy of Sciences-KFKI Energy Research Institute (EKI), P.O. Box 49 H-1525; Budapest 114, Hungary

---Irradiation affects the properties of reactor pressure vessel material. Surveillance programmes are developed to monitor the material properties changes due to irradiation. These programmes have a standard layout, e.g. material selection, specimen sampling, etc. They often rely on destructive testing, mainly for the determination of the fracture toughness. This paper focuses on the use of magnetic measurements, Barkhausen signals to determine the irradiation effects, attempting to predict fracture toughness changes on nuclear reactor structural materials and correlating these measurements to mechanical testing and microstructure. Research in electromagnetic non-destructive testing to characterise irradiation effects is not new; several research efforts have been performed dating back several decades. However, their results have not presented any conclusive result for practical application. Even so, there are contradictory results among different research groups. Since the 1990s the EKI has been investigating this topic and problem. As with the fracture toughness measurements the magnetic fingerprint of a material involves the gaining of a thorough understanding of the heats and allotropy of material. For this study, two types of nuclear reactor materials were investigated: one sensitive to irradiation effects, the JRQ IAEA’s reference material (A533B –type) and one resistant material, the 15KH2MFA WWER’s reactor pressure vessel steels. Samples of these materials were irradiated at different neutron fluences up to high fluence of 10^{23} n/m^2. The samples were carefully identified within the original heat block, i.e. forged or rolled plate. Herein, a new interpretation of the neutron effects and magnetic changes based on material properties accounting manufacturing and microstructure are presented. We show how the microstructure anisotropy on the magnetic measurements can mask the irradiation effects. A correlation among irradiation effects and the magnetic measurements is explained based on this study.
MONDAY, SESSION 7

3:30 PM

Evaluation of Magnetic Barkhausen Noise for the Measurement of Stress in HY-80 Submarine-Hull Steel Using Flux-Control

---Arash A. Samimi and Lynann Clapham, Applied Magnetics Group, Department of Physics, Queen’s University, Kingston, Ontario, Canada; Arash A. Samimi and Thomas W. Krause, NDE Lab, Department of Physics, Royal Military College of Canada, Kingston, Ontario, Canada

---Evaluation of the stress state within submarine hulls can contribute to risk assessments, which provide assurance that in-service induced stresses will not compromise submarine hull integrity under normal operating conditions. The goal of this work was to develop surface Barkhausen measurements for rapid interrogation of the hull surface with the intention of identifying areas of higher residual stress. A novel flux controller was used to optimize the magnetization capability of the Barkhausen measurement system by controlling the sinusoidal magnetic waveforms. The dependence of surface magnetic Barkhausen noise on uni-axial tensile stress in HY-80 submarine-hull steel was investigated. The sample was stressed past its yield point (~500 MPa), and Barkhausen measurements were performed under flux-controlled conditions, parallel and perpendicular to the applied stress direction. M-H hysteresis loops, extracted from Barkhausen signals, were used to qualitatively measure coercivity and permeability variations with stress. An increase in Barkhausen signal amplitude and permeability along tensile stress in elastic region followed by a sharp decrease at the onset of plastic deformation was observed. Results are discussed in light of domain wall models, with a focus on potential application of Barkhausen measurements for qualitative stress analysis of structural ferromagnetic steels.

3:50 PM

New Approaches to Bi-Axial Stress and Fatigue Degradation Estimates Via Barkhausen Noise

---Valeriy Vengrinovich, Valeriy Busko, Dmitriy Dmitrovich, and Dmitriy Vintov, Institute of Applied Physics, Minsk, Belarus

---Stress and material degradation estimates are the most promising applications of Barkhausen Noise (BN) in QNDE. Despite, real quantitative evaluation of those parameters in the conditions of materials pre-history uncertainty, are of great concern. The reasons for both tasks are quite different. In case of stress values NDE, the solution can be found by taking into consideration main properties of stress tensor components (STC): interdependence, dependence on residual plastic deformation (RPD) and micro structure (MS). Calibration procedure and reference samples are also very important. In this elaboration we propose new technique which takes into consideration mainly all pointed factors. The laboratory experiments are described to estimate the contribution of RPD and to propose the quantitative parameter, quasi-invariant to MS. Considering also the elastic interdependence of STCs we discuss the new type of calibrating grids, integrating said influencing factors. These can enable the stress measuring facilities instead of usually applied stress estimates. The technique validation in S.-Petersberg in the Institute of Metrology using their stress reference, has shown promising capability of the technique. The role of the surface in the scenario of fatigue degradation is significant. On the other hand, structural changes over fatigue process are not sufficient to cause significant changes in the indirect micro structure characteristics, usually measured in non-destructive testing: electrical conductivity, magnetic permeability, sound velocity, etc. Other material characteristics, like stress or grain microstructure, are much more influential. Therefore, until now a reliable diagnosis of fatigue in the early stages is very problematic. Significant progress was made in the study of fractal characteristics of BN [1] in conjunction with the change of meso structure of steel. Our approach is based on the measurements of the Layer-by-layer (LbL) distribution of BN parameters. LbL measurements of BN have been implemented after consecutive (step-by-step) removal of layers by electrolytic etching. The main conclusion is that, while the fatigue degradation of the metal is in progress, the BN properties of the layers at larger depths more and more differ from the BN properties on the surface. Thus, the progress in the NDE of fatigue can be achieved, if one can measure the difference between BN power on the surface and in the subsurface layer respectively. The LbL technique, described above, contributes to the problem solution.
Magnetic Barkhausen Noise (MBN) emission, caused by sudden irreversible changes in magnetization inside the material subjected to continuously varying magnetic field, depends on mechanical properties such as stress, microstructure or hardness. In this paper, the authors will review their techniques developed for quantitative determination of (1) applied and residual stress levels in near-surface regions (using the MBN peak amplitudes only) and also of (2) residual stress depth profiles (using the frequency dependence of the MBN). (1) The MBN peak amplitude shows a clear trend with changing stress where the sign of stress and the magnetostriction slope \((d\lambda/dM)\) define whether the trend is rising or descending. By relating the maximum differential anhysteretic susceptibility to the MBN peak amplitude, an analytic description of this trend was proposed, successfully explaining both the experimental results for high strength steels obtained by the authors and, more generally, experimental data for other various materials found in the literature. (2) Utilizing the fact that the frequency dependent attenuation of Barkhausen emissions exists as they propagate through a material, a quantitative technique for extracting the stress information from different depths inside the material is proposed. The practical applications of both developed techniques will also be discussed.

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Auto-Calibration Principles for Two-Dimensional Residual Stress Measurements by Barkhausen Noise Technique

---Ulana Cikalova, Jürgen Schreiber, Susanne Hillmann, and Norbert Meyendorf, Fraunhofer IZFP Dresden, Maria-Reiche-Str. 2, 01109 Dresden, Germany

---The magnetic Barkhausen Noise (BN) is well suited to evaluate the effects of mechanical stresses of ferromagnetic materials, e.g. the indirect detection of residual stress states. The most common causes for the occurrence of residual stresses are manufacturing processes, such as casting, welding, machining, forming, heat treatment, etc., consecutive repairs and design changes, and the installation or assembly and overloads during the operating life of a construction. A significant calibration effort based on a set of reference values and/or test samples is needed for these measurements, which require a great deal of time and material resources. Additionally, it is impossible to determine the stress states of different components \((\sigma_{xx} \text{ and } \sigma_{yy})\) at the surface. Therefore, a new auto-calibration method was developed to analyze two-dimensional stresses. A fixed calibration function based on defined parameters (determined experimentally) was applied. To adjust the auto-calibration function to the experimental reference values by varying functional parameters, a large number of measurement points were used. We present a method that can calculate, based on the multi-dimensional stress state at the measuring point, the stress components \(\sigma_{xx}\) and \(\sigma_{yy}\) for two perpendicular magnetization directions using the Barkhausen Noise effect.
Calculation of a Universal Stress-Depth Calibration Profile Using a White Noise Approximation to the Magnetic Barkhausen Noise Spectrum

---Orfeas Kypris, Ikenna C. Nlebedim*, and David C. Jiles*, Iowa State University, Department of Electrical and Computer Engineering, Ames, IA 50011; *U.S. Department of Energy, Ames Laboratory, Ames, IA 50011

---Magnetic Barkhausen emissions are the result of discontinuous domain wall motion in ferromagnetic specimens subjected to a changing magnetic field. Residual stress arising from dislocations and pining of the domain walls, affects the amplitude of the measured signal at the surface of a ferromagnetic component. It was previously shown that the reciprocal of the peak envelope and RMS amplitudes of the Barkhausen signal vary linearly with stress. This relationship can be used as a calibration tool in a frequency-dependent model aimed at extracting the Barkhausen signal of varying amplitudes corresponding to specific depth ranges. In a previous study, the frequency-dependent model was calibrated under conditions of uniform stress to yield three distinct linear relationships of stress versus the reciprocal of the peak Barkhausen voltage, one for each depth range. However, calculating a universal calibration curve which holds for all depth ranges and is unique to a material still remains a challenge. This can be achieved by eliminating the source of variation between the linear relationships corresponding to successive depth ranges. In this work, we quantitatively analyze the model assumptions and parameters in an attempt to identify the source of variation between the linear relationships and to achieve a universal calibration profile.
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ADJOURN
Session 8
### SESSION 8
**GUIDED WAVES II**  
Peter Cawley and Ronald A. Roberts, Co-Chairpersons  
Key Ballroom 12

<table>
<thead>
<tr>
<th>Time</th>
<th>Title</th>
<th>Authors</th>
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<tr>
<td>8:30 AM</td>
<td>Prediction of Guided Wave Scattering by Defects in Rails Using Numerical Modelling</td>
<td>Craig S. Long and Philip W. Loveday, CSIR Material Science and Manufacturing, South Africa</td>
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<td>8:50 AM</td>
<td>Design of Distributed Sparse Arrays for Lamb Wave SHM Based Upon Estimated Scattering Matrices</td>
<td>Xin Chen, Jennifer E. Michaels, and Thomas E. Michaels, Georgia Institute of Technology, School of Electrical and Computer Engineering, Atlanta, GA 30332-0250</td>
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<td>Resonant Phenomena of Circumferential Lamb Waves Generated by Eight Transducers Located Evenly on Girths and Wall Thickness Measurements</td>
<td>Hideo Nishino and Keiichi Morita, The University of Tokushima, Institute of Technology and Science, Tokushima, Japan</td>
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<td>Investigation of Guided Wave Propagation in Pipes Buried in Soil</td>
<td>Eli Leinov, Peter Cawley, and Michael J. S. Lowe, Imperial College, Mechanical Engineering, London, United Kingdom</td>
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<td>10:10 AM</td>
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<td>10:30 AM</td>
<td>Ultrasonic Guided Waves in Eccentric Pipes</td>
<td>Roshan K. Pattanayak, Krishnan Balasubramaniam, and Prabhu Rajagopal, Center for NDE, Indian Institute of Technology Madras, Chennai, Tamilnadu, India</td>
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<td>Impact Damage Detection in Composite Panels Using Guided Ultrasonic Waves</td>
<td>Bibi I. M. Murat, Pouyan Khalili, and Paul Fromme, University College London, Department of Mechanical Engineering, London, United Kingdom</td>
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<td>11:10 AM</td>
<td>Intelligent Feature Selection Techniques for Pattern Classification of Lamb Wave Signals</td>
<td>Mark Hinders and Corey Miller, College of William &amp; Mary, Department of Applied Science, Williamsburg, VA 23187-8795</td>
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<td>Guided Wave Mode Conversion Across Waveguide Transitions: A Study Using Frequency Domain Finite Element Approach</td>
<td>Vamshi Krishna Chillara and Cliff J. Lissenden, The Pennsylvania State University, University Park, PA 16802</td>
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<td>12:10 PM</td>
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Prediction of Guided Wave Scattering by Defects in Rails Using Numerical Modelling
---Craig S. Long and Philip W. Loveday, CSIR Material Science and Manufacturing, South Africa

---A guided wave based monitoring system for welded freight rail, has previously been developed. The current arrangement consists of alternating transmit and receive stations roughly 1 km apart, and is designed to reliably detect complete breaks in the rail. Current research efforts are focused on extending this system to include a pulse-echo mode of operation in order to detect, and possibly locate and characterize damage, before a complete break occurs. For monitoring and inspection applications, it is beneficial to distinguish between scattering defects which do not represent damage (such as welds) and cracks which could result in rail breaks. In the paper we investigate the complex interaction between selected incoming propagating modes and various weld and crack geometries in an attempt to relate scattering behavior to defect geometry. An efficient hybrid method is employed which models the volume containing the defect with conventional solid finite elements, while the semi-infinite incoming and outgoing waveguides are accounted for using the SAFE method. This method naturally separates propagating modes and is carried out in the frequency domain. Some effort is made to validate the model and to determine appropriate modelling parameters to ensure an efficient, reliable and accurate analysis.

Design of Distributed Sparse Arrays for Lamb Wave SHM Based upon Estimated Scattering Matrices
---Xin Chen, Jennifer E. Michaels, and Thomas E. Michaels, Georgia Institute of Technology, School of Electrical and Computer Engineering, Atlanta, GA 30332-0250

---A common practice in guided wave structural health monitoring is collecting measurements from a transducer array using the pitch-catch method. Among different array configurations, the spatially-distributed array provides a cost-effective solution for rapid interrogation of large, plate-like structures. Several guided wave imaging techniques have been proposed and demonstrated for damage detection and localization. However, the performance of these imaging methods can be compromised by a mismatch between a particular transducer array geometry and the scattering characteristics of a defect of interest. This study proposes a method, which is based upon experimentally estimating scattering matrices, to quantify the ability of a specific array geometry to interrogate a scatterer. A Monte Carlo simulation is then performed to vary the transducer locations to find the array geometry that is best matched to a specific directional scatterer. The efficacy of the proposed method is evaluated experimentally by introducing notches of different lengths, orientations and locations on an aluminum plate specimen that is instrumented with a spatially-distributed array.
9:10 AM

Temperature Dependent E and G Measurement of Materials Using Ultrasonic Guided Waves
---Suresh Periyannan and Krishnan Balasubramaniam, Indian Institute of Technology Madras, Mechanical Engineering, Chennai, Tamil Nadu, India

---This is the novel technique for measuring the mechanical properties of elastic isotropic material, as a function of temperature, using ultrasonic wave modes. These techniques can be used for measure the Young’s modulus (E) and Shear Modulus (G) of material. Here, the L (0, 1) wave mode is used for measuring E and T (0, 1) mode for G. The scope of measurement is made from room temperature to maximum utility temperature of material. In this work, the material is required in the form of a waveguide with an ultrasonic guided wave generator at one end and an embodiment (such as a notch or a bend) at the other end for obtaining reflected signals. The transducer is kept at room temperature while the end (along with the embodiment) is kept inside a heating device such as a temperature controlled furnace. The time of flight difference (δTOF), as a function of temperature, between the guided wave reflections from the embodiment and the end of the waveguide, is used to measure the material properties. Several materials were tested and the data was compared with values obtained from literature. For instance, Inconel -690 waveguide with embodiment of a ‘L’ bend was evaluated from 45°C to 1100°C at a frequency of 0.5 MHz L (0, 1) and T (0, 1) modes. The comparison between the literature values and the measured values were found to be in agreement with a regression correlation factor R=0.999 or better, for both E and G measurements. Advantages of the method over conventional methods of such measurements will also be discussed.

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9:30 AM

Resonant Phenomena of Circumferential Lamb Waves Generated by Eight Transducers Located Evenly on Girths and Wall Thickness Measurements
---Hideo Nishino and Keiichi Morita, The University of Tokushima, Institute of Technology and Science, Tokushima, Japan

---Piezoelectric ring-shaped sensor (PeRS) as well as magnetostrictive sensor (MsS) have been widely used for guided wave inspections of piping. The PeRS is normally consisted of plural transducer elements located along girth at regular interval. Due to the structure, in addition to the axially propagating torsional mode guided waves, circumferential (C-) Lamb waves have also been generated as spurious waves at the same time. Especially in the resonant conditions determined by both the specific frequencies and locations of sensor elements, the C-Lamb waves are dominantly and preferentially generated as spurious signals that distort axially propagating guided waves. In this paper, these troublesome phenomena are used not for the axially propagating guided waves but much usefully for the measurements of wall thicknesses. The purpose of the paper is to present a newly developed method for measuring a wall thickness using resonant phenomena of the C-Lamb waves generated by the PeRS. The resonant phenomena were theoretically and experimentally investigated. The results show that the experimental estimations of wall thicknesses agreed excellently with the theoretical ones.
9:50 AM

Investigation of Guided Waves Propagation in Pipes Buried in Soil
---Eli Leinov, Peter Cawley, and Michael J. S. Lowe, Imperial College, Mechanical Engineering, London, United Kingdom

Long-range ultrasonic guided waves inspection is a well established method for the detection of corrosion defects in pipelines, and is currently used routinely in a variety of industries, e.g., petrochemical and energy. The majority of testing is done in above-ground pipelines when long propagation distances may be achieved. However, when applied to pipes buried in soil, the test range tends to be significantly compromised because of attenuation of the waves caused by energy radiating into the soil. Moreover, the variability of soil conditions dictates different attenuation characteristics, which in-turn results in different, unpredictable, test ranges. We investigate experimentally the propagation and attenuation characteristics of guided waves in pipes buried in soil using a well characterized full scale experimental rig. The apparatus consists of an 8”-diameter, 6-meters long steel pipe embedded over 3 meters in a rectangular container filled with fine sand. Guided waves are excited in the pipe and recorded using a transducer ring (Guided Ultrasonics Ltd). Acoustical properties of the sand are measured independently and used to make model predictions of wave behavior in the buried pipe. We present systematic measurements of the guided waves under a range of conditions, including loose, compacted and water saturated sand.

10:30 AM

Ultrasonic Guided Waves in Eccentric Pipes
---Roshan K. Pattanayak, Krishnan Balasubramaniam and Prabhu Rajagopal, Center for NDE, Indian Institute of Technology Madras, Chennai, T.N., India

Seamless tubes are today used across many industries. Eccentricity in the pipe cross section is an important problem in the seamless tube manufacturing process. Here we seek to study the feasibility of using ultrasonic guided waves for fast inspection of tubes and pipes for possible eccentricity. Guided waves are well established in the long range inspection of structures such as pipes and plates. However studies of guided waves in structures with more complex cross sections are limited and analytical solutions are difficult to obtain. Recent developments have made the Semi Analytical Finite Element (SAFE) method widely accessible for researchers to study guided wave properties in complex structures. The advantage of this method is that only the cross-section of a structure is modelled, while the wavefield in the axial direction is assumed to be harmonic. In this paper we use the SAFE method to study guided wave characteristics in eccentric pipes. Without loss of generality, the material properties of mild steel are assumed for the pipe material. The outer (OD) and inner (ID) diameters of the pipes are taken as 60 mm and 50 mm respectively, while the center-distance between the OD and ID circle is varied from 0 (ideal pipe) to 3 mm. Eccentricity is assumed to be uniform in the axial direction. The effect of eccentricity on the modal structures and velocities of lower order guided wave modes are then studied. Validation studies are also presented. The results show that even small eccentricity in the pipe can strongly affect guided wave mode structures and velocities. The potential of guided waves to inspect the seamless tube manufacturing process is discussed.
Impact Damage Detection in Composite Panels Using Guided Ultrasonic Waves
---Bibi I. M. Murat, Pouyan Khalili, and Paul Fromme, University College London, Department of Mechanical Engineering, London, United Kingdom

---Composite materials such as carbon fiber reinforced panels offer many advantages for aerospace applications, e.g., good strength to weight ratio. However, impact during the operation and servicing of the aircraft can lead to barely visible and difficult to detect damage. Depending on the severity of the impact, fiber breakage or delaminations can be induced which reduce the functionality of the structure. Efficient structural health monitoring of such plate-like components can be achieved using guided ultrasonic waves propagating along the structure and covering critical areas. However, the guided wave propagation in such anisotropic and inhomogeneous materials needs to be understood from theory and verified experimentally to achieve sufficient coverage of the structure. Using noncontact laser interferometer measurements the guided wave propagation in carbon fiber reinforced panels was investigated experimentally. Good agreement with calculations using a full three-dimensional Finite Element (FE) model was achieved. Impact damage was induced in the composite panels and the guided wave scattering at the damage measured and quantified. Good agreement with predictions was found and barely visible impact damage in composite panels detected.

Intelligent Feature Selection Techniques for Pattern Classification of Lamb Wave Signals
---Mark Hinders and Corey Miller, College of William & Mary, Department of Applied Science, Williamsburg, VA 23187-8795

---Lamb wave interaction with flaws is a complex, three-dimensional phenomenon, which often frustrates signal interpretation schemes based on mode arrival time shifts predicted by dispersion curves. As the flaw severity increases, scattering and mode conversion effects will often dominate the time-domain signals, obscuring available information about flaws because multiple modes may arrive on top of each other. Even for idealized flaw geometries the scattering and mode conversion behavior of Lamb waves is very complex. Here, multi-mode Lamb waves in a metal plate are propagated across a rectangular flat-bottom hole in a sequence of pitch-catch measurements corresponding to the double crosshole tomography geometry. The flaw is sequentially deepened, with the Lamb wave measurements repeated at each flaw depth. Lamb wave tomography reconstructions are used to identify which waveforms have interacted with the flaw and thereby carry information about its depth. Multiple features are extracted from each of the Lamb wave signals using wavelets, which are then fed to statistical pattern classification algorithms that identify flaw severity. In order to achieve the highest classification accuracy, an optimal feature space is required but it’s never known a priori which features are going to be best. For structural health monitoring we make use of the fact that physical flaws, such as corrosion, will only increase over time. This allows us to identify feature vectors which are topologically well-behaved by requiring that sequential classes "line up" in feature vector space. An intelligent feature selection routine is illustrated that identifies favorable class distributions in multi-dimensional feature spaces using computational homology theory. Betti numbers and formal classification accuracies are calculated for each feature space subset to establish a correlation between the topology of the class distribution and the corresponding classification accuracy.
High Temperature Ultrasonic Transducers for Generation of Guided Waves for Non-Destructive Evaluation of Pipes
---K. Sinding, C. Searfass, B. R. Tittmann, Penn State University, 212 Earth Engineering Science Building, 309E, University Park, PA 16803

---Applications for non-destructive evaluation and structural health monitoring of steam generators requires ultrasonic transducers capable of withstanding the high of the pipes and heat exchangers. These applications required a strong coupling of the transducer to the heat exchanger’s complex geometry at the elevated temperatures. Our objective is to use spray-on piezoelectrics for depositing comb transducers onto the curved surfaces. Our approach is to adapt the sol-gel process to allow for deposition onto curved surfaces. We show results for composite transducers such as lead zirconate titanate/ bismuth titanate and bismuth titanate/ lithium niobate. The comb transducers were prepared by precision laser spallation. We have shown the ability of these materials to produce second harmonic waves in rods.

Guided Wave Mode Conversion Across Waveguide Transitions: A Study Using Frequency Domain Finite Element Approach
---Vamshi Krishna Chililara and Cliff J. Lissenden, The Pennsylvania State University, University Park, PA 16802

---Ultrasonic NDE has been a valuable tool for structural inspection. Guided waves are a superior choice with regard to the inspection of structures like aircraft wings, rails, pipes etc. but appropriate mode selection is a key to identifying specific kinds of defects. Several approaches including Semi-analytical Finite element approach (SAFE) exist for obtaining dispersion curves and wave structures for waveguides which are homogeneous in the wave propagation direction. In general, the structures in real-life have transitions which are either geometric in nature or arise from using more than one material in the structure. Examples include skin-stringer joints, welds, and rivets. This renders the waveguides inhomogeneous and hence there is a need to incorporate the effects of these inhomogeneities in the process of guided wave mode selection. Conventional finite element approaches can handle these inhomogeneities by computing the structural response in the time domain. However, this work attempts to use a frequency domain finite element approach for characterizing inhomogeneous waveguides. Specific examples of Rayleigh-Lamb and Shear-Horizontal mode excitations are presented to validate the approach. Then a specific case of an inhomogeneous wave guide i.e., a waveguide transition is considered to demonstrate the applicability of the approach for guided wave mode selection.
SESSION 9
JOINT ICNDT/QNDE WORKSHOP ON BEST PRACTICE IN NDT/NDT EDUCATION
Mike Farley and Manfred Johannes, Co-Chairpersons
Key Ballroom 10

8:30 AM An Integrated Education Program for NDT Professionals
---Matthew E. Gallagher and David J. Gilbert, The British Institute of NDT, Newton Building, St. George’s Avenue, Northampton, United Kingdom; Philip Picton, The University of Northampton, United Kingdom

8:50 AM The Engineering Doctorate in NDE
---Peter Cawley, 460B Mechanical Engineering, Imperial College, Exhibition Road, London, SW7 2AZ, United Kingdom

9:10 AM NDE Education in the USA
---B. Boro Djordjevic, Materials and Sensors Technologies, Inc., 798 Cromwell Park Drive, Suite C, Glen Burnie, MD 21061

9:30 AM NDE Education – Requirements, Status, and Gaps Indian Scenario
---B. Venkatraman, Indira Gandhi Centre for Atomic Research, Kalpakkam, India

9:50 AM Double Degree Master Studies in Non-Destructive Testing
---Christian Boller, Fraunhofer Institute of Nondestructive Testing (IZFP), Dresden and Saarbrucken, Germany (Presented by Bernd Koehler)

10:10 AM Break

10:30 AM The Need for “Non-Destructive Testing (NDT) for Engineers” as a Stepping Stone to Post-Graduate Studies in NDT in South Africa
---Manfred Johannes, SAINT, 93 Uitspanweg, Die Wilgers, Tshwane, 0041, South Africa

10:50 AM Iowa State University’s Undergraduate Minor and Online Graduate Certificate in NDE
---Nicola Bowler, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

12:10 PM Lunch
8:30 AM

An Integrated Education Program for NDT Professionals
---Matthew E. Gallagher and David J. Gilbert,
The British Institute of NDT, Newton Building, St George's Avenue, Northampton, United Kingdom; Philip Picton, The University of Northampton, United Kingdom

---The British Institute for NDT has been developing its integrated program for over six years. This presentation reports on its current status and outlines planned further development. Key features of the program are the collaboration between the Institute and the University of Northampton and the links made between work-based learning, vocational certification, academic awards and professional engineer registration. The aim of the program is the development of flexible pathways for individuals working, or embarking on a career, in NDT, Condition Monitoring and related inspection and test technologies.

8:50 AM

The Engineering Doctorate in NDE
---Peter Cawley, 460B Mechanical Engineering, Imperial College, Exhibition Road, London SW7 2AZ, United Kingdom

---The Engineering Doctorate (EngD) degree was conceived in the UK as a means of improving the quality of engineers in industry and providing a doctoral training route that emphasised industrial application alongside academic excellence. The EngD in NDE was launched by the UK Research Centre in NDE in 2004; in general the students spend the first year at university with the bulk of the rest of the four year course being spent at their sponsoring company. They undertake 16 one week courses over the four years, including compulsory modules covering all the major NDE techniques, the rest of the time being devoted to their main research topic. They are examined by thesis and oral exam, as for a UK PhD. The award of the degree requires novel findings, also as for a PhD, and this can be in application as well as new scientific results. The EngD approach provides a broad experience and thorough NDE grounding for the students, and has provided our industry with a significant number of high quality recruits, as well as an effective route for technology transfer. To date 48 students have enrolled, 16 have already completed and are working in industry with 28 on track to complete. Of the four who opted to leave before completion, all were employed by our industry sector or suppliers. This paper will discuss the origins of the degree, its relationship with RCNDE and give examples of projects and their findings.
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<th>Time</th>
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<tr>
<td>9:10 AM</td>
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<td>B. Boro Djordjevic</td>
<td>Materials and Sensors Technologies, Inc., Suite C, Glen Burnie, MD 21061</td>
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<td></td>
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<td></td>
<td>---Non-Destructive Testing/Evaluation (NDT/NDE) is commonly used in manufacturing, services, forensic engineering, mechanical engineering, electrical engineering, civil engineering, systems engineering, aeronautical engineering, art and in medicine. Industrial NDT, NDI or NDE is an interdisciplinary engineering skill that lacks full engineering status and a coordinated and structured educational path. In USA, as well as in the world, NDT has wide technical recognition, extensive service support but no recognized educational home in academia or in engineering curriculum. The NDT know how and personnel skills are supported via national professional societies/associations, (such as ASNT) but lack deep support from the professional engineering community. NDT technology and processes are not adequately covered during the engineering design and are poorly supported in the system engineering process. In perspective, we have community college and advanced degrees in NDE but no coordinated and broad-based college level programs. This paper will review the NDT education mechanisms in the USA and comment on the critical NDT needs in the manufacturing and maintenance operations.</td>
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<td>NDE Education – Requirements, Status and Gaps Indian Scenario</td>
<td>B. Venkatraman</td>
<td>Indira Gandhi Centre for Atomic Research, Kalpakkam, India</td>
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**Double Degree Master Studies in Non-Destructive Testing**
---Christian Boller, Fraunhofer Institute of Nondestructive Testing (IZFP), Dresden and Saarbrücken, Germany (Presented by Bernd Koehler)

---Nondestructive testing is a discipline increasingly required in complementation to subjects such as engineering, physics, chemistry and even computer science or applied mathematics, providing those subjects an enhanced scope of applicability. Fraunhofer IZFP with six university professors teaching at various universities in Germany and even in the USA, numerous scientific staff lecturing at those universities, a professor teaching at a university of applied sciences and a further number of lecturers teaching at different academies and educational institutions provides a huge potential for high level NDT academic education. Based on a 60 ECTS distant learning NDT master course taught in German Fraunhofer IZFP started academic teaching in April 2011 through the academic provision and organization of Dresden International University (DIU), a privatized spin-off of Dresden Technical University. An increasing request from universities throughout Europe as well as overseas led to the idea to establish a 120 ECTS double degree on-site NDT master course taught in English, where the sending university will provide a degree as well as DIU. The 120 ECTS NDT master course due to start in 2014 will allow the student to meet the requirements set at the sending home university as well as at DIU. The course has currently been accredited by the Saxonian Ministry of Science and Art for DIU and by the Chinese Ministry of Education for the Southwest Jiaotong Technical University in Chengdu/China. This can be extended to virtually any university and accreditation authority that is able to meet the requirements for the course set. The curriculum has been established in a sandwich course such that the student will be taught at his/her sending university as well as at DIU. The course lasts for 2 to 2.5 years depending on the requirements of the sending university and is fully taught in English. Table 1 shows the curriculum for the 4 terms option (the 5 terms option applies when the master thesis is requested to last for 1 year). Term 1 will take place at the sending university’s location while term 2 is run at Fraunhofer IZFP in Dresden and term 3 at Fraunhofer IZFP in Dresden and/or Saarbrücken. Term 4 and a possible term 5 is again run at the sending university’s location. Students will also attend the basic (BC) course of the German NDT Society DGZfP and will receive a certificate. If conditions allow the students may also stay with Fraunhofer IZFP for their master thesis. The course will be split into the following types of modules taught:

- **Basic Modules (BM):** taught in term 1 consisting of lectures and exercises; success of modules is proven by examination;
- **Specific Modules (SM):** taught in term 2 consisting of lecturing and laboratory sessions, with a "clinic" provided for exam preparation. Exams will be preferably provided the week after the block course;
- **Specific Actions (SA):** taught in term 3 and assessed through the German Society for Non-Destructive Testing (DGZfP) (BC-course) and supervised by Fraunhofer IZFP (research internship);
- **Master Thesis (MT):** supervised at the sending university or at Fraunhofer IZFP.

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The Need for “Non-Destructive Testing (NDT) for Engineers” as a Stepping Stone to Post-Graduate Studies in NDT in South Africa
---Manfred Johannes, SAINT, 93 Uitspanweg, Die Wilgers, Tshwane, 0041, South Africa

---Non-destructive testing is performed to codes and standards, which govern the application and the frequency of use the NDT methods. At present virtually all these codes and standards are compiled to govern manufacturing processes and construction activities. The only standard governing in-service inspection (ISI) is ASME XI, which governs the ISI on Nuclear installations. The codes just give general directions, but do not specifically address failure mechanisms such as fatigue crack formation and growth and the difficulties associated with detecting these failure mechanisms which manifest themselves and propagate in-service. Because the engineers have not been trained in NDT, they are not equipped to tackle these problems and hence they make use of the third party inspection companies to draw up inspection scopes and control the inspection of the plant. In order to equip engineers to understand the intricacies and basics of NDT, continuous development course for engineers in NDT have been instituted, with the aim of making the engineer aware of what he is lacking. Following on these courses, specific NDT courses for engineers will be offered. These courses will then allow the successful candidates to complete an MSc-degree in NDT, which will mainly be done by research work. It is the aim of this paper to outline the structure of this system and to receive comments and suggestions from representatives who have been through this process of equipping the engineering fraternity with NDT knowledge and capabilities.

Iowa State University’s Undergraduate Minor and Online Graduate Certificate in NDE
---Nicola Bowler, Iowa State University, Center for Nondestructive Evaluation, 1915 Scholl Road, Ames, IA 50011

---Nondestructive evaluation is a ‘niche’ subject that is not yet offered as an undergraduate or graduate major in the United States. The undergraduate minor in NDE offered within the College of Engineering at Iowa State University (ISU) provides a unique opportunity for undergraduate aspiring engineers to obtain a qualification in the multi-disciplinary subject of NDE. The minor requires 16 credits of coursework within which a core course and laboratory in NDE are compulsory. The industrial sponsors of Iowa State’s Center for Nondestructive Evaluation, and others, strongly support the NDE minor and actively recruit students from this pool. Since 2007 the program has graduated 10 students per year and enrollment is rising. In 2011, ISU’s College of Engineering established an online graduate certificate in NDE, accessible not only to campus-based students but also to practicing engineers via the web. The certificate teaches the fundamentals of three major NDE techniques; eddy-current, ultrasonic and X-ray methods. This paper describes the structure of these programs and plans for development of an online, coursework-only, Master of Engineering in NDE and thesis-based Master of Science and PhD degrees in NDE.
Session 10
SESSION 10
NDE FOR CIVIL ENGINEERING MATERIALS
John S. Popovics and Dan J. Naus, Co-Chairpersons
Key Ballroom 3

8:30 AM State-of-the-Art of Non-Destructive Testing Methods and Technologies for Nuclear Power Plant Safety-Related Concrete Structures
---Herbert Wiggenhauser, BAM-Federal Institute for Materials Research and Testing, Berlin, Germany; Dan J. Naus, Oak Ridge National Laboratory, One Bethel Valley Road, Oak Ridge, TN 37831-6069

9:10 AM Characterization of Flaws in Structural Steel Members Using Diffuse Wave Fields
---Thomas Schumacher and Andrew Chen, University of Delaware, Civil and Environmental Engineering, Newark, DE 19711

---James Bittner and Didem Ozevin, University of Illinois at Chicago, Civil and Materials Engineering, Chicago, IL 60607

9:50 AM Corrosion Assessment of Embedded Steel in Concrete from Current Practice to Enhanced Techniques
---Yann Le-Pape, EDF Inc., Chevy Chase, MD; David B. Scott, Electric Power Research Institute, Nondestructive Evaluation Nuclear, Charlotte, NC; Amir Pourasae, Clemson University, Glenn Department of Civil Engineering, Clemson, SC; M. T. Ghasr and Reza Zoughi, Missouri University of Science and Technology, Elec. and Comp. Engineering Department, Rolla, MO 65409

10:10 AM Break

10:30 AM Comparison of Temporal Characteristics of Microwave Dielectric Properties of Mortar With and Without Alkali-Silica (ASR) Gel at R-, S-, and X-Bands
---Ashkan Hashemi, Kristen M. Donnell, and Reza Zoughi, Applied Microwave Nondestructive Testing Laboratory (amntl), Electrical and Computer Engineering Department, Missouri University of Science and Technology, Rolla, MO 65409; Kimberly E. Kurtis, School of Civil and Environmental Engineering, Georgia Institute of Technology, 788 Atlantic Drive, Atlanta, GA 30332-0355

10:50 AM Corrosion Detection in Concrete Rebars Using a Spectroscopic Technique
---Edward J. Garboczi, National Institute of Standards and Technology, Materials and Structural Systems, 100 Bureau Drive, Stop 861, Gaithersburg, MD 20899

11:10 AM Measurement and Simulation of Millimeter Wave Scattering Cross-Sections from Steel-Reinforced Concrete
---Ahmed M. Hassan, Nicos Martys, Edward Garboczi, Robert McMichael, Mark Stiles, David Plusquellic, Paul Stutzman, Shuangzhen Wang, and Virgil Provenzano, National Institute of Standards and Technology, Gaithersburg, MD 20899; Jack Surek, David Novotny, Jason Coder, Mike Janezic, and Sung Kim, National Institute of Standards and Technology, Boulder, CO 80305

11:30 AM Multi-Mode Dynamic Crack Measurement in Concrete Structures Using Digital Image Correlation
---Michael J. McGinnis, University of Texas at Tyler, Department of Civil Engineering, Tyler, TX; Wesley J. Keller and Stephen Pessiki, Lehigh University, Department of Civil and Environmental Engineering, Bethlehem, PA 18064

11:50 AM Eddy Current Inspection of Corrosion Defects for Concrete Embedded Steel Members
---George V. Minesawa and Eiichi Sasaki, Tokyo Institute of Technology, Department of Civil and Environmental Engineering, 2-12-1 M1-23 Ookayama, Meguro-ku, Tokyo, Japan

12:10 PM Lunch
8:30 AM

State-of-the-Art of Non-Destructive Testing Methods and Technologies for Nuclear Power Plant Safety-Related Concrete Structures

---A state-of-the-art-report was compiled for Oak Ridge National Laboratory (ORNL). This report is summarizing available data and information on non-destructive testing methods and technologies for application to nuclear power plant safety-related concrete structures. The inspection of nuclear power plant concrete structures presents challenges different from conventional civil engineering structures. Wall thicknesses can be in excess of one meter and the structures often have increased steel reinforcement density with more complex detailing. The accessibility for any testing method may be limited due to the presence of liners and other components and there can be a number of penetrations or cast-in-place items present. The objective of the report is to present the state-of-the-art of non-destructive testing methods and technologies for the inspection of thick, heavily-reinforced nuclear power plant concrete cross-sections with particular respect to: locating steel reinforcement and identification of its cover depth; locating tendon ducts and identification of the condition of the grout materials; detection of cracking, voids, delamination, and honeycombing in concrete structures; detection of inclusions of different materials or voids adjacent to the concrete side of the containment liner; methods capable of identification of corrosion occurrence on the concrete side of the containment liner. As part of the assessment the various methods were described and categorized. Recommendations and resource requirements to investigate methods or technologies having high potential relative to inspection and assessment were provided.

9:10 AM

Characterization of Flaws in Structural Steel Members Using Diffuse Wave Fields
---Thomas Schumacher and Andrew Chen, University of Delaware, Civil and Environmental Engineering, Newark, DE 19711

---Ultrasonic stress waves are commonly used to characterize flaws in materials. Recently, not only the early coherent portions of a wave but also the later diffuse portions have been used by researchers to study flaws and characterize the state of a material and its properties. The later portions are also referred to as coda waves. The idea is that later portions of a signal contain additional useful information from a material since they have interacted with the material for a longer period of time. The authors of this paper are currently conducting ultrasonic experiments on structural steel plates employing novel broad-band point-contact acoustic emission sensors. The sensors were mounted at several locations along the width of the specimen where one sensor was used as a transmitter and two as receivers. After taking a reference measurement, a groove was cut into the steel specimen and another measurement taken. This was repeated several times. Cross-correlation and magnitude squared coherence were used to compare the signals. In this paper we introduce the new sensor, the experimental setup, and the signal processing techniques. Finally, we will present and discuss the experimental results.
9:30 AM

**Stress State Identification of the Gusset Plates Using Nonlinear Ultrasonic Rayleigh Waves**
---James Bittner and Didem Ozevin, University of Illinois at Chicago, Civil and Materials Engineering, Chicago, IL 60607

---The identification of stress states within existing structures is critical to determine excessive loading, potential to reach yielding state and the extension of structural aging. In this study, nonlinear ultrasonic Rayleigh waves are utilized to measure the stress state of gusset plates at fracture critical truss bridges. A small amplitude ultrasonic perturbation is introduced to the structure at 1MHz, and the propagating waves are measured using wedged transducers. As the change in ultrasonic properties with stress is small, the coupling correction method is developed and the distance between receiver and transmitter is fixed with a hand-held holder design. Additionally, the reference ultrasonic frequency (stress-free condition) may change depending on the structural material and the paint properties; an approach to use the reference point from low stressed area of gusset plate is utilized. The calibration curve between ultrasonic peak frequency and stress is developed for biaxial loading condition to obtain the coefficients K1 and K2 for parallel and perpendicular stresses. The developed methodology is applied to two gusset plates at two different truss bridges. The comparison of the experimental data with the numerical simulations shows that the measured error in stress values are within 15% considering the overall stress range.

9:50 AM

**Corrosion Assessment of Embedded Steel in Concrete From Current Practice to Enhanced Techniques**
---Yann Le-Pape, EDF Inc., Chevy Chase, MD; David B. Scott, Electric Power Research Institute, Nondestructive Evaluation Nuclear, Charlotte, NC; Amir Poursaeed, Clemson University, Glenn Department of Civil Engineering, Clemson, SC; M. T. Ghasr and Reza Zoughi, Electrical and Computer Engineering Department, Rolla, MO

---Maintenance and repair of corrosion affects a wide variety of reinforced concrete structures and industries, namely infrastructure and energy. It incurs annual costs of billions of dollars. Several inspection methods are regularly used for investigation of corrosion of reinforcing or prestressed steel each with varying levels of success, advantages, and disadvantages. A portion of these techniques were utilized as part of a state-of-the-art case study performed on four prestressed concrete beams exhibiting heavy corrosion. The investigation included visual inspection of the beams using an optical microscope, concrete cover measurements, and a reliability study of existing electrochemical techniques – half-cell potential, surface resistivity, galvanostatic pulse, and destructive testing of three of the beams. The fourth beam was utilized to perform enhanced electrochemical techniques – electrochemical impedance spectroscopy, potentiodynamic cyclic polarization, and potentiostatic linear polarization resistance. Wideband microwave synthetic aperture focusing technique resulting in 3D high-resolution images (i.e., holography) was also used. Additionally, this technique was applied to reinforced concrete mockups with varying levels of steel corrosion. Currently, the results indicate that the “enhanced” electrochemical techniques provide more reliable results compared to traditional techniques. The results also show that microwave holography, as a true nondestructive technique, provides images that potentially indicate levels of corrosion.
10:30 AM

**Comparison of Temporal Characteristics of Microwave Dielectric Properties of Mortar With and Without Alkali-Silica (ASR) Gel at R-, S- and X-Bands**

---Ashkan Hashemi, Kristen M. Donnell, and Reza Zoughi, Applied Microwave Nondestructive Testing Laboratory (amntl), Electrical and Computer Engineering Department, Missouri University of Science and Technology (S&T), Rolla, MO 65409; Kimberly E. Kurtis, School of Civil and Environmental Engineering, Georgia Institute of Technology, 788 Atlantic Drive, Atlanta, GA 30332-0355

---Presence of alkali-silica reaction (ASR) gel in concrete structures, as a result of using reactive aggregates in the presence of sufficient amounts of water and alkali concentrations, causes significant deterioration over time and adversely affects their long-term performance. Hence, there is significant interest in detecting ASR gel and evaluating its temporal behavior. Microwave techniques are well-suited in evaluating ASR due to the inherent sensitivity of microwave signals to the presence of free water and bound water as a result of ASR gel production. Microwave techniques have shown great potential for evaluating critical materials properties of cement-based materials. Recently, microwave dielectric properties of two sets of mortar samples containing reactive and non-reactive aggregates were investigated, during 84 days after they were cast, at S-band (2.6-3.95 GHz) and X-band (8.2-12.4 GHz). Lower frequencies may also be sensitive to the presence of bound water present in the ASR gel. Consequently, a new set of measurements was conducted, using the same constituent materials, at R-band (1.7-2.6 GHz). In this paper, the temporal dielectric properties of these mortar samples at R-band are compared to those measured at S-band and X-band in order to examine sensitivity of each frequency band to the presence of ASR gel.

10:50 AM

**Corrosion Detection in Concrete Rebars Using a Spectroscopic Technique**

---Edward J. Garboczi, NIST, Materials and Structural Systems, 100 Bureau Drive, Stop 861, Gaithersburg, MD 20899

---Detecting the early corrosion of steel in reinforced concrete is a goal that has been much pursued. Since 2010, NIST has been pursuing a large project to develop an electromagnetic (EM) probe that detects the actual corrosion products via spectroscopic means. Several principal iron corrosion products, such as hematite and goethite, are antiferromagnetic at field temperatures. At a given applied EM frequency, which depends on temperature, these compounds undergo a resonance that can be detected spectroscopically, which pinpoints the presence of these particular iron corrosion products. The electromagnetic waves tend to be of higher frequency, on order of 100 GHz, so getting them through the cover concrete and back out again to the detector has been challenging. We have successfully detected these two iron corrosion products, and are developing equipment and methodologies that will be capable of penetrating the typical 50 mm of cover concrete in the field. The novel part of this project is that we actually detect specific compounds, rather than just look at changes in rebar cross-section. This method has the potential of providing an early-corrosion probe for steel in reinforced concrete, and for other applications where steel is covered by various layers and coatings.
Measurement and Simulation of Millimeter Wave Scattering Cross-Sections from Steel-Reinforced Concrete

---Ahmed M. Hassan, Nicos Martys, Edward Garboczi, Robert McMichael, Mark Stiles, David Plusquellic, Paul Stutzman, Shuangzhen Wang, and Virgil Provenzano, National Institute of Standards and Technology, Gaithersburg, MD 20899; Jack Surek, David Novotny, Jason Coder, Mike Janezic, and Sung Kim, National Institute of Standards and Technology, Boulder, CO 80305

---Some iron oxide corrosion products exhibit antiferromagnetic magnetic (AFM) properties at around 100 GHz at normal temperatures. In particular, resonances (AFMR) can be detected in laboratory conditions, which serve as the basis for a new non-destructive spectroscopic method for detecting early corrosion. When attempting to measure the steel corrosion in reinforced concrete in the field, the actual local rebar geometry must be taken into account. Experiments and numerical simulations have been developed at around 100 GHz to sort out these effects. The experimental setup involves an Agilent PNA with converter heads to up-convert the output frequency, which is then connected to a horn antenna followed by a 7.5 cm diameter polymer lens to focus the waves on the sample. Two sets of samples were studied: uniform cylindrical rods and genuine rebars with different kinds of coatings, including corrosion products. The electromagnetic scattering cross sections from uniform rods were calculated numerically using classical modal expansion. The finite-element electromagnetic solver COMSOL was used to model more complex rebar geometry and non-uniform corrosion layers. Experimental and numerical data were compared to help quantify and understand local geometrical effects on AFMR measurements.

Multi-Mode Dynamic Crack Measurement in Concrete Structures Using Digital Image Correlation

---Michael J. McGinnis, University of Texas at Tyler, Department of Civil Engineering, Tyler, TX; Wesley J. Keller and Stephen Pessiki, Lehigh University, Department of Civil and Environmental Engineering, Bethlehem, PA 18064

---Cracking in concrete structures is common, because concrete is relatively weak in tension (as compared to compression), and therefore susceptible to cracking caused by numerous actions including applied load, drying shrinkage, and thermal effects. Embedded steel reinforcement is often used to provide internal tension force capacity in concrete, and also to limit the width and movement of cracks that do occur. An important problem in the evaluation of concrete structures in service is the measurement of multi-mode crack movement under dynamic loading. This study focuses on dynamic crack measurement in concrete structures using three-dimensional digital image correlation (3D DIC). In 3D DIC, a stochastic pattern is applied to the structure surface, a pair of cameras capture images of the pattern, and the images are divided into regions several pixels square called facets. These facets are tracked through using pattern recognition and photogrammetric triangulation principles, yielding essentially full-field surface displacements. Laboratory experiments were performed using a novel set-up that reliably simulated mode I, II and III crack movements with displacement amplitudes less than 10 microns, and frequencies in the range 10 to 30 Hertz. The 3D DIC results were verified with independent determinations of displacement based on acceleration and displacement measurements.
Eddy Current Inspection of Corrosion Defects for Concrete Embedded Steel Members

---George V. Minesawa and Eiichi Sasaki, Tokyo Institute of Technology, Department of Civil and Environmental Engineering, 2-12-1 M1-23 Ookayama, Meguro-ku, Tokyo, Japan

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Accidental failure of steel truss member at the passage through the bridge RC deck has revealed the risks posed by development of corrosion defects in steel members below surface of the RC deck, a location difficult to inspect by current NDE technologies. An inspection method using Eddy Current (EC) technology has been proposed and validated through numerical simulation and by actual inspection for the detection of corrosion damage in steel members partially covered by concrete. 3D FEM analysis of the inspection target steel member embedded in concrete and of the EC probe was performed for assessing the defect detectability, for various defect sizes, shapes and depths below concrete surface. Numerical analysis for the proposed EC probe configurations has been performed, being compared probe’s suitability for the inspection of corrosion defects. Laboratory inspections and the equivalent numerical analysis were performed for corrosion defect evaluation using steel plate specimens with corrosion defects. The effect of the concrete cover was evaluated. Finally, EC inspection of concrete embedded H-shape steel profile specimens, similar to the actual corrosion damaged bridge member, was performed for validation of the proposed EC inspection procedure.
Session 11
SESSION 11
ADDITIVE MANUFACTURING
John A. Slotwinski, Chairperson
Key Ballroom 11

8:30 AM Additive Manufacturing Overview and NDE Challenges
---John A. Slotwinski, National Institute of Standards and Technology, Engineering Laboratory, Intelligent Systems Division, Gaithersburg, MD 20899

8:50 AM Physical and Chemical Characterization Techniques for Metallic Powders
---Paul E. Stutzman, Chiara F. Ferraris, Stephanie S. Watson, Max A. Peltz, and Edward J. Garboczi, National Institute of Standards and Technology, Materials and Structural Systems Division, Gaithersburg, MD 20899; John A. Slotwinski, National Institute of Standards and Technology, Engineering Laboratory, Intelligent Systems Division, Gaithersburg, MD 20899

9:10 AM Application of Physical and Chemical Characterization Techniques to Two Metallic Powders
---Stephanie S. Watson, Paul E. Stutzman, Chiara F. Ferraris, Max A. Peltz, and Edward J. Garboczi, National Institute of Standards and Technology, Materials and Structural Systems Division, Gaithersburg, MD 20899; John A. Slotwinski, National Institute of Standards and Technology, Engineering Laboratory, Intelligent Systems Division, Gaithersburg, MD 20899

9:30 AM Infrared Thermography for Laser-Based Powder Bed Fusion Additive Manufacturing Processes
---Shawn Moylan, John Slotwinski, and Daniel Falvey, National Institute of Standards and Technology, Intelligent Systems Div., 100 Bureau Drive, Stop 8220, Gaithersburg, MD 20899-8220

9:50 AM The Integration of Computed Tomography in Direct Digital Manufacturing of Metallic Components
---Richard Martukanitz, Griffin Jones, Todd Palmer, and Edward Reutzel, Center for Innovative Materials Processing through Direct Digital Deposition, Penn State University, State College, PA 16801; Aditya Patel and Jeffrey Urbanski, GE Inspection Technologies, LP, Lewistown, PA

10:10 AM Break

10:30 AM Porosity of Additive Manufacturing Parts for Process Monitoring
---John A. Slotwinski, National Institute of Standards and Technology, Engineering Laboratory, Intelligent Systems Division, 100 Bureau Drive, Stop 8220, Gaithersburg, MD 20899-8220; Edward J. Garboczi, National Institute of Standards and Technology, Engineering Laboratory, Structural Systems Division, Gaithersburg, MD 20899-8220

10:50 AM Metrology for QC of Additively Manufactured Custom Cranial Implants
---Shane Collins, Oxford Performance Materials, 30 South Satellite Road, South Windsor, CT 06074

11:10 AM Neutron Measurements of Stresses in a Test Artifact Produced by Laser-Based Additive Manufacturing
---Thomas Gnaupel-Herold, National Institute of Standards and Technology, Center for Neutron Research, Gaithersburg, MD 20899-6102; John A. Slotwinski and Shawn Moylan, National Institute of Standards and Technology, Intelligent Systems Division, Gaithersburg, MD 20899-8220

11:30 AM Neutron Characterization and Advanced Imaging Techniques for Additive Manufacturing

11:50 AM Adjourn Session

12:10 PM Lunch
8:30 AM

Additive Manufacturing: Overview and NDE Challenges
---John A. Slotwinski, NIST, Engineering Laboratory, Intelligent Systems Division, Gaithersburg, MD 20899

---Additive manufacturing (AM) processes are capable of producing highly complex and customized parts, without the need for dedicated tooling, and can produce parts directly from the part design information. These types of processes are poised to revolutionize the manufacturing industry, yet there are several challenges that are currently preventing more widespread adoption of AM technologies. Traditional NDE methods could be utilized in both in-process and post-process applications, although currently there are very few examples of in-situ sensors for monitoring AM processes. This talk will give an overview of AM technology, and discuss the potential benefits and challenges of using NDE in AM applications.

8:50 AM

Physical and Chemical Characterization Techniques for Metallic Powders
---Paul E. Stutzman, Chiara F. Ferraris, Stephanie S. Watson, Max A. Peltz, and Edward J. Garboczi, National Institute of Standards and Technology, Materials and Structural Systems Division, Gaithersburg, MD 20899; John A. Slotwinski, National Institute of Standards and Technology, Intelligent Systems Division, Gaithersburg, MD 20899

---Systematic studies have been done on two different powder materials used for additive manufacturing: stainless steel and cobalt-chrome. An extensive array of characterization techniques were applied to these two powders. The physical techniques included laser diffraction particle size analysis, X-ray computed tomography for size and shape analysis, and optical and scanning electron microscopy. Techniques sensitive to chemistry, including X-ray diffraction, elemental analysis using the X-rays generated during scanning electron microscopy, and X-ray photoelectron spectroscopy, were also employed. The background of these techniques will be summarized and some typical findings on virgin additive manufacturing powders will be given.
9:10 AM

**Application of Physical and Chemical Characterization Techniques to Two Metallic Powders**

---Stephanie S. Watson, Paul E. Stutzman, Chiara F. Ferraris, Max A. Peltz, and Edward J. Garboczi, National Institute of Standards and Technology, Materials and Structural Systems Division, Gaithersburg, MD 20899; J. A. Slotwinski, National Institute of Standards and Technology, Intelligent Systems Division, Gaithersburg, MD 20899

---Systematic studies have been done on two different powder materials used for additive manufacturing: stainless steel and cobalt-chrome. The characterization of these powders is important in NIST efforts to develop appropriate measurements and standards for additive materials and to document the property of powders used in a NIST-led additive manufacturing material round robin. An extensive array of characterization techniques were applied to these two powders, in both virgin and recycled states. The physical techniques included laser diffraction particle size analysis, X-ray computed tomography for size and shape analysis, and optical and scanning electron microscopy. Techniques sensitive to chemistry, including X-ray diffraction, elemental analysis using the X-rays generated during scanning electron microscopy, and X-ray photoelectron spectroscopy, were also employed. Results of these techniques will be used to shed light on the question: how does virgin powder change after being exposed to and recycled from one or more additive manufacturing processes? In addition, these findings can give insight into the actual manufacturing process.

9:30 AM

**Infrared Thermography For Laser-Based Powder Bed Fusion Additive Manufacturing Processes**

---Shawn Moylan, John Slotwinski, and Daniel Falvey, National Institute of Standards and Technology, Intelligent Systems Division, 100 Bureau Drive, Stop 8220, Gaithersburg, MD 20899-8220

---Additive manufacturing (AM) has the potential to revolutionize discrete part manufacturing, but improvements in processing of metallic materials are necessary before AM will see widespread adoption. A better understanding of AM processes, resulting from physics-based modeling as well as direct process metrology, will form the basis for these improvements. Infrared (IR) thermography of laser-based AM processes can provide direct process metrology as well as data necessary for the verification of physics-based models. We review selected works examining how IR thermography was implemented and used in various laser-based AM process. This previous work, as well as significant experience at the National Institute of Standards and Technology in temperature measurement and IR thermography for machining processes, shapes our own research into AM process metrology with IR thermography. We discuss our experimental design as well as plans for future IR measurements of a powder bed fusion AM process.
The Integration of Computed Tomography in Direct Digital Manufacturing of Metallic Components
---Richard Martukanitz, Griffin Jones, Todd Palmer, and Edward Reutzel, Center for Innovative Materials Processing through Direct Digital Deposition, Penn State University, State College, PA 16801; Aditya Patel and Jeffrey Urbanski, GE Inspection Technologies, LP, Lewistown, PA

Direct digital manufacturing (DDM) or additive manufacturing processes utilize precise manipulation of high energy heat sources for consolidation of powder or wire stock provided at the point of addition or through a continually recharged powder bed. However, the exploitation of DDM of metallic components for critical applications will require the integration of advanced design and materials, process control, and inspection technologies. Since computed tomography (CT) provides a level of spatial detail commensurate with the DDM process, while operating in a completely digital environment, it is considered an important enabling technology for widespread adoption of DDM. This presentation will describe and discuss the use of CT for measuring the impact of DDM processing parameters and conditions on part quality for metallic systems that include titanium and nickel-based alloys. Detailed processing information obtained by data logging along with thermal simulation data and mechanical property testing will be correlated with spatial data obtained by CT. This will include test data representing directed energy deposition and powder bed fusion processes, both using a laser as the energy source. Primary defects of interest, such as gas induced porosity and lack of fusion, are correlated quantitatively with process descriptors formulated from empirical and simulation information.

Porosity of Additive Manufacturing Parts for Process Monitoring
---John A. Slotwinski, NIST, Engineering Laboratory, Intelligent Systems Division, Gaithersburg, MD 20899; Edward J. Garboczi, NIST, Engineering Laboratory, Structural Systems Division, Gaithersburg, MD 20899

Some metal additive manufacturing processes can produce parts with internal porosity, either intentionally (with careful selection of the process parameters) or unintentionally (if the process is not well understood.) Material porosity is undesirable for aerospace parts - since porosity could lead to premature failure - and desirable for some biomedical implants, since surface-breaking pores allow for better integration with biological tissue. Changes in a part’s porosity during an additive manufacturing build may also be an indication of an undesired change in the process. We are developing an ultrasonic sensor for monitoring changes in porosity in metal parts during fabrication on a metal powder bed fusion system, for use as a process monitor. This paper will describe our work to develop an ultrasonic-based sensor for monitoring of part porosity during an additive build, including background theory, the development and detailed characterization of reference additive porosity samples, and a potential design for in-situ implementation.
Metrology for QC of Additively Manufactured Custom Cranial Implants
---Shane Collins, Oxford Performance Materials, 30 South Satellite Road, South Windsor, CT 06074

---Additive manufacturing has proven a substantially enabling technology for the aerospace and medical industries. With this enhanced freedom of design comes a challenge to adequately measure the dimensions of complex surfaces. Subsequently, the need is to compare actual outcomes to the intended geometry and determine how to use this data to effectively deliver quality products and manage manufacturing processes. An example of the use of optical metrology within an ISO13485 quality system to assure quality of patient specific cranial implants will be presented. Further, the heuristic use of the same data to uncover machine drift before the machine's own diagnostic routines were able to detect an issue will be discussed briefly.

Neutron Measurements of Stresses in a Test Artifact Produced by Laser-Based Additive Manufacturing
---Thomas Gnäupel-Herold, National Institute of Standards and Technology, Center for Neutron Research, Gaithersburg, MD 20899-6102; John Slotwinski and Shawn Moylan, National Institute of Standards and Technology, Intelligent Systems Division, Gaithersburg, MD 20899-8220

---A stainless steel test artifact produced at NIST and similar to proposed standardized test artifact was examined using neutron diffraction. The artifact contained a number of structures with different aspect ratios pertaining to wall thickness, height above base plate, and side length. Through spatial resolutions of the order of one millimeter the volumetric distribution of stresses in several was measured. It was found that the stresses peak in the tensile region around 500 MPa but otherwise do not follow a clear cut recipe. The presence of an accommodation layer (a one millimeter high, thin walled, hence weaker lattice structure deposited on the base plate, followed by a fully dense AM structure) has only minor effects of the stresses.
Since additive manufacturing (AM) builds up components in sequential layers, the associated material properties may be inherently anisotropic and significant residual stresses may develop throughout the part. However, each layer is also temporarily available for inspection, so this technology presents a unique opportunity for advanced nondestructive evaluation (NDE) of material properties as well as process diagnostics. Oak Ridge National Laboratory (ORNL) is leveraging decades of experience in characterization of advanced materials along with significant resources such as the Spallation Neutron Source (SNS) and the High Flux Isotope Reactor (HFIR) to address some of these significant challenges and opportunities in AM. Specifically, ORNL is using neutron diffraction techniques to measure the strains in the material lattice to determine the residual stresses present in a component. Neutrons are also being used to image complex internal structures for geometric accuracy through the use of neutron radiography and computed tomography. ORNL is also exploring in-situ monitoring techniques such as infrared thermography to document thermal distributions across the build plane and to identify porosity within a part. Combining these techniques with other NDE approaches, such as resonance ultrasound spectroscopy and X-ray CT imaging, can provide powerful information about the mechanical performance and material properties unique to AM.
Session 12
SESSION 12
ICBM-BARKHAUSEN NOISE AND MICROMAGNETIC TESTING
Robert Fix and Lasse Suominen, Co-Chairpersons
Key Ballroom 9

8:30 AM  Barkhausen Noise: From Chaos to Order
---Valeriy Vengrinovich, Institute of Applied Physics, Belarus Academy of Sciences, Minsk, Belarus

9:10 AM  Barkhausen Noise Technique – The Key to Fast Damage Evaluation of Technical Components
---Ulana Cikalova, Jürgen Schreiber, Susanne Hillmann, and Norbert Meyendorf, Fraunhofer IZFP Dresden, Dresden, Germany; Klaus Szielasko, Fraunhofer IZFP Saarbrücken, Saarbrücken, Germany

9:30 AM  Utilization of Frequency-Domain Information of Barkhausen Noise Signal in Quantitative Prediction of Material Properties
---Aki Sorsa and Kauko Leiviskä, University of Oulu, Control Engineering Laboratory, Oulu, Finland; Suvi Santa-aho, Minnamari Vippola, and Toivo Lepistö, Tampere University of Technology, Department of Materials Science, Tampere, Finland

9:50 AM  Application of the Modified J-A Model in Magnetic Non-Destructive Evaluation
---Neelam G. Prabhu Gaunkar, Ikenna C. Nlebedim*, and David C. Jiles, Iowa State University, Department of Electrical and Computer Engineering, Ames, IA 50011; *Ames Laboratory, U.S. DOE, Ames, IA 50011

10:10 AM  Break

10:30 AM  Monitoring of Surface Burn After Grinding Larger Bearing Rings
---M. Neslusan, M. Micietova, and M. Cillikova, Department of Machining and Production Technologies, University of Žilina, Univerzitná 1, 010 26 Žilina, Slovakia

10:50 AM  Improved Grinding Quality Inspection of Large Bearing Components Using Barkhausen Noise Analysis
---Francis M. Kolarits, The Timken Company, Timken Technology Center, North Canton, OH 44706-0930

11:10 AM  Analysis of Surface Integrity of Grinded Gears Using Barkhausen Noise Analysis and X-Ray Diffraction
---Lucie Vrkoslavová and Petr Louda, Technical University of Liberec, Institute for Nanomaterials, Advanced Technologies and Innovation, Liberec, Czech Republic; Jiří Malec, Department of Analytic Services, PCS s.r.o., Žďár nad Sázavou, Czech Republic

11:30 AM  The Application of Wavelet Shrinkage Denoising to Magnetic Barkhausen Noise Measurements
---James J. Thomas, American Stress Technologies, Inc., 540 Alpha Drive, Pittsburgh, PA 15238

11:50 AM  A New Barkhausen Noise Technique for Applications at Miniaturized Geometries
---Susanne Hillmann and Norbert Meyendorf, Fraunhofer IZFP Dresden, Maria-Reiche-Str. 2, 01109 Dresden, Germany

12:10 PM  Lunch
Barkhausen Noise: From Chaos to Order
---Valeriy Vengrinovich, Institute of Applied Physics, Belarus Academy of Sciences, Minsk, Belarus

---Statistical Markov theory for Barkhausen Noise (BN) and hysteresis loop is considered using the model according to which the domain walls in domain crystal form a connected system, each arrangement of which is the point in the phase space. Accordingly, the magnetization process of imperfect crystal with domain structure is described as discontinuous nonuniform Markov process of birth or other type evolutionary process, for certainty, logistic-type. Then the solution of the Kolmogorov differential equations of Markov birth-type process (solution of the PDF - probability distribution function) of magnetization conditions for the complete hysteresis loop, which is finally described analytically like the ordering of BN under the influence of exciting magnetic field (EMF). The aftereffect of BN under the immediate stoppage of EMF was observed and investigated in our laboratory. The pronounced effect of BN ordering affected by bi-frequency magnetization is also observed and investigated. It was shown that simultaneous impact of high and low frequency EMF gives rise to unit impulse of magnetization which collects all domain walls discontinuities in a strong unit ordered process. This ordering effect is investigated in different EMF conditions and its main properties are discussed in the report. The analogy with other known physical effects like sea waves ordering or large discontinuities in amorphous ferromagnets is underlined. The high level of BN ordering becomes apparent considering its fractal features considered by J.Screiber in the German IZiP, who investigated the Barkhausen discontinuities close-range interaction and provided its correlation analysis. Main ordering effects of BN occur like a reaction to material degradation and stress state. We define here the BN behaviour under the influence of bi-axial stress and also elasto-plastic effect observable by way of expanded magnetic elasto-plastic loops. The effect of micro magnetic elasto-plasticity is investigated experimentally for two steel types: ferrito-perlitic and martensate. The new look at the micro magnetic ordering gives rise to some new applications, which are also considered in the report. Stabilization of EMF parameters and use of available materials with characteristic ordering properties makes it possible to design stress gage like an alternative to well known strain gage. Its accuracy is validated within the level of ±0.35% in the temperature range from -40 to +50°C. Several of discussed effects, namely BN aftereffect, rotating EMF, low frequency ordering were integrated in the new BN instrument INTROSCAN-2 developed in the Institute of Applied Physics and “NPF Diagnostics Inc.”. Together with software supplement it integrates the new tools for bi-axial stress measurement, anisotropic properties investigation, selection of the optimal EMF parameters. The instrument is widely applicable in pipelines, machinery and civil engineering. The prospective applications: fine structure assessment with fractals, material degradation, bi-axial stresses, elasto-plasticity, layer-by-layer analysis and SHM are as well discussed.

9:10 AM

Barkhausen Noise Technique – The Key to Fast Damage Evaluation of Technical Components
---Ulana Cikalova, Jürgen Schreiber, Susanne Hillmann, and Norbert Meyendorf, Fraunhofer IZFP Dresden, Dresden, Germany; Klaus Szielasko, Fraunhofer IZFP Saarbrücken, Saarbrücken, Germany

---Components in industrial plants are generally designed for a defined service life time based on specific operational loads and safe life design principles. From an economic aspect, exploitation of all measures respective to extending their potential service life is of interest today. Safe life means component operation up to a specified non-critical damage with a defined probability to occur and measured in terms of time and possibly applied stresses. The occurring damage, with some randomness, is considered to be non-visible and their quantification, due to the cumulative damage model, is quite sophisticated. However, the Barkhausen Noise Technique, as a Nondestructive Testing (NDT) method, is able to provide very fast and reliable information on characteristics, such as stiffness, residual life, stress condition, degradation or hardness without prior knowledge of the state of the corresponding material and therefore raises increasing demands. This paper presents the opportunity of using common magnetic parameters and unconventional Barkhausen Noise parameters to characterize the materials state substantially. This approach will be described in detail and demonstrated by means of examples from various industrial applications.
Utilization of Frequency-Domain Information of Barkhausen Noise Signal in Quantitative Prediction of Material Properties

---Aki Sorsa and Kauko Leiviskä, University of Oulu, Control Engineering Laboratory, Oulu, Finland; Suvi Santa-aho, Minnamari Vippola, and Toivo Lepistö, Tampere University of Technology, Department of Materials Science, Tampere, Finland

---This paper describes different approaches for utilizing frequency-domain information of Barkhausen noise (BN) signal in quantitative prediction of material properties. Different approaches include the calculation of power spectral density (PSD), moving window PSD for obtaining the BN profile and the utilization of BN spectrum. The PSD value is calculated directly from the BN signal and is related to overall Barkhausen activity. The application of moving PSD filtering produces the so called BN profile. Peak height, position and width of the profile can then be calculated and used. Spectrum gives the signal power as the function of frequency. This information can be related to material properties and thus utilized in predictions. This paper mainly discusses the different approaches but also presents some results which show that frequency-domain information can be important. It is common in the literature that only time-domain properties of the BN signal are used. However, prediction of material properties is case-dependent and thus it may be beneficial to use also frequency-domain information.

Application of the Modified J-A Model in Magnetic Non-Destructive Evaluation

---Neelam G. Prabhu Gaunkar, Ikenna C. Nlebedim*, and David C. Jiles, Iowa State University, Department of Electrical and Computer Engineering, Ames, IA 50011; *Ames Laboratory, U.S. DOE, Ames, IA 50011

---Detection and estimation of surface and subsurface defects is essential for preventing structural failures of engineering parts and equipment. Many nondestructive testing methods are developed and employed in monitoring defects such as micro-crack and residual stresses. Because such defects affect the magnetic properties of ferromagnetic materials, non-destructive evaluation (NDE) based on characterizing the magnetic hysteresis behavior of the materials can offer a useful approach for preventing structural failures. The magnetic properties of ferromagnetic materials such as the permeability, coercivity or remanence are known to be sensitive to the mechanical and microstructural state of materials. The Jiles-Atherton (J-A) model has been successfully used to model the magnetic hysteresis of ferromagnetic materials under stress and can thus be applied to magnetic NDE. We have extended its applicability using a modified version of the model and improved its capability for predicting and interpreting the hysteresis behavior in two phase ferromagnetic materials. We will further investigate the validity of using the modified J-A model for predicting the magnetic hysteresis behavior in two phase magnetic materials with surface stress.
10:30 AM

**Monitoring of Surface Burn After Grinding Larger Bearing Rings**

---M. Neslusan, M. Micetova, and M. Cillikova, Department of Machining and Production Technologies, University of Žilina, Univerzitná 1, 010 26 Žilina, Slovakia

---This paper deals with detection of surface burn after grinding operations on larger bearing rings made of case-hardened steels. The paper reports about calibration of Barkhausen noise technique for nondestructive monitoring of grinding operations for rings of diameter in the range of 600 up to 4000 mm. Properly suggested monitoring concept enables to detect thermal damage due to grinding wheel wear as well as insufficient coolant supply. Further, grinding burn associated with lack of coolant can be clearly distinguished from damage corresponding grinding wheel wear. The paper also discusses increasing magnetoelastic responses obtained after grinding rings of higher diameters. Results of hardness measurement as well as corresponding X-ray diffraction are also reported in the paper to verify information about surface integrity obtained through micromagnetic technique.

10:50 AM

**Improved Grinding Quality Inspection of Large Bearing Components Using Barkhausen Noise Analysis**

---Francis M. Kolarits, The Timken Company, Timken Technology Center, North Canton, OH 44706-0930

---Assuring that the finished surfaces of precision large bearing components are free from grinding injury is critical due to the high initial value of these bearings, heavy application loadings and high costs associated with potential early application failures. Inspecting bearing raceway surfaces for grind burn can be done by nital etching but this method is time consuming, involves using hazardous acids, is non-quantitative and does not provide information about residual stresses. An experimental study was performed to assess scanning Barkhausen Noise Analysis (BNA) to detect various levels of induced grind injury on four steels used in large bearing ring production. Test samples having approximately 0.25 m diameter were fabricated from bearing steels heat treated by case carburizing, induction hardening and through hardening. A series of grinding cycles was designed and subsequently the entire ground surface on each sample was tested by scanning BNA. Selected samples were then evaluated by nital etching or destructive metallurgical tests. BNA results are compared with specific grinding power, nital etch and destructive measurements to show BNA to be an effective technique for identification of grind injury on these steel materials. Similar relative trends in the BNA response are present regardless of alloy or heat treatment.
Analysis of Surface Integrity of Grinded Gears Using Barkhausen Noise Analysis and X-Ray Diffraction
---Lucie Vrkoslavová and Petr Louda, Technical University of Liberec, Institute for Nanomaterials, Advanced Technologies and Innovation, Liberec, Czech Republic; Jiří Malec, Department of Analytic Services, PCS s.r.o., Žďár nad Sázavou, Czech Republic

The contribution is focused to present results of study grinded gears made of 18CrNiMo7-6 steel used in the wind power plant for support (service) purposes. These gears were case-hardened due to standard hard case and soft core formation. This heat treatment increases wear resistance and fatigue strength of machine parts. During serial production some troubles with surface integrity have occurred. When solving complex problems lots of samples were prepared. For grinding of gears were used different parameters of cutting speed, number of material removal and lots from different subsuppliers. Material characterization was carried out using Barkhausen noise analysis (BNA) device; X-ray diffraction (XRD) measurement of surface residual stresses was done as well. Depth profile of measured characteristics, e.g. magnetoelastic parameter and residual stress was obtained by step by step layers’ removing using electrolytic etching. BNA software Viewscan was used to measure magnetizing frequency sweep (MFS) and magnetizing voltage sweep (MVS). Scanning of Magnetoelastic parameter (MP) endwise individual teeth were also carried out with Viewscan. These measurements were done to find problematic surface areas after grinding such as thermal damaged locations. Plots of the hardness and thickness of case-hardened layer on cross sections were measured as well. Evaluation of structure of subsurface case-hardened layer and core was made on etched metallographic patterns. The aim of performed measurements was to find correlation between case-hardening depth, conditions of grinding, residual stresses and structural and magnetoelastic parameters. Based on correlation of measured values and technological parameters optimizing the production of gears will be done.

The Application of Wavelet Shrinkage Denoising to Magnetic Barkhausen Noise Measurements
---James J. Thomas, American Stress Technologies, Inc., 540 Alpha Drive, Pittsburgh, PA 15238

The application of Magnetic Barkhausen Noise (MBN) as a non-destructive method of defect detection has proliferated throughout the manufacturing community. Instrument technology and measurement methodology have matured commensurately as applications have moved from the R&D labs to the fully automated manufacturing environment. These new applications present a new set of challenges including a bevy of error sources. A significant obstacle in many industrial applications is a decrease in signal to noise ratio due to (i) environmental EMI and (ii) compromises in sensor design for the purposes of automation. The stochastic nature of MBN presents a challenge to any method of noise reduction. An application of wavelet shrinkage denoising is proposed as a method of decreasing extraneous noise in MBN measurements. The method is tested and yields marked improvement on measurements subject to EMI, grounding noise, and even measurements in ideal conditions.
A New Barkhausen Noise Technique for Applications at Miniaturized Geometries

---Susanne Hillmann and Norbert Meyendorf, Fraunhofer IZFP Dresden, Maria-Reiche-Str. 2, 01109 Dresden, Germany

---The magnetic Barkhausen Noise technique is a well suited method for the characterization of ferromagnetic materials. Most sensors are composed with a magnetic yoke that excites the electromagnetic field in the material, and a coil or Hall-Element, which is located between both feet of the yoke to record the Barkhausen Noise. Due to both factors, the overall size of the sensors and the spot size at the material are relatively large. For some applications Barkhausen Noise Sensors for miniaturized samples with complex geometries are needed, for example small mass production components or measurements inside of boreholes. Therefore, a new design for a Barkhausen Noise sensor was developed. The principle of exiting the Magnetic Field changes from a magnetic yoke to a thin tip. The alternating current flows through the tip into the material and induces a magnetic field, which in turn generates the Barkhausen Noise. A small coil that is wound around the tip, records the Barkhausen Noise Signal. With this design, the contact point between sensor and material is very small and it is possible to apply the sensor to very small samples or inside boreholes. We present an appropriate sensor design and the first promising measurement results of this technique at different small samples with varying hardness inside boreholes.
Session 13
NOTE: Student posters are to be displayed in the Key Ballroom 7 and 8 on Monday, July 22nd, from 3:00 to 6:00 p.m. for evening judging ONLY—not for public display. For Monday’s judging, no identification (author names, institutional names, etc.) should be shown on the posters in order to preserve anonymity during the closed judging period. The posters will be open for public viewing with author and institutional titles during the regular Poster Session 13 on Tuesday, July 23rd, from 1:30-3:10 p.m. For more details on the student poster competition, please see the "Conference Guide" document (page 8) on the QNDE web site at:

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Signal Processing and Computation

CUDA Memory Limitation in Finite Element Optimization to Reconstruct Cracks
---Sivamayam Sivasuthan, Victor U. Karthik, and Samuel Ratnajeevan H. Hoole, Michigan State University, Department of Electrical and Computer Engineering, East Lansing, MI 48824

Examination of Laplace Transform for Pulsed Eddy Current Signal Display and Analysis
---D. R. Desjardins and T. W. Krause, Royal Military College of Canada, Department of Physics, P. O. Box 17000, Station Forces, Kingston, Ontario, K7K 7B4, Canada

Image De-Noising Via Spectral Distribution Similarity Analysis for Ultrasonic NDE
---B. Xiao, M. Li, R. Gongzhang, R. O’Leary, and A. Gachagan, University of Strathclyde, Department of Electronic & Electrical Engineering, Glasgow, Scotland, United Kingdom

Robust Frequency Diversity Based Algorithm for Clutter Noise Reduction of Ultrasonic Signals Using Multiple Sub-Spectrum Phase Coherence
---Rui Gongzhang, Minghui Li, Bo Xiao, Timothy Lardner, and Anthony Gachagan, Center for Ultrasonic Engineering, University of Strathclyde, Glasgow, United Kingdom

Time-Delay Estimation Via Third-Order Cumulant Cross-Correlation Method Used in Liquid Viscosity Measurement
---Shiyuan Zhou, Yao Xu, Dingguo Xiao, and Chunguang Xue, Beijing Institute of Technology, School of Mechatronical Engineering, Beijing, China

Knowledge Extraction Algorithms Dedicated for Identification of Steel Bars in Reinforced Concrete Structures
---Pawel Karol Frankowski, Tomasz Chady, and Ryszard Sikora, West Pomeranian Univ. of Tech., Szczecin, Poland

Eddy Current

Including the Skin-Effect in the Circuit Theory of Eddy-Current Induction
---Robert R. Hughes and Steve M. Dixon, University of Warwick, Department of Physics, Gibbet Hill Road, Coventry, CV4 7AL, United Kingdom

Eddy Current Coil Interaction with Edges in the Inspection of Holes
---Hui Xie¹, Yi Lu², and John R. Bowler¹ ², ¹Department of Electrical and Computer Engineering, Iowa State University, Ames, IA 50011; ²Iowa State University, Center for NDE, Ames, IA 50011

Development of Bolt Hole Inspection Technique by Eddy Current Testing
---Dong-Man Suh, Raynar/Kunjang University College, NDT Department, Daejon, Korea; Ji-Eun Jang, Kwan-Seob Jang, and Hong-Geun Lee, Sae-An Corporation, Seoul, Korea

Ferrite Core Probe Interaction with Cracks
---Yi Lu¹ and Theodoros Theodoulidis², Iowa State University, Ames, IA 50011; ¹Center for NDE, ²Department of Mechanical Engineering, University of Western Macedonia, Greece

A Feasibility Study for Lamb Wave Mixing Nonlinear Technique
---Dong Jin Lee, Younho Cho, and Weibin Li, School of Mech. Eng., Pusan Nat’l Univ., Pusan, South Korea
**Eddy Current**

A Study on Nondestructive Evaluation Technique by the Use of Interface Guided Waves on Shrink Fit Structure

---Jaesun Lee¹, Younho Cho¹, Jun-Pil Park¹, Joseph L. Rose², Hyung Huh³, Keun-Bae Park³, and Dong-Ok Kim³, ¹School of Mech.Eng., Pusan Nat’l Univ., Pusan, South Korea; ²Dept. of Eng. Science and Mechanics, Penn State University, State College, PA; ³Korea Atomic Energy Res. Institute, Daejeon, South Korea

A Comparison of NDI Techniques for the Inspection of Thick Multi-Layer Metallic Structures

---Doyle Motes², David S. Forsyth², Mark Keiser², Gary Steffes¹, and John C. Aldrin³,
¹AFRL/RXLP, Wright-Patterson AFB, OH 45433; ²TRI/Austin, Austin, TX 78746; ³Computational Tools, Gurnee, IL 60031

**Guided Waves**

Multiple Scattering of Surface Waves by Cavities in a Half-Space

---Haidang Phan, Younho Cho, and Taeho Ju², Pusan National University, School of Mech. Eng., Pusan, South Korea; Jan D. Achenbach² and J. Qiu², ²Northwestern University, Center for QEFP, Evanston, IL 60208

**NDE Sensors and Systems**

3D Microwave Imaging System Using a Manual Non-Uniform Scanning Process

---M. T. Ghaz, Joseph T. Case, Joseph Bacon, and Reza Zoughi, Missouri Univ. of Science and Technology, Applied Microwave Nondestructive Testing Lab, Elec. & Comp. Eng. Dept., Rolla, MO 65409

3:10 PM Break
Implementation of Automated 3D Defect Detection for Low Signal-to Noise Features in NDE Data

---The need for robust defect detection in NDE applications requires the identification of subtle, low-contrast changes in measurement signals usually in very noisy data. Most algorithms rarely perform at the level of a human inspector and often, as data sets are now routinely 10+ Gigabytes, require laborious manual inspection. We present two automated defect segmentation methods, simple threshold and a binomial hypothesis test, and compare effectiveness of these approaches in noisy data with signal to noise ratios at 1:1. The defect-detection ability of our algorithm will be demonstrated on 3D CT data, UT phased array data, and using simulated data generated by XRSIM. The latter is a physics-based forward model useful in demonstrating the effectiveness of data processing approaches in a simulation which includes complex defect geometry and realistic measurement. Such simulations provide an effective means to determine a figure of merit for the processing algorithm. These large data sets represent significant demands on compute resources and easily overwhelm typical PC platforms; however, the emergence of graphics processing units (GPU) processing power provides a means to overcome this bottleneck. Processing large, multi-dimensional datasets requires an optimal GPU implementation which addresses both computational complexity and memory-bandwidth usage.

Guided Wave Radiation from a Point Source in the Proximity of a Pipe Bend

---Throughout the oil and gas industry corrosion and erosion damage monitoring play a central role in managing asset integrity. Recently, the use of guided wave technology in conjunction with tomography techniques has provided the possibility of obtaining point-by-point maps of wall thickness loss over the entire volume of a pipeline section between two ring arrays of ultrasonic transducers. However, current research has focused on straight pipes while little work has been done on pipe bends which are also the most susceptible to developing damage. Tomography of the bend is challenging due to the complexity and computational cost of the 3-D elastic model required to accurately describe guided wave propagation. To overcome this limitation, we introduce a 2-D anisotropic inhomogeneous acoustic model which represents a generalization of the conventional unwrapping used for straight pipes. The shortest-path ray-tracing method is then applied to the 2-D model to compute ray paths and predict the arrival times of the fundamental flexural mode, A0, excited by a point source on the straight section of pipe entering the bend and detected on the opposite side. Excellent agreement is found between predictions and experiments performed on an 8" diameter (D) pipe with 1.5 D bend radius. The 2-D model also reveals the existence of an acoustic lensing effect when the source is placed on the outer radius of the bend, or in its proximity, which leads to a focusing phenomenon also confirmed by the experiments. The computational efficiency of the 2-D model makes it ideally suited for tomography algorithms.
Thermal Stability of Curved Ray Tomography for Corrosion Monitoring

---Guided wave tomography is being developed as an effective tool for continuous monitoring of corrosion and erosion depth in pipelines. A transmit- and receive-ring arrays of ultrasonic transducers encircle the pipe and delimit the section to be monitored. In curved ray tomography (CRT), the depth profile is estimated from the time delay matrix, $T$, whose $i$-$j$ entry is the arrival time difference between the current and baseline signals measured between transducers $j$ and $i$ of the transmit and receiving arrays, respectively. Under perfectly stable experimental conditions, the non-zero entries of $T$ are only due to the occurrence of damage and provide a reliable input to CRT. However, during field operation, $T$ can develop non-zero entries due to a number of environmental changes ranging from temperature variations to degradation of transducer-pipe coupling and transducer intrinsic performance. Here, we demonstrate that these sources of instability can be eliminated by exploiting the spatial diversity of array measurements in conjunction with EMAT transducer technology which is intrinsically stable owing to its non-contact nature. The study is based on a full scale experiment performed on a schedule 40, 8” diameter, 3 m length pipe, monitored with two EMAT ring arrays in the temperature range from 20 to 175°C. It is shown that a 10% wall thickness loss is consistently reconstructed within 1% accuracy over the entire temperature range. We also present long term stability tests of a pair of EMAT transducers subject to thermal cycles up to 400°C which confirm the extraordinary intrinsic stability of these transducers.

Ultrasonic Estimation of the Contact Angle of a Sessile Droplet

---Surface tension is an important parameter to many industrial processes, especially those in which droplet formation and evaporation drive the process, examples include: spraying, printing, washing, and coating. Optical techniques, such as the drop-shape method, are now widely used to measure the contact angle of a sessile droplet deposited on a substrate which then allows the surface tension to be determined from Young’s equation. However, the need for producing high resolution images of a drop deposited on an opaque substrate requires complex optical systems and limits measurements accuracy in the case of small drops. This paper proposes a novel ultrasonic technique for the evaluation of the contact angle that uses Rayleigh wave backscattering from the droplet. The principle of the measurement is based on the existence of quasi-Stoneley waves circling around the contact line of the droplet. Because the energy of the Stoneley wave is confined within a thin fluid layer in contact with the substrate, its propagation characteristics are influenced by the contact angle between the drop and the substrate. The existence of the quasi-Stoneley wave is confirmed by ultrasonic scattering experiments performed with a range of droplet diameters. The sensitivity of quasi-Stoneley wave to the contact angle is then revealed by real-time monitoring of the droplet evaporation process during which the contact angle increases monotonically while the drop diameter remains constant.
Sparse Signal Reconstruction from Polychromatic X-ray CT Measurements via Mass Attenuation Coefficient Discretization

--- We propose a method for reconstructing sparse images from polychromatic X-ray CT measurements via mass attenuation coefficient discretization. The material of the inspected object and the incident spectrum are assumed to be unknown. We first rewrite the measurement equation in terms of integral expressions of mass attenuation and then discretize the resulting integrals. We then develop a penalized constrained least-squares optimization approach for reconstructing the underlying object from log-domain measurements, where an active set approach is employed to estimate incident energy density parameters and the nonnegativity and sparsity of the image density map are imposed using negative-energy and smooth l1-norm penalty terms. We compare the proposed method with the standard filtered back projection (FBP), which ignores the polychromatic nature of the measurements and sparsity of the image density map. Numerical simulations using both realistic simulated and real X-ray CT data are presented.

Improved Detection of Rough Defects for Ultrasonic NDE Inspections Based on Finite Element Modelling of Elastic Wave Scattering

--- Defects which possess rough surfaces greatly affect ultrasonic wave scattering behavior, often reducing the magnitude of reflected signals. NDE inspections rely upon this response for detecting and sizing flaws. For safety critical components reliable characterization is crucial, making an accurate means to predict reductions in signal amplitude essential. An extension of Kirchhoff Theory has formed the basis for UK power industry inspection justifications. However, it is widely recognized that these predictions are pessimistic owing to analytical approximations. A numerical full field modelling approach does not fall victim to such limitations. Here a Finite Element method is used to aid in the inspection of large pressure vessel forgings for embedded rough defects. The ultrasonic response from multiple rough surfaces defined by the same statistical class is calculated for normal incident compression waves. The approach is validated by comparing coherent scattering with predictions made by Kirchhoff Theory. At lower levels of roughness excellent agreement is observed, whilst higher values confirm the pessimism of Kirchhoff Theory. Furthermore, the mean amplitude in the specular direction is calculated. This represents the information obtained during an inspection, indicating that reductions due to increasing roughness are significantly less than the coherent component currently being used.
Fundamentals of Imaging with Phased Arrays

---When imaging with ultrasonic phased arrays, what do we actually image? What quantitative information is contained in the image? Ad-hoc delay-and-sum methods such as the synthetic aperture focusing technique (SAFT) and the total focusing method (TFM) fail to answer these questions. We have shown that a new quantitative approach allows the formation of flaw images by explicitly inverting the Thompson-Gray measurement model. To examine the above questions, we have set up a software simulation test bed that considers a 2-D scalar scattering problem of a cylindrical inclusion with the method of separation of variables. It is shown that in SAFT types of imaging the only part of the flaw properly imaged is the front surface specular response of the flaw. Other responses (back surface reflections, creeping waves, etc.) are improperly imaged and form artifacts in the image. In the case of TFM-like imaging the quantity being properly imaged is an angular integration of the front surface reflectivity. The other, improperly imaged responses are also averaged, leading to a reduction in some of the artifacts present. Our results have strong implications for flaw sizing and flaw characterization with delay-and-sum images.

Microwave NDE for Health-Monitoring of Concrete Structures Containing Alkali-Silica (ASR) Gel

---Reactive aggregates combined with sufficient moisture and concentration of alkali agents are the three basic requirements for Alkali-Silica (ASR) gel formation in concrete. For health-monitoring of concrete structures, while in service, and in order to investigate the probability of ASR gel formation in existing structures, one technique is to identify whether the initial aggregate used in the concrete mixture is reactive or non-reactive. In this paper, a microwave nondestructive testing approach is proposed which is capable of distinguishing between different hardened mortar samples having reactive and non-reactive aggregates. This method involves soaking several hardened mortar samples and conducting temporal microwave dielectric property measurements to detect any potential additional ASR gel formation as a result of exposure to free water (i.e., soaking). Consequently, these samples were submerged in water and dried in ambient conditions for three cycles each lasting ~ 65 days. Preliminary results have indicated that water evaporation rates, during the drying periods, are different for samples with the reactive aggregates as compared to those with the non-reactive aggregates. This paper presents the results of this investigation and the results of a dielectric mixing model development in an attempt to explain and predict these changes.
Air-Coupled Ultrasonic Method for Reconstruction Internal Structure within Reinforced Concrete Elements

---It is important to characterize internal damage within reinforced concrete elements caused by excessive external loads, such as those caused by earthquake. Here we present an air-coupled ultrasonic scanning approach for this purpose. Contactless ultrasonic wave pulse generation is provided by an electrostatic transducer mounted on an automated scanning frame, which maintains constant air gap distance to concrete surface and provides accurate spatial position of the transducer. This system enables many test data to be collected over a large area and in a reasonably short amount of time. Ultrasonic test data are collected through two different types of full-scale steel-reinforced concrete columns: 1) a column containing controlled artificial defects including embedded styrofoam, a pre-cracked concrete block, and de-bonded steel; and 2) a column subjected to simulated earthquake loads across the plastic hinge zone (high damage area) of the column. Internal images are reconstructed from the data in two forms: stacked time signals and tomographs based on velocity and attenuation. The developed images demonstrate that it is possible to detect internal defects and monitor the progression of degradation process and detect internal damage.

Nonlinear Mixing of Two Collinear Rayleigh Waves in an Isotropic Nonlinear Elastic Half-Space

---Nonlinear mixing of two collinear, initially monochromatic, plane Rayleigh waves in an isotropic, nonlinear elastic half-space is analyzed. Based on the Hamiltonian formalism, a coupled system of dynamic equations is derived for the slow-varying amplitudes of the harmonic and combination frequency components of the fundamentals. Numerical results on the nonlinear interactions and evolutions of these frequency components over the propagation distance are provided for different ratios of the fundamental wave frequencies and are explained by different energy transfer characteristics among these frequency components. The change of the velocity profiles over the propagation distance is also discussed. It is illustrated that the horizontal velocity component forms a shock wave while the vertical velocity component forms a pulse if the two mixing frequencies are close enough. The model is extended to the case of radiation from a finite sized source.
Paraxial Ray-Tracing Approach for the Simulation of Ultrasonic Inspection of Welds

---On-site inspection of bimetallic or austenitic welds can be very difficult to interpret owing to their internal structures. Skewing and splitting of the ultrasonic beam may occur due to the anisotropic and inhomogeneous properties of the welding material. In this paper, we present a ray-based method to simulate the propagation of ultrasonic waves in such structures. The formalism is based on dynamic ray tracing system in Cartesian coordinates along a reference ray. Standard ray tracing consists in the solution of a system of linear ordinary differential equations of the first order and is used to determine the trajectory of the ray. Likewise, dynamic ray tracing (DRT) also called paraxial ray tracing consists in the solution of an additional system of linear ordinary differential equations along the ray allowing paraxial quantities to be computed. It is used to evaluate the geometrical spreading and amplitude along the ray and in its vicinity. DRT is applied on a smooth representation of the elastic properties of the weld obtained thanks to an image processing technique applied on a macrograph of the weld. Simulation results are presented and compared to finite elements and experimental results.

Quantitative Multi-Modal NDT Data Analysis

---A single NDT technique is often not adequate to provide assessments about the integrity of test objects with the required coverage or accuracy. In such situations, it is often resorted to multi-modal testing, where complementary and overlapping information from different NDT techniques are combined for a more comprehensive evaluation. Multi-modal material and defect characterization is an interesting task which involves several diverse fields of research, including signal and image processing, statistics and data mining. The fusion of different modalities may improve quantitative nondestructive evaluation by effectively exploiting the augmented set of multi-sensor information about the material. It is the redundant information in particular, whose quantification is expected to lead to increased reliability and robustness of the inspection results. There are different systematic approaches to data fusion, each with its specific advantages and drawbacks. In our contribution, these will be discussed in the context of nondestructive materials testing. Practical results adopting different schemes for fusion of thermography, GMR and Eddy Current on a reference metallic specimen with built-in notches will be presented and discussed.
Guided Wave Propagation and Scattering in Pipeworks Comprising Elbows

---Guided waves (GW) are used to inspect pipeworks in various industries. Specific features of pipeworks lead to complex scattering phenomena. Simulations tools able to handle such a complexity can help interpreting measurements and optimizing testing configurations. They must take into account both long range propagation and local scattering phenomena. Here, a modal formulation is derived to deal with pipeworks comprising arbitrarily curved elbows linking otherwise straight pipes. First, the semi-analytic finite element method is extended in curvilinear coordinates to predict guided modes in elbows. Then, GW scattering at the junction of a straight pipe with an elbow is investigated. Modal solutions in both parts being known, the mode-matching method is derived to compute modal reflection and transmission coefficients given as elements of a scattering matrix. Further, the global scattering matrix of a pipework comprising an arbitrary number of elbows linking straight pipes is considered. For this, a general formulation presented in this conference series is used which can handle multiple scattering phenomena that possibly arise. Interestingly, the overall formulation only requires meshing the pipe section to compute both the modal solutions and the integrals resulting from the mode-matching for computing elementary scattering matrices. Parametric studies illustrate the various computation steps.

Feature Extraction for Ultrasonic Sensor Based Defect Detection in Ceramic Components

---High density silicon carbide materials are commonly used as the ceramic element of hard Armour inserts used in traditional body Armour systems to reduce their weight, while providing improved hardness, strength and elastic response to stress. Currently, Armour ceramic tiles are inspected visually offline using an X-ray technique that is time consuming and very expensive. In addition, from X-rays multiple defects are also misinterpreted as single defects. Therefore, to address such a need, industrial manufacturers demands a new on-line system based on the ultrasonic non-destructive approach that would be far more cost effective and reliable as the methodology aids in quality control including implementation of accept/reject criteria. This paper presents a recent methodology developed to detect, locate and classify various manufacturing defects in ceramic tiles using sub band coding of ultrasonic test signals. The wavelet coefficients in the different frequency bands are processed in several ways that are used as features into artificial neural network (ANN). Two different classifiers using artificial neural network (supervised) and clustering (un-supervised) are supplied with features generated by a pre-processing technique and their classification performance are compared. This investigation establishes experimentally that sub band coding can be reliably used as a feature extraction method that provides superior time-frequency resolution for classifying various defects with 100% accuracy than X-ray technique.
Experimental Considerations for High Frequency Imaging of Bulk Wavefields

---Wavefield imaging generally refers to generation of a wavefield by a fixed source and its subsequent measurement on a 2D spatial grid. This type of imaging as applied to guided waves has been shown to be a powerful tool for both determining the nature of the wave propagation and providing quantitative scattering information for defects. Acquisition of higher frequency bulk wavefields in the 1-10 MHz range over larger areas is more challenging because of not only the bandwidth requirements but also the need for fine spatial sampling to prevent spatial aliasing. Here we consider acquisition of wavefield data generated by an angle-beam transducer-wedge combination mounted on a plate, motivated by the eventual goal of characterizing scattering from defects. Unlike guided waves, which excite the plate throughout its thickness, the angle beam bulk waves bounce back and forth between the plate surfaces, resulting in the well-known multiple “skips” or “V-paths.” The goal of the bulk wavefield measurement process is to obtain high quality data over the surface of interest in a reasonable time. The specific experimental setup includes a Polytec laser vibrometer and controller, a function generator, an amplifier, and a data acquisition system. The vibrometer is mounted on an XYZ scanning stage, which is programmed to move point-to-point on a rectilinear grid to acquire waveform data. Factors affecting the scan time and signal quality include the excitation signal, analog filtering, number of averages, temporal sampling interval, spatial sampling interval, and digital filtering. We consider the tradeoffs between data quality and scan time for specific transducer-wedge combinations mounted on aluminum plates, and discuss parameters selected for use during upcoming experiments for characterizing scattering from defects.

Numerical Design Optimization of an EMAT for A0 Lamb Wave Generation in Steel Plates

---In this research, an electromagnetic acoustic transducer (EMAT) for A0 Lamb wave generation on steel plates is developed for an operation point of 0.50 MHz-mm. A key objective of the development is to maximize the excitation and reception of the A0 mode, while minimizing those of the S0 mode. The EMAT design regarded in this research is a simple low frequency EMAT design, consisting of an induction coil and a permanent magnet. A finite element (FE) model of the EMAT is developed, coupling the electromagnetic and elastodynamic phenomena. An optimization process using a genetic algorithm is implemented, employing the magnet diameter and liftoff distance from the plate as design parameters and the A0-S0 peak amplitude as the fitness function. The optimal design suggested by the optimization process is physically implemented and the experimental measurements are compared to the FE simulation results. Good agreement is found between simulation and experiment. In a further step, the variations of the design parameters are studied numerically and experimentally and the proposed EMAT design exhibits a robust behavior to small changes of the design parameters. Furthermore, robustness is found for reasonable variations of the magnetic permeability and plate thickness.
Nondestructive Estimation of Depth of Surface Opening Cracks in Concrete Beams

---Concrete is one of the most widely used construction materials and thus assessment of damage in concrete is of the utmost importance from both a safety point of view and a financial point of view. Of particular interest are surface opening cracks that extend through the concrete cover, as this can expose the steel reinforcement bars underneath and induce corrosion in them. This corrosion can lead to significant subsequent damage in concrete such as cracking and delamination of the cover concrete as well as rust staining on the surface of concrete. Concrete beams are designed and constructed in such a way to provide controllable crack depths via a compressive force applied at an eccentricity to the beam. Two different types of measurements are made in-situ to estimate real surface crack depth while the beams are loaded: one based on the impact-echo method and the other one based on the diffuse ultrasonic method. These measurements are compared to both the crack depth visually observed on the sides of the beams and the theoretical crack depth based on cross sectional analysis and the modulus of rupture of the concrete. Discussions are given as to the advantages and disadvantages of each method.

Phased Array Tuning for Optimal Ultrasonic Guided Wave Mode and Frequency Selection

---Ultrasonic guided waves have become widely used in a variety of nondestructive evaluation applications due to their efficiency in defect detection, ability to inspect hidden areas, and other reasons. With a thorough understanding of guided wave mechanics, researchers can predict which guided wave modes will have a high probability of success in a particular nondestructive evaluation application. However, work continues to find optimal mode and frequency selection for a given application. This “optimal” mode could give the highest sensitivity to defects or the greatest penetration power, increasing inspection efficiency. Since material properties used for modeling work may be estimates, in many cases guided wave mode and frequency selection can be adjusted for increased inspection efficiency in the field. In this work, a phased comb array transducer is used to sweep in the phase velocity – frequency space in an effort to determine the optimal mode point for interface waves used to inspect thick bonded structures. By sweeping through nearby mode points, the optimal mode and frequency can be selected which has the highest sensitivity to physically-based features correlated with defect detection. In this application, these features include amplitude ratio, pulse width, and frequency ratio.
Evaluation of Thermal Embrittlement of Structural Steels Using Nonlinear Rayleigh Waves

---Nondestructive evaluation of thermal aging of structural alloys is useful for in situ surveillance of components in high temperature environments. Thermal aging of alloy steel causes incoherent precipitates in the lattice structure, which inhibit the dislocations in the material from moving along their slip planes, resulting in embrittlement and increased hardness. The number of these obstacles (precipitates) in alloy steels that are long-term exposed to high temperatures increases due to the enhanced diffusion and this leads to an increase of the elastic nonlinearity for a given dislocation density. This effect can be measured using nonlinear ultrasound, which has already shown to be highly sensitive to various other microstructural changes. The objective of this research is to investigate the sensitivity of nonlinear ultrasound to the microstructural changes due to thermal aging. Accelerated aging is simulated by isothermal heat treatments and the thermal degradation of alloy steel is experimentally assessed using a nonlinear ultrasonic technique, in particular nonlinear Rayleigh wave based second harmonic generation technique. In addition, thermoelectric power measurements, hardness measurements, and other mechanical characterization are performed to support the data obtained from the nonlinear measurements.

Biosmart Self Healing Material

---Internal stresses might induce microscopic cracks in concrete, which can provide pathways for harmful chemicals to ingress and can lead to loss of strength and integrity. Recent research in the field of concrete materials suggests that it might be possible to develop a smart cement-based material that is capable of self-healing by leveraging the metabolic activity of microorganisms to induce biogenic calcium carbonate precipitation. Nonetheless, the limited research on biomineralization in cement-based systems has shown promising results to recover cracks can occur on the surface of concrete and reduce permeability. However limited research has been conducted to define self-healing of concrete. Objective of this study is to engineer a self-healing concrete that is able to repair itself continuously and internally during its service life. Compressive strength results of damaged mortar samples with microorganisms showed significantly higher strength development compared to samples without microorganisms at 28 days. In order to quantify the self-healing process, the relative ultrasonic wave velocity changes were also monitored on a daily basis, and were calculated afterwards using the coda wave interferometry method. The damaged mortar samples with microorganisms show a much higher gain of ultrasonic wave velocity growth compared to samples without microorganisms.
Evaluation of Mechanical Changes in Concrete Due to Carbonation Reaction by Nonlinear Rayleigh Surface Waves

---Developing conventional linear ultrasonic techniques for evaluating changes in properties in concrete is challenging since concrete exhibits a heterogeneous, multi-scale microstructure with variability of local material properties. This paper presents a nonlinear ultrasonic method for detecting carbonation in concrete. Concrete structures are incessantly exposed to environmental effects. One of the most prevalent environmental interactions is carbonation, in which carbon dioxide penetrates the surface of concrete and reacts with calcium hydroxide, a produce of Portland cement hydration in concrete. Carbonation is of interest because of its role in initiation of reinforcement corrosion but also because of its increasing use during curing to alter the surface properties of cement-based materials and as a method to “sink” carbon in cement-based materials. To assess changes induced by carbonation, nonlinear Rayleigh surface wave measurements are performed on uncarbonated and carbonated concrete samples. In order to eliminate the effects of contact conditions, the generated signals are detected by an air-coupled transducer at locations along the propagation axis. The nonlinearity parameter, $\beta$ is used to quantify the degree of carbonation. A comparison between two samples demonstrates that pores are filled by the carbonation product and the nonlinearity parameter shows a decreasing trend with the progress of carbonation.

Air-Coupled Generation and Detection of Ultrasound in Concrete

---It is well known that liquid coupling agents which are used to couple an ultrasonic transducer to a solid specimen cause a number of problems including inconsistency in results and slowness of the inspection. This is especially true in ultrasonic measurements of concrete components, where the surface roughness can dominate contact techniques. In interrogation applications in the ultrasonic frequency range, it is often necessary to smooth and polish every single point of inspection for repeatable contact, making it impractical to apply traditional contact methods to the inspection of these structures. To address this issue, a fully noncontact, air-coupled measurement setup in the mid to high ultrasonic frequencies (50-150 kHz) is presented. The setup generates and detects Rayleigh surface waves in this frequency range with a sufficiently high signal to noise ratio (SNR), which enables the performance of a fast scan with a small number of signal averages. Using this setup, ultrasonic velocity and attenuation in intact and microstructurally damaged concrete specimens are measured and compared. Also, detection of surface breaking macro-cracks is demonstrated. Finally, the possibility of generating nonlinear Rayleigh waves in concrete using this noncontact setup is explored.
A Clamp Fixture with Interdigital Capacitive Sensor for In Situ Evaluation of Wire Insulation

---An interdigital capacitive sensor has been designed and optimized for testing aircraft wires by applying a quasi-numerical model developed and reported previously. The sensor consists of two patches of interdigitated electrodes, connected by a long signal bus strip, that are intended to conform to two sides of an insulated wire. The electrodes are deposited using photolithography upon a 25.4-μm-thick Kapton® film. The two electrode patches are attached to the two jaws of a plastic spring-loaded clamp, with each jaw having a milled groove designed such that the electrodes conform to the curved surface of the insulated wire. An SMA connector and cable connects between the electrodes on the clamp and an LCR meter. Segments of pristine M5086 aircraft wire, each 10 cm long, were immersed in fluids commonly found in aircraft environments, to cause accelerated chemical degradation. The effects of Jet A fuel, de-icing fluid, hydraulic fluid, aircraft cleaner, isopropyl alcohol and distilled water were studied. The frequency-dependent capacitance and dissipation factor of one pristine wire segment and of those degraded in the six fluid environments were measured in the frequency range 100 Hz to 1 MHz. Significant changes in capacitance and dissipation factor were observed for all degraded wires, compared with results for the pristine sample, suggesting the feasibility of detecting insulation degradation in the field. The results were also consistent with those of a similar experiment performed on sheets of Nylon 6, the material that comprises the outermost layer of M5086 wire.

Resonance Decoupling for Eddy-Current Crack Detection

---Resonance shifting has been used in proximity testing by many authors however the effect of resonance decoupling on eddy-current crack detection inspections has received little attention. A study was performed to investigate the effect of resonance decoupling shifts in the presence of defects on eddy-current signal strength and defect detection. Eddy-current inspections were performed by sweeping through a range of frequencies up to and beyond the resonance of the ECT probe. Results were compared to impedance measurements of the probe on and off large defects on an impedance analyzer and a relationship found between the defect signals of an ECT sweep scan and the shift in resonance. The resulting relationship showed that defect signals follow the gradient of the difference between coupled and uncoupled impedance profiles. The observations suggest the possibility of inferring information about the dimensions of defects by comparing them to an accurate model of the resonance decoupling.
Signal Processing and Computation

CUDA Memory Limitation in Finite Element Optimization to Reconstruct Cracks
--- Sivamayam Sivasuthan, Victor U. Karthik, and Samuel Ratnajeewan H. Hoole, Michigan State University, Department of Electrical and Computer Engineering, East Lansing, MI 48824

--- In the NDE of steel plates, besides the detection of cracks, what is also important is their characterization. Characterization is necessary for determining whether any discovered crack demands withdrawal of the part from service. In eddy current crack identification the response of a part to a coil is compared to the response without a crack. When different, the presence of the crack is flagged. But to characterize it, the computed response from eddy current analysis with a crack described by parameters is optimized to match measurements. This is heavy computation. Recently, Graphical Processing Unit (GPU) computing has had great success in many very large numerical computations. In this paper we discuss the often undiscussed GPU memory limitation in Finite Element Optimization. In GPU computing the memory of the NVIDIA GPU is limited (4GB on a PC today). This paper assesses the implications of memory limits to problem size in light of the various ways to store a large matrix in order to overcome these limits. We revive old element-by-element finite element solvers from the early 1980s for working on a highly memory limited PC 282 to launch an FEM-Optimization kernel on thousands of CUDA threads exploiting the NVIDIA GPU architecture.

Signal Processing and Computation

Examination of Laplace Transform for Pulsed Eddy Current Signal Display and Analysis
--- D. R. Desjardins and T.W. Krause, Royal Military College of Canada, Department of Physics, P. O. Box 17000, Station Forces, Kingston, Ontario, K7K 7B4, Canada

--- A challenge for the application of pulsed eddy current in the inspection of tube, rod and plate structures, commonly encountered in nuclear and aerospace structures for example, is the extraction of relevant features from signals obtained in the time-domain. Exact analytical solutions for the pulsed eddy current response of coils in the presence of conducting structures can be formulated in the s-domain by means of the Laplace transform, but are often too complex to re-invert to the time domain for experimental validation. Rather than tackle the difficulties of inversion, experimental data can be represented in the complex frequency s-domain, thus making it more amenable to theoretical analysis and therefore, interpretation. The transient response of a receive coil centered on the axis of a transmit coil within a conducting tube and above a ferromagnetic conducting half space is measured and displayed in s-space. Geometrical and material characteristics, such as probe lift-off, wall thickness, electrical conductivity and magnetic permeability may be determined from the experimental data displayed in the s-domain using these analytical methods. The s-domain representation of material defects is also presented and a comparison of the experimental and theoretical data in complex frequency space is discussed.
Signal Processing and Computation

Image De-Noising Via Spectral Distribution Similarity Analysis for Ultrasonic Non-Destructive Evaluation
---B. Xiao, M. Li, R. Gongzhang, R. O’Leary, and A. Gachagan, University of Strathclyde, Department of Electronic & Electrical Engineering, Glasgow, Scotland, United Kingdom

---Ultrasonic detection and characterization of flaws in coarse-grained materials exhibiting heterogeneous and scattering microstructure is of particular importance but remains challenging. Most spectral based de-noising methods in literature are sensitive to material properties, which necessitate a troublesome parameters optimization process and consequently impede their application into ultrasonic image processing. In order to improve flaw visibility in an image, we propose a novel and robust clutter suppression method through spectral distribution similarity analysis (SDSA). This method isometrically segments all the time-series data in a dataset acquired by the Full-Matrix-Capture technique, and then censuses the spectral distribution of global segments and of local segments for every focusing point in the Total-Focusing-Method image. The index computed by measuring the similarity between two spectral distributions reveals the possibility of a legitimate flaw indication. Experiments on two highly scattering samples were conducted to validate this method. By applying SDSA, crack visibility is greatly enhanced with an average >20 dB target-to-noise ratio enhancement for the stainless steel weld sample, whilst ~30dB improvement for the austenitic steel sample. The proposed technique retains excellent performance for both samples when the selected segment length is varied, proving its robustness and highlighting its potential for application across various materials.

Signal Processing and Computation

Robust Frequency Diversity Based Algorithm for Clutter Noise Reduction of Ultrasonic Signals Using Multiple Sub-Spectrum Phase Coherence
---Rui Gongzhang, Minghui Li, Bo Xiao, Timothy Lardner, and Anthony Gachagan, Center for Ultrasonic Engineering, University of Strathclyde, Glasgow, United Kingdom

---This paper presents a robust frequency diversity based algorithm for clutter reduction in ultrasonic A-scan waveforms. The performance of conventional spectral-temporal techniques like Split Spectrum Processing (SSP) is highly dependent on the parameter selection, especially when the signal to noise ratio (SNR) is low. Although spatial beamforming offers noise reduction with less sensitivity to parameter variation, phased array techniques are not always available. The proposed algorithm first selects an ascending series of frequency bands. A signal is reconstructed for each selected band in which a defect is present when all frequency components are in uniform sign. Combining all reconstructed signals through averaging gives a probability profile of potential defect position. To facilitate data collection and validate the proposed algorithm, Full Matrix Capture is applied on the austenitic steel and high nickel alloy (HNA) samples with 5MHz transducer arrays. When processing A-scan signals with unrefined parameters, the proposed algorithm enhances SNR by 30dB for both samples and consequently, defects are more visible in B-scan images created from the large amount of A-scan traces. Importantly, the proposed algorithm is considered robust, while SSP is shown to fail on the austenitic steel data and only achieves 10dB SNR enhancement on the HNA data.
**Signal Processing and Computation**

**Time-Delay Estimation Via Third-Order Cumulant Cross-correlation Method Used in Liquid Viscosity Measurement**

---Shiyuan Zhou, Yao Xu, Dingguo Xiao, and Chunguang Xue, Beijing Institute of Technology, School of Mechatronical Engineering, Beijing, China

---The reliability and accuracy of ultrasonic liquid viscosity measurement is directly determined by the reliability and accuracy of time-delay estimation. In practical measurement, noises lead to signal interference and low precision of time-delay estimation. In this paper, the third-order cumulant cross-correlation time-delay estimation method is applied to the measurement of liquid viscosity based on ultrasonic technology. Simulation calculation shows that the third-order cumulant cross-correlation time-delay estimation method can effectively suppress the effect of correlated Gaussian noise sources. Thus, in the case of low signal-to-noise ratio, this method still can accurately calculate the time delay of the pulse, effectively improving the reliability and the accuracy of viscosity measurement.

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**Signal Processing and Computation**

**Knowledge Extraction Algorithms Dedicated for Identification of Steel Bars in Reinforced Concrete Structures**

---Pawel Karol Frankowski, Tomasz Chady, and Ryszard Sikora, West Pomeranian University of Technology, Szczecin, Poland

---The purpose of this paper is to present knowledge extraction algorithms, dedicated for new electromagnetic system used to evaluation of steel bars in reinforced concrete structures. Said system consists of eddy current transducers, XYZ scanner, an excitation subsystem, a data acquisition subsystem with lock in amplifier and a controlling computer. Good data understanding requires extraction and selection of useful patterns from measurement results. These patterns could be presented and stored as an association rules. This paper presents how this process could be automatized. One of the most important stage of knowledge extraction is data cleaning and preparation. It is also important to select most useful attributes to analysis. For those purposes, selected filters and methods were applied, achieved results are presented. The main, final result of knowledge extraction in this case is identification of reinforced concrete structure parameters. Many different classifiers can be used for that purpose. This paper presents also results of the classifiers evaluation.
Eddy Current

Including the Skin-Effect in the Circuit Theory of Eddy-Current Induction
---Robert R. Hughes and Steve M. Dixon, University of Warwick, Department of Physics, Gibbet Hill Road, Coventry, CV4 7AL, United Kingdom

---Electromagnetic coupling to electrically conducting materials, via eddy-current generation is the foundation of eddy-current testing and is frequently modelled as a simple transformer circuit. This is done by approximating the eddy-currents to a single coil turn at the surface of the material, however this approach ignores the influence of the skin-effect on the coupling system. A new transformer circuit model theory is explained considering the response the skin-effect has on the measured properties of an inductive coil above the material surface. This new approach can be used to estimate the electrical changes in the coil as it decouples from the surface.

Eddy Current

Eddy Current Coil Interaction with Edges in the Inspection of Holes
--- Hui Xie1, Yi Lu2, and John R. Bowler1,2, 1Department of Electrical and Computer Engineering, Iowa State University, Ames, IA 50011; 2Center for NDE, Iowa State University, Ames, IA 50011

--- An analytical method is given for finding the electromagnetic field due to a circular induction coil at the opening of a borehole in a conductor. To keep the problem relatively simple, it is assumed initially that the hole is of infinite depth and perpendicular to the surface of a homogeneous half-space conductor. From knowledge of the field, the variation in the coil impedance with position has been calculated to show its variation with position as the coil passes out of the hole. The procedure represents a step in the process of constructing an efficient semi-analytical model that predicts inductive probe signals due to cracks at the borehole edge. The field is determined using the truncated region eigenfunction expansion method in which the domain of the problem is truncated in the axial direct. This means that the solution representing can be represented in series form. Matrix equations are derived for the expansion coefficients found from interface conditions on the electromagnetic field at the bore-hole surface and extended into the air to the upper truncation limit some distance from the conductor. A comparison of the variations in coil impedance with axial position shows good agreement with experiment.---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 Nondestructive Evaluation.
Eddy Current

Development of Bolt Hole Inspection Technique by Eddy Current Testing
---Dong-Man Suh, Raynar/Kunjang Univ. College, NDT Dept., Daejon, Korea; Ji-Eun Jang, Kwan-Seob Jang, and Hong-Geun Lee, Sae-An Corp., Seoul, Korea

---Although the conventional eddy current testing is a powerful method to detect flaws in testing materials, it is difficult to detect defects in the deep bolt hole of the important testing materials due to the surface roughness. Especially bolt hole of the automotive engine block is so difficult to detect a defect because the eddy current signal is changing from the inside surface roughness in bolt hole. The present paper relates to a defect impedance measurement using eddy current (ECT). And we set up another ECT method by scanning bolt hole. The signals were stored with a program for displaying the ECT signal on a graph, which processes a resultant value to be displayed. So, in this study, we have investigated performance of eddy current testing method by measuring impedance variation of fabricate of specimens. From the investigation results, eddy current test can be one of thread detect for inspection of defect by impedance plane. And we apply eddy current testing method by scanning the thread of bolt hole. The investigation results obtained from mock-up specimens.

Ferrite Core Probe Interaction with Cracks
---Yi Lu¹ and Theodoros Theodoulidis², Iowa State University, Ames, IA 50011; ¹Center for Nondestructive Evaluation; ²Department of Mechanical Engineering, University of Western Macedonia, Greece

---An analytical model of an axisymmetric ferrite-cored probe interaction with a crack in a conductive plate has been developed. The solution of the incident field in a conductor without a crack is given in series of Fourier-Bessel functions using the radially truncated region eigenfunction expansion (TREE) method. During the solution construction, the reflection and transmission coefficient matrices representing the end effects of the ferrite core are introduced. The electric current dipole density that accounts for the electromagnetic field in a planar crack is derived using a volume element method. The impedance variation of a ferrite-cored probe due to a crack is determined by a reciprocity theorem. The numerical prediction of the probe impedance change as a function of positions has been verified by both experiments and FEM simulations showing excellent agreement.---This work was supported by the NSF Industry/University Cooperative Research program.
Eddy Current

A Feasibility Study for Lamb Wave Mixing Nonlinear Technique
---Dong Jin Lee1, Younho Cho1*, Weibin Li1,
1School of Mechanical Engineering, Pusan National University, Pusan, South Korea

---The acoustic nonlinearity $\beta$ is known as a promising tool for measuring the fatigue damage of the structures. To measure the nonlinear parameter, several methods were used to investigate the appropriate harmonic components for representing the material nonlinearity. However, the trend of material nonlinearity is difficult to extract because of the experimental system or external environment factors. Therefore, we investigated various aspects of nonlinear feature by the Lamb wave mixing technique. Two Lamb wave modes with different frequency were induced to generate the harmonic waveform which is related to the certain sub-harmonic frequency. In this study, it will be proposed that the Lamb wave mixing technique can be used as an alternative promising approach.

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Eddy Current

A Study On Nondestructive Evaluation Technique By The Use Of Interface Guided Waves On Shrink Fit Structure
---Jaesun Lee1, Younho Cho1*, Jun-Pil Park1, Joseph L.Rose2, Hyung Huh3, Keun-Bae Park3, Dong-Ok Kim3, 1School of Mechanical Engineering, Pusan National University, Pusan, South Korea, 2Department of Engineering Science and Mechanics, Pennsylvania State University, State College, PA; 3Korea Atomic Energy Research Institute, Daejeon, South Korea

---Guided wave was widely studied for plate and pipe due to the great application area. Guided wave has advantage on long distance inspection for an inaccessible area and apart from transducer. Quite often shrink fit structures were found in nuclear power facilities. In this paper, two pipes were designed with perfect shrink fit condition for Stainless Steel 316. The displacement distribution was calculated with boundary condition. The interface wave propagation pattern was analyzed by the numerical modeling. The experimental result shows a possibility of weld delamination and defect detection.
Eddy Current

A Comparison of NDI Techniques for the Inspection of Thick Multi-layer Metallic Structures
---Doyle Motes², David S. Forsyth², Mark Keiser², Gary Steffes¹, and John C. Aldrin³; ¹Air Force Research Laboratory (AFRL/RXLP), Wright-Patterson AFB, OH 45433; ²TRI/Austin, Austin, TX 78746; ³Computational Tools, Gurnee, IL 60031

---As many USAF airframes operational lifetimes are being extended past their original retirement dates, the inspections of these structures and the ability of inspectors to reliably identify defects is critical to maintaining the fleet at maximum readiness. Additionally, there have been pushes to incorporate automated systems that may significantly reduce depot inspection times through advancements over present man-hour intensive NDI methods by minimizing unnecessary component disassembly, repair, and/or airframe retirement. Previously, the authors reported on work conducted to validate a GMR sensor array mounted to a Boeing Mobile Automated Scanner (MAUS). In this work, the results from two additional inspection technologies are presented using the same configurable fatigue crack specimens from the GMR sensor array validation program as targets. These technologies include a manual ET ring probe (presently used in the inspection of thick, multi-layer metallic structures) and a single ET probe mounted to a different MAUS system. Probability of Detection (POD) data from all of the different inspection techniques are presented and compared here with emphasis maximum detection depth, fatigue crack specimen thickness, effects of different fastener type/material on sensor response, and inspection time.

Guided Waves

Multiple Scattering of Surface Waves by Cavities in a Half-Space
---Haidang Phan, Younho Cho, and Taeho Ju², Pusan National University, School of Mech. Eng., Pusan, South Korea; Jan D. Achenbach² and J. Qu², Northwestern University, Center for QEFp, Evanston, IL 60208

---Scattering of surface waves from multiple two-dimensional cavities at the surface of a homogenous, isotropic, linearly elastic half-space is analyzed in this work. For the case of multiple cavities, the scattered field is shown to be equivalent to the total radiation from the distributions of tractions, calculated from the incident wave, over the surfaces of the cavities. The multiple-scattering model is obtained from the known single-scattering calculation for a cavity by the use of the self-consistent method. The second order approximation to the multiple-scattering problem by an array of cavities is then considered and solved analytically. The vertical displacement at some distance from the cavities is calculated and verified by the solution of the same problem obtained by the boundary element method (BEM). The analytical and BEM results are graphically displayed and show good agreement when the depths of the cavities are small compared to the wavelength.
Millimeter-Wave three-dimensional (3D) imaging technique based on synthetic aperture radar (SAR) algorithm is a robust tool for nondestructive evaluation (NDE) applications. Conventionally, it takes a relatively long time to perform raster scanning on dense grids, required for millimeter-wave imaging. The long scan time is due to the fact that the scanning system has to stop, at every position in the scan grid, while the reflectometer makes the measurements over a relatively wide frequency range. This sweep time and the acceleration/deceleration time associated with the stop and go movement of the scanner results in a substantially long measurement time at these frequencies. Furthermore, vector reflectometers are expensive and bulky instruments that may not be readily available for in-field testing. An imaging system will be presented consisting of a novel Ka-band (26.5-40 GHz) interferometry-based reflectometer which is used along with a manual scanner. This unique millimeter-wave imaging system involves free-hand manual scanning while the reflectometer continuously sweeps over the desired frequency range resulting in a non-uniformly sampled wide-band reflection measurements data. The measured data is then passed through a novel SAR algorithm that produces focused 3D or 2D images in real-time. The measurement methodology along with a few experimentally obtained images will be presented.
Session 14
SESSION 14  
BENCHMARK VALIDATION NDE  
Lester W. Schmerr, Jr., Chairperson  
Key Ballroom 10

3:30 PM  Comparison of Two Modeling Approaches of Eddy Current Industrial Non-Destructive Testing of Steel Pipes  
---A. Trillon and F. Deneuville, VMF-VRA (Vallourec Research Aulnoye), Aulnoye-Aymeries, France; Christophe Reboud, CEA LIST, Centre de Saclay, Gif-sur-Yvette, France; F. Foucher, Extende, Massy, France; D. Lesselier, Laboratoire des Signaux et Systems (L2S), Supelec, Gif-sur-Yvette, France; L. Maurice, EDF-CEIDRE, Saint-Denis, France

3:50 PM  Solution to the WFNDEC 2013 Eddy Current Benchmark Problem Via a Coupled VIM-BEM Approach  
---Roberto Miorelli and Christophe Reboud, CEA LIST, Departement Imagerie Simulation pour le Controle, Gif-sur-Yvette, France; Theodoros Theodoulidis, University of Western Macedonia, Department of Mechanical Engineering, Kozani, Greece

4:10 PM  Results of the 2013 UT Modeling Benchmark Obtained with Models Implemented in CIVA  
---Gwenael Toullelan, Raphaele Raillon, and Sylvain Chatillon, CEA LIST, 91191 Gif-sur-Yvette, France; Sebastien Lonne, EXTENDE, Le Bergson, 15 Avenue Emile Baudot, 91 300 Massy, France

4:30 PM  A Proposed Benchmark for Simulation of Photon Interactions in Radiographic Testing  

4:50 PM  Towards an Eddy Current Benchmark on Ferromagnetic Materials  
---Javier I. Etcheverry, Gustavo A. Sanchez, and Daniel H. Ziella, Tenaris Siderca R&D, Applied Physics Department, Campana, Buenos Aires, B2804MHZ, Argentina

5:10 PM  Eddy Current Benchmark Analysis with COMSOL  
---Javier I. Etcheverry and Daniel H. Ziella, Tenaris Siderca R&D, Applied Physics Department, Campana, Buenos Aires, B2804MHZ, Argentina
3:30 PM

Comparison of Two Modeling Approaches of Eddy Current Industrial Non-Destructive Testing of Steel Pipes

---A. Trillon and F. Deneuville, VMF - VRA (Vallourec Research Aulnoye), Aulnoye-Aymeries, France; C. Reboud, CEA - LIST, Centre de Saclay, Gif-sur-Yvette, France; F. Foucher, Extende, Massy, France; D. Lesselier, Laboratoire des Signaux et Systèmes (L2S), Supélec, Gif-sur-Yvette, France; L. Maurice, EDF - CEIDRE, Saint-Denis, France

---In the framework of the NDT working groups proposed by the COFREND (the French Confederation for Non-Destructive Examinations), the working group on « Eddy current modeling» has for objectives to provide some modeling benchmarks in relation with representative industrial configurations, and where the modeling results from different candidates codes can be compared with experimental results. One of the benchmarks has been proposed by Vallourec. It corresponds to the case of the industrial non-destructive testing of seamless steel pipes by Eddy current method with encircling coils. In this benchmark, the centering of the steel pipe in the coil is consecutively considered as perfect and with an off-centering in relation with the conditions of the guiding. Some first codes for Eddy current modeling have been evaluated by the Research center of Vallourec (VRA Vallourec Research Aulnoy) and by Extende on the configurations described in this benchmark. The tested codes use different modeling methods: a semi-analytical method through the CIVA software developed by the CEA on the one hand; and a finite element method through the softwares Flux and Comsol on the other hand. Then, the results of the different codes have been compared with experimental results. The conclusions are that the results obtained from the two modeling methods are very similar between them and coherent to experimental data. It proves that these two simulations methods are valid and could be used in a complementary way.

3:50 PM

Solution to the WFNDEC 2013 Eddy Current Benchmark Problem Via a Coupled VIM-BEM Approach

---Roberto Miorelli and Christophe Reboud, CEA LIST, Département Imagerie Simulation pour le Contrôle, Gif-sur-Yvette, France; Theodoros Theodoulidis, University of Western Macedonia, Department of Mechanical Engineering, Kozani, Greece

---We present theoretical results for the WFNDEC 2013 eddy current benchmark obtained with a newly developed integral equation-based approach. The model proposed is based on the joint use of Volume Integral Method (VIM) and Boundary Element Method (BEM). We refer hereafter to the VIM-BEM to identify this coupled approach implemented in the simulation platform CIVA, developed at CEA LIST. The benchmark problem consists of measurements of the variations of impedance of a pancake coil inspecting different specimen configurations at 1 and 5 kHz frequencies in absolute mode. The benchmark test cases are obtained from different combinations of two aluminum plates with one hole or one hole and a radial narrow crack. Eddy current signals have been recorded with the coil for a longitudinal scan along the crack line and passing through the hole(s) center(s). The VIM-BEM approach yields numerical results that fit very well to the experimental ones in all benchmark test cases and for both frequencies. Moreover, it considerably increases the computational efficiency (CPU times get much smaller) compared to a resolution with VIM only.
**Results of the 2013 UT Modeling Benchmark Obtained With Models Implemented In CIVA**
---Gwenael Toullelan, Raphaele Raillon, and Sylvain Chatillon, CEA LIST, 91191 Gif-sur-Yvette, France; Sebastien Lonne, EXTENDE, Le Bergson, 15 Avenue Emile Baudot, 91 300 Massy, France

---This communication presents the results obtained on the configurations proposed in the 2013 Ultrasonic Testing (UT) modeling benchmark with the models implemented in the CIVA software. The results concern echoes from side drilled holes (SDH), flat bottom holes (FBH) and breaking notches in a planar block examined with a matrix phased array. In CIVA, the field radiated by the probe is computed by applying the so-called pencil-model, the Kirchhoff approximation is applied to predict the response of FBH and notches and the SOV (Separation Of Variables) model is used for the SDH responses. The comparison between simulated and experimental results are presented and discussed.

**A Proposed Benchmark for Simulation of Photon Interactions in Radiographic Testing**

---In continuation of previous efforts a possible benchmark problem is defined for comparison of different RT simulators. The benchmark shall focus on comparison of basic photon interactions. MCNP (Monte Carlo N-Particle code) shall serve as reference. For the energy range 100keV to 10MeV we propose a set of monoenergetic calculations for a geometrical setup consisting of two plates of different materials. A lesson learned during evaluation of the last benchmarks is, that for higher energies the lateral plate dimension has to be increased for reliable analysis. As an extension to the previous benchmarks the considered physical effects should include all those available for photons and electrons in MCNP. We propose to compare profiles and spectra of scatter radiation, as well as scatter ratios.
Towards an Eddy Current Benchmark on Ferromagnetic Materials
---Javier I. Etcheverry, Gustavo A. Sánchez, and Daniel H. Ziella, Tenaris Siderca R&D, Applied Physics Department, Campana, Buenos Aires, B2804MHA, Argentina

Ferromagnetic materials present unique difficulties for eddy currents inspection, due to the signals produced by localized variations of permeability. The latter are mainly due to residual magnetization and residual stresses. Numerical simulations are very useful in the design and optimization of successful inspection techniques, but it is not clear that are up to the task in such a complex situation. Many of the available tools are based on a linearity assumption, and do not have an easy way of including position dependent properties, or residual magnetization. In this work we present some preliminary measurements scanning a single coil over a steel plate with a notch, for different applied and residual magnetic fields. The goal is to develop a benchmark that is useful to assess how much a realistic residual magnetization will affect simple linear predictions, and explore more complex numerical approaches to understand their capabilities and limitations. Preliminary numerical simulations will also be presented.

Eddy Current Benchmark Analysis with COMSOL
---Javier I. Etcheverry and Daniel H. Ziella, Tenaris Siderca R&D, Applied Physics Department, Campana, Buenos Aires, B2804MHA, Argentina

Several benchmark studies in eddy currents have been proposed by the WFNDEC. Also, there are many analytical exact and approximate solutions of interest to quantitatively evaluate the capability of numerical codes to predict the magnitude of the induced currents effects. In this paper we present the results obtained using COMSOL for a representative set of cases of interest. We analyze the accuracy of the results, but also the elements that we believe are relevant from the perspective of the NDE specialist (simplicity, computer requirements, things to take into account to get good results, problems faced when solving, failures, etc.).
Session 15
SESSION 15
ULTRASONICS-NONLINEAR EFFECTS
Peter B. Nagy and Dan Barnard, Co-Chairpersons
Key Ballroom 11

3:30 PM Ultrasonic Evaluation of Residual Stresses in Aero Engine Materials Using Bulk and Rayleigh Surface Waves
---Sebastian Hubel, Martin Spies, Alexander Dillhoefer, and Hans Rieder, Fraunhofer-Institute for Industrial Mathematics ITWM, Image Processing Department, 67663 Kaiserslautern, Germany; Joachim Bamberg, Roland Hessert, and Christina Preikszas, MTU Aero Engines GmbH, Zerstoerungsfreie Pruefverfahren, 80995 Munich, Germany

3:50 PM Reflection and Diffraction Corrections for Nonlinear Materials Characterization by Quasi-Static Pulse Measurement
---Peter B. Nagy, University of Cincinnati, School of Aerospace Systems, 731 Rhodes Hall, ML 0070, Cincinnati, OH 45221-0070; Jianmin Qu, Northwestern University, Department of Civil and Environmental Engineering, Evanston, IL 60208-3109; Laurence J. Jacobs, Georgia Institute of Technology, College of Engineering, Atlanta, GA 30332-0360

4:10 PM Application of the Non-Collinear Mixing Technique for the Evaluation of Closed Cracks
---P. Blanloeuil and A. Meziane, Universite Bordeaux, 12M, UMR 5295, F-33400, Talence, France; A. J. Croxford, Department of Mechanical Engineering, University of Bristol, Queen's Building, University Walk, Bristol BS8 1TR, United Kingdom

4:30 PM Influence of Localized Microstructure Evolution on Higher Harmonic Generation of Guided Waves
---Gloria Choi, Yang Liu, and Clifford J. Lissenden, The Pennsylvania State University, Department of Engineering Science and Mechanics, 212 Earth and Engineering Science Building, University Park, PA 16802

4:50 PM Characterization of Microstructural Changes in Plates Using Guided Wave Third Harmonic Generation
---Yang Liu, Cliff J. Lissenden, and Joseph L. Rose, The Pennsylvania State University, Department of Engineering Science and Mechanics, University Park, PA 16802

5:10 PM Limitations and Improvements for Harmonic Generation Measurements
---Steven R. Best, Anthony J. Croxford, and Simon A. Neild, University of Bristol, Department of Mechanical Engineering, Bristol, Avon, United Kingdom

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Ultrasonic Evaluation of Residual Stresses in Aero Engine Materials Using Bulk and Rayleigh Surface Waves
---Sebastian Hubel, Martin Spies, Alexander Dillhoefer, and Hans Rieder, Fraunhofer-Institute for Industrial Mathematics ITWM, Image Processing Department, 67663 Kaiserslautern, Germany; Joachim Bamberg, Roland Hessert, and Christina Preikszas, MTU Aero Engines GmbH, Zerstorungsfreie Pruefverfahren, 80995 Munich, Germany

---To satisfy the high demands in view of technical reliability, weight, power, economic efficiency and lifetime of modern aero engines, it is essential to benefit from the full potential of the employed materials. In this respect, residual stresses in the bulk of components are of considerable importance as they have e.g., a strong influence on component distortions during the whole manufacturing process and therefore also on the efficiency of these processes. On the other hand, residual stresses are deliberately introduced e.g., by shot-peening or cold-work in the near-surface areas of highly loaded components. The aim of our research was to test whether the measurement of residual stresses using ultrasound is applicable for nickel- and titanium-based alloys used in aero engine manufacturing. In this contribution we first report on basic investigations performed with regard to the achievable measuring effects. In uniaxial tensile tests we determined the time-of-flight sensitivity of different ultrasonic waves in dependence of the stresses applied to specimens made of Inconel IN718 and the Titanium alloy Ti6242. We have calculated weighting factors describing the correlation between the change in stresses and the change in the velocities of longitudinal waves and of shear waves with different polarization directions with respect to the applied stresses. Based on these results, we have further investigated the potential to quantitatively characterize near-surface residual stress profiles by exploiting the frequency dependence of the penetration depth of Rayleigh waves. In our contribution we give a short overview over the basic principles of the ultrasonic method, we illustrate the modification and assembly of a high-precision ultrasound time-of-flight measurement system and present the results obtained for bulk and surface waves. We also discuss the effect of texture on the measurement results and analyze the results with respect to future work.

Reflection and Diffraction Corrections for Nonlinear Materials Characterization by Quasi-Static Pulse Measurement
---Peter B. Nagy, University of Cincinnati, School of Aerospace Systems, 731 Rhodes Hall, ML 0070, Cincinnati, OH 45221-0070; Jianmin Qu, Northwestern University, Department of Civil and Environmental Engineering, Evanston, IL 60208-3109; Laurence J. Jacobs, Georgia Institute of Technology, College of Engineering, Atlanta, GA 30332-0360

---A harmonic acoustic tone burst propagating through an elastic solid with quadratic nonlinearity produces not only a parallel burst of second harmonic but also an often neglected quasi-static pulse associated with the acoustic radiation-induced eigenstrain. Although initial analytical and experimental studies by Yost and Cantrell suggested that the pulse might have a right-angled triangular shape with the peak displacement at the leading edge being proportional to the length of the tone burst, more recent theoretical, analytical, numerical, and experimental studies proved that the pulse has a flat-top shape and the peak displacement is proportional to the propagation length. In this talk, analytical and numerical simulation results are presented to illustrate two types of finite-size effects. First, the finite axial dimension of the specimen cannot be simply accounted for by a linear reflection coefficient that neglects the nonlinear interaction between the combined incident and reflected fields. Second, the quasistatic pulse generated by a transducer of finite aperture suffers more severe divergence than both the fundamental and second harmonic pulses generated by the same transducer. These finite-size effects can make the top of the quasi-static pulse sloped rather than flat and therefore must be taken into consideration in the interpretation of experimental data.
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Application of the Non-Collinear Mixing Technique for the Evaluation of Closed Cracks
---P. Blanloeuil and A. Meziane, Univ. Bordeaux, I2M, UMR 5295, F-33400 Talence, France, Arts et Métiers ParisTech, I2M, UMR 5295, F-33400 Talence, France; A. J. Croxford, Department of Mechanical Engineering, University of Bristol, Queens Building, University Walk, Bristol BS8 1TR, United Kingdom

---Detecting cracks at an early stage is critical for many industries. Linear ultrasonic methods have limited capabilities to detect closed cracks. By contrast, nonlinear acoustic methods are sensitive to closed cracks and contacting interfaces. However, they are also sensitive to exterior sources of nonlinearity, such as any produced by electronics, or the inherent nonlinearity of the material. Therefore, it is necessary to develop new methods that are only sensitive to the nonlinearity generated by the crack. This paper presents both a numerical and an experimental study of the non-collinear mixing technique, applied to the evaluation of a contacting interface with friction. A finite element (FE) model is built to demonstrate the feasibility of the method. The interface is modelled using a unilateral contact law with Coulomb friction and the explicit FE software Plast2D is used to solve the dynamic problem. The method is then applied experimentally to a solid-solid interface and the nonlinear response is obtained as a function of the applied load. Experimental and numerical results show good agreement.

4:30 PM

Influence of Localized Microstructure Evolution on Higher Harmonic Generation of Guided Waves
---Gloria Choi, Yang Liu, and Clifford J. Lissenden, The Pennsylvania State University, Department of Engineering Science and Mechanics, 212 Earth and Engineering Science Building, University Park, PA 16802

---Higher harmonic generation can be used to detect precursors to fatigue cracks such as persistent slip bands and increasing dislocation density because these types of microstructure evolution result in nonlinear material behavior. Characterization of precursors to macroscale damage has huge advantages in terms of prognostics and maintenance decision making. It is well known that internal resonance, where power flux from the primary mode to the secondary mode is nonzero and these two modes are synchronized, results in a cumulative secondary wave field; i.e., the amplitude of the secondary mode increases linearly with propagation distance. This is an important condition because it enables material-related nonlinearity to be distinguished from measurement system nonlinearities. The issue of localized microstructure evolution complicates matters for ultrasonic guided waves because it results in the nonlinearity of the waveguide being nonhomogeneous. In this presentation, the influence of localized microstructure evolution on nonlinear guided waves is studied by finite element simulations of an aluminum plate. The material nonlinearity is represented through a hyperelastic material model, whereby the microstructure evolution is linked to evolution of the third order elastic constants. Localization is studied by decreasing the waveguide subdomain having evolved material parameters.
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Characterization of Microstructural Changes in Plates Using Guided Wave Third Harmonic Generation
---Yang Liu, Cliff J. Lissenden, and Joseph L. Rose, The Pennsylvania State University, Department of Engineering Science and Mechanics, University Park, PA 16802

---Linear ultrasonic waves are sensitive to features like scattering, attenuation, and reflection coefficients that are good indicators of material macro damage state. In many cases such as fatigue cracks propagate very quickly once initiated, such that there is insufficient remaining life once macroscale cracks become detectable with linear ultrasonics. Therefore, the ability to detect the changes in microstructural features such as dislocation density and persistent slip bands that precede crack initiation is highly desirable. Nonlinear ultrasonics has been shown to have the capability to provide sensitivity to microstructural changes. Higher harmonic generation of plate waves combines sensitivity of nonlinear ultrasonics and the long range inspection capability of guided waves attracts much research interest. Despite the success in using second harmonics of plate waves to characterize material microstructural changes, one major challenge is the difficulty in exciting these primary modes with the current state of transducer technology. In this work, we provide an option to characterize material microstructural evolution using cumulative third harmonics of plate waves. One major advantage of this method is the good excitability of primary modes that are capable of generating cumulative third harmonics.

5:10 PM

Limitations and Improvements for Harmonic Generation Measurements
---Steven R. Best, Anthony J. Croxford, and Simon A. Neild, University of Bristol, Department of Mechanical Engineering, Bristol, Avon, United Kingdom

---A typical acoustic harmonic generation measurement comes with certain limitations. Firstly, the use of the plane wave-based analysis used to extract the nonlinear parameter, $\beta$, ignores the effects of diffraction, attenuation and receiver averaging which are common to most experiments, and may therefore limit the accuracy of a measurement. Secondly, the method usually requires data obtained from a through-transmission type setup, which may not be practical in a field measurement scenario where access to the component is limited. Thirdly, the technique lacks a means of pinpointing areas of damage in a component, as the measured nonlinearity represents an average over the length of signal propagation. Here we develop a three-dimensional model of harmonic generation, based on a quasi-linear assumption, aimed at addressing these issues. The model provides a realistic representation of a typical experiment and is used as an alternative means of extracting $\beta$ from experimental measurements. The presence of a reflecting boundary is then incorporated into the model to assess the feasibility of performing single-sided measurements. Experimental validation is provided where possible. Finally, a focusing acoustic source is modelled to provide a theoretical indication of the afforded advantages when the nonlinearity is localized.
Session 16
SESSION 16
CIVIL MATERIALS AND STRUCTURES
Larry Jacobs, Chairperson
Key Ballroom 3

3:30 PM Feasibility Study of Prompt Gamma Neutron Activation for NDT Measurement of Moisture in Stone and Brick
---Richard A. Livingston and Mohamad Al-Shekhly, University of Maryland, Materials Science & Engineering Department, College Park, MD; Carol Grissom and Emily Aloiz, Smithsonian Institution, Museum Conservation Institute, Suitland, MD; Rick Paul, National Institute of Standards and Technology, Chemical Sciences Division, Gaithersburg, MD 20899

3:50 PM Evaluating the Integrity of the RC Structure Repaired by Epoxy Injection Using Simulated Transfer Function of the Impact-Echo Response
---Chia-Chi Cheng, Jiunn-Hong Wu, Keng-Tsan Hsu, and Ying-Tsu Ke, Chaoyang University of Technology, Department of Construction Engineering, Taichung, Taiwan

4:10 PM Inspection of Large Diameter Storage Tank Floors Using Magnetostrictively-Generated Guided Waves
---Alan R. Puchot, Adam C. Cobb, Charles E. Duffer, and Glenn M. Light, Southwest Research Institute, 6220 Culebra Road, San Antonio, TX 78238

4:30 PM Non-Destructive Inspection Protocol for Reinforced Concrete Highway Barriers and Bridge Railings
---Satish R. Chintakunta, Engineering and Software Consultants, Inc., Chantilly, VA; Shane D. Boone, Federal Highway Administration, TFHRC, McLean, VA

4:50 PM Omni-Directional Guided Wave Mode Control with Annular Array Transducers in Plate Like Structures
---Jaya Prakash Koduru, Sepandarmaz Momeni, and Valery Godinez, MISTRAS Group, Inc., Products and Systems Division, 195 Clarksville Road, Princeton Junction, NJ 08536
3:30 PM

Feasibility Study of Prompt Gamma Neutron Activation for NDT Measurement of Moisture in Stone and Brick
---Richard A. Livingston and Mohamad Al-Shekhly, University of Maryland, Materials Science & Engineering Department, College Park, MD; Carol Grissom and Emily Aloiz, Smithsonian Institution, Museum Conservation Institute, Suitland, MD; Rick Paul, National Institute of Standards and Technology, Chemical Sciences Division, Gaithersburg, MD

---The conservation of stone and brick art or architecture often involves damage caused by moisture. The feasibility of a NDT method based on prompt gamma neutron activation (PGNA) for measuring the element hydrogen as an indication of water is being evaluated. This includes systematic characterization of the lithology and physical properties of eight building stones and one brick used in the buildings of the Smithsonian Institution in Washington, D.C. To determine the required dynamic range of the NDT method, moisture-related properties was measured by standard methods. Cold neutron PGNA was also used to determine chemically bound water (CBW) content. The CBW does not damage porous masonry, but creates an H background that defines the minimum level of detection of damaging moisture. The CBW was on the order of 0.5% for all the stones. The upper bound of moisture content, set by porosity through water immersion, would be on the order of 5%. Thus the dynamic range is about 1 00. The H count rates were roughly 1-3 cps. Taking into account differences in neutron energies and fluxes and sample volume between cold PGNA and a portable PGNA instrument, it appears that it would be feasible to apply PGNA in the field.

3:50 PM

Evaluating the Integrity of the RC Structure Repaired by Epoxy Injection Using Simulated Transfer Function of the Impact-Echo Response
---Chia-Chi Cheng, Jiunn-Hong Wu, Keng-Tsan Hsu, and Ying-Tsu Ke, Chaoyang University of Technology, Department of Construction Engineering, Taichung, Taiwan

---Cracks and honeycombs are often found inside reinforced concrete structure caused by excessive external force, or improper casting of concrete. The repairing method usually involves epoxy injection. The impact-echo method, which is a sensitive for detecting of the interior voids, may not be applicable to assess the integrity of the repaired member as both air and epoxy are less in acoustic impedances. In this study, the repaired RC structure was evaluated by the simulated transfer function of the IE displacement waveform where the R-wave displacement waveform is used as a base of a simulated force-time function. The effect of different thickness of the epoxy layer to the amplitude corresponding to the interface is studied by testing on specimen containing repaired naturally delaminated cracks with crack widths about 1 mm, 3 mm and 5 mm. The impact-echo responses were compared with the drilling cores at the test positions. The results showed the cracks were not fully filled with epoxy when the peak amplitude corresponding to the interface dropped less than 20%. The peak corresponding to the thicker epoxy layer tends to be larger in amplitude. A field study was also performed on a column damaged by earthquake before and after repairing.
4:10 PM

Inspection of Large Diameter Storage Tank Floors Using Magnetostrictively-Generated Guided Waves
---Alan R. Puchot, Adam C. Cobb, Charles E. Duffer, and Glenn M. Light, Southwest Research Institute, 6220 Culebra Road, San Antonio, TX 78238

---Aboveground steel storage tanks are a common means for storing liquid products such as oil or water at many industrial sites. These tanks are constructed on-site by first welding together rectangular sections of relatively thin (~0.25 inch) steel plates to create a floor and then creating a wall by welding thicker (>0.75 inch) steel plates to the floor. A common concern with tanks of this type is metal loss resulting from corrosion on both the top and bottom of the floor, particularly near the walls, and it is important to maintain the integrity of these tanks for both economic and environmental reasons. There are two common inspection approaches for this type of storage tank. The first is to inspect the floor using magnetic-based techniques after emptying the tank, which is time consuming and expensive. The second is to inspect the floor using bulk-wave ultrasound from the outside of the in-use tank, but this approach has limited range. This paper reports on a new approach using guided waves generated with magnetostrictive-based sensors to inspect in-use storage tanks from the outside. This approach potentially provides increased coverage of the tank compared to the conventional bulk-wave ultrasonic approach. Preliminary results using this approach have been reported previously, but those efforts involved collection and interpretation of individual waveforms to detect wall loss. This paper discusses improvements made to the inspection approach by combining multiple recorded guided waves signals together using a synthetic aperture focusing technique to create an image of the floor integrity. Experimental results using a laboratory mock-up will be provided as well as future work recommendations.

4:30 PM

Non-Destructive Inspection Protocol for Reinforced Concrete Highway Barriers and Bridge Railings
---Satish R. Chintakunta, Engineering and Software Consultants Inc., Chantilly, VA; Shane D. Boone, Federal Highway Administration, TFHRC, McLean, VA

---Reinforced concrete highway barriers and bridge railings serve to prevent errant vehicles from departing the travel way at grade separations. Despite the important role that they play in maintaining safety and their ubiquitous nature, barrier inspection rarely moves beyond visual inspection. In August 2008, a tractor-trailer fatally departed William Preston Lane, Jr. Memorial Bridge after it dislodged a section of the bridge barrier. Investigations following the accident identified significant corrosion of the anchor bolts attaching the bridge railing to the bridge deck. As a result of the information gathered during its investigation of the accident, the National Transportation Safety Board (NTSB) made recommendations to the Federal Highway Administration concerning Non-Destructive Evaluation (NDE) of concrete bridge railings. The Center for Non Destructive Evaluation (NDE) at Turner Fairbank Highway Research Center in McLean, VA is currently evaluating feasibility of using four technologies – ground penetrating radar (GPR), ultrasonic pulse-echo, digital radiography and infrared thermal imaging methods to develop bridge inspection methods that augment visual inspections, offer reliable measurement techniques, and are practical, both in terms of time and cost, for field inspection work. Controlled samples containing predefined corrosion levels in reinforcing steel and voids of different sizes were embedded in concrete barriers and also in the anchorage systems for laboratory testing. All four NDE techniques were used and the methods provide useful and complementary information. An inspection protocol for detecting and measuring the corrosion of reinforced steel and voids embedded in the barrier and the anchorage system will be developed as part of this research. The identified technologies shall be further developed for field testing utilizing a structure with a barrier in good condition and a structure with a barrier in poor condition.
Omni-Directional Guided Wave Mode Control with Annular Array Transducers in Plate Like Structures
---Jaya Prakash Koduru, Sepandarmaz Momeni, and Valery Godinez, Mistras Group Inc., Products and Systems Division, 195 Clarksville Road, Princeton Junction, NJ 08536

Guided waves with their long range propagation characteristics are attractive for online monitoring of large structures like ships, oil tanks, pressure vessels etc. Their multi-modal nature offers attractive possibilities for structural inspection. However, the presence of multiple modes propagating with different velocities complicates the analysis. Often it is desirable to control the modes propagating in a structure. Linear array transducers and phased linear array transducers have been used in literature to control the guided wave modes generated in the structure. However, they are directional and excite guided waves only along their axis. Annular arrays are their axi-symmetric counterpart and excite omni-directional guided waves in plate like structures. The element spacing and phase delays between elements used for linear array transducers are not valid for annular arrays and needs to be computed numerically. In this paper, the transducer design of both fixed wave length annular arrays and phased annular arrays is discussed. The optimum electrode spacing, excitation amplitude and phase are numerically computed. Experimental observations of guided wave mode and frequency control with the designed transducers in a plate like structure are presented.
SESSION 17
NDE OF WELDS
Marino Morra and Mark Lozev, Co-Chairpersons
Key Ballroom 12

3:30 PM  Towards Real Time Diagnostics of Hybrid Welding Laser/GMAW
---Timothy Mcjunkin, Dennis C. Kunerth, and Corrie Nichol, Idaho National Laboratory, 1765 North Yellowstone Highway, Idaho Falls, ID 83415-2209; Evgueni Todorov and Steve Levesque, Edison Welding Institute; Feng Yu and Robert Danna Couch, Electric Power Research Institute, Charlotte, NC 28269

3:50 PM  Experimental Determination of the Complex Stiffness Tensor and Euler Angles in Anisotropic Media Using Ultrasonic Waves
---Naima Alaoui Ismaili, MATEIS, INSA-Lyon F-69621 Villeurbanne Cedex; Philippe Guy, Laboratoire Vibrations Acoustique, INSA-Lyon F-69621 Villeurbanne Cedex; Bertrand Chassignole, Departement MMC, EDF R&D, Sites des Renardieres, 77818 Moret-sur-Loing

4:10 PM  Array Imaging of Austenitic Welds by Measuring Weld Material Map
---Zheng Fan and Michael J. S. Lowe, Imperial College, Mechanical Engineering, London, United Kingdom

4:30 PM  Technique Development for Field Inspection of Cracking in Seam Welded Ducts
---Eric B. Shell, Wyle, Advanced NDI, 2700 Indian Ripple Road, Dayton, OH 45440; Greg C. Liljestrom, Wyle, Advanced NDI, Oklahoma City, OK

4:50 PM  Non-Collinear Wave Mixing for NDE of Titanium Diffusion Bonds
---Edwill Escobar-Ruiz and Peter Cawley, Imperial College, Mechanical Engineering, London, United Kingdom; Alberto Ruiz, Universidad Michoacana de San Nicolas de Hidalgo, Instituto de Investigaciones Metalurgicas, Morelia, Mexico; Waled Hassan, Rolls-Royce Corporation, Indianapolis, IN 46225; Ian Collison, Rolls-Royce, Derby, United Kingdom; Peter B. Nagy, University of Cincinnati, School of Aerospace Systems, Cincinnati, OH 45221-0070
Towards Real Time Diagnostics of Hybrid Welding Laser/GMAW

---Timothy Mcjunkin, Dennis C. Kunerth, and Corrie Nichol, Idaho National Laboratory, 1765 North Yellowstone Highway, Idaho Falls, ID 83415-2209; Evgueni Todorov and Steve Levesque, Edison Welding Institute; Feng Yu and Robert Danna Couch, Electric Power Research Institute

---Methods are currently being developed towards a more robust system real time feedback in the high throughput process combining laser welding with gas metal arc welding. A combination of ultrasonic, eddy current, electronic monitoring, and visual techniques are being applied to the welding process. Initial simulation and bench top evaluation of proposed real time techniques on weld samples are presented along with the concepts to apply the techniques concurrently to the weld process. Consideration for the eventual code acceptance of the methods and system are also being researched as a component of this project. The goal is to detect defects or precursors to defects and correct when possible during the weld process.

Experimental Determination of the Complex Stiffness Tensor and Euler Angles in Anisotropic Media Using Ultrasonic Waves

---Naima Alaoui Ismaili, MATEIS, INSA-Lyon F-69621 Villeurbanne Cédex; Philippe Guy, Laboratoire Vibrations Acoustique, INSA-Lyon F-69621 Villeurbanne Cédex; Bertrand Chassignole, Département MMC, EDF R&D, Site des Renardières, 77818 Moret-sur-Loing

---The aim of this work is to measure the complex elastic tensor and Euler angles in very complex anisotropic media like austenitic steel welds, by inverse problem resolution from experimental data. The obtained experimental characteristics of the anisotropic material will be injected in a FEM code developed by EDF enabling the simulation of an actual ultrasonic NDE of welds. The present work aims to provide reliable input data to the 3D future development of the code. In particular, this complex elastic tensor will allow to predict by modeling beam skewing and attenuation in an austenitic weld. The investigation of such anisotropic media is very complex because of the directional dependency of the elastic stiffness tensor. Then we will discuss the use of a hybrid genetic algorithm to overcome this difficulty. The identification method is based on waveforms spectra reconstruction associated to a physical model describing wave propagation in plates, during underwater measurements. The entire procedure is qualified and validated using simulated data. Moreover, a comparison of the estimated elastic coefficients with literature values and ultrasonic measurements obtained in transmission is also given, at the end of the paper.
Array Imaging of Austenitic Welds by Measuring Weld Material Map
---Zheng Fan and Michael J. S. Lowe, Imperial College, Mechanical Engineering, London, United Kingdom

---It is difficult to inspect for defects in austenitic welds ultrasonically due to complicated material properties inside the weld. Weld microstructures typically lead to weld stiffnesses that are both anisotropic and inhomogeneous, so that ultrasonic waves tend to deviate and scatter. A weld performance map is commonly used to describe how the material properties vary throughout the weld, and this idea has been applied to wave propagation models. In this work, we developed a non-destructive method to measure this map using ultrasonic arrays. A material model (previously published by others) with a small number of parameters has been applied to describe the weld performance map. It uses the information of the welding procedure and rules for crystalline growth to predict the orientations, therefore it has a good physical foundation. An inverse model has then been developed to measure the weld performance map based on the matching of predictions by the ray tracing method to selected experimental array measurements. The process is validated by both finite element models and experiments. The results have been applied to correct array images to compensate for deviations of the ultrasonic rays.

Technique Development for Field Inspection of Cracking in Seam Welded Ducts
---Eric B. Shell, Wyle, Advanced NDI, 2700 Indian Ripple Road, Dayton, OH 45440; Greg C. Liljestrom, Wyle, Advanced NDI, Oklahoma City, OK

---Engine bleed air distribution system ducts, consisting of alloyed titanium couplers connected to unalloyed titanium tubes using a lap seam welds have become a location of frequent cracking and rupture. Excess hydrogen, which has a greater solubility in the alloy, precipitates out in the tube and forms titanium hydride. This results in an embrittled microstructure, localized micro-cracking, and eventual link-up to form large cracks. The cracks are hidden from direct view by the coupler, requiring an appropriate periodic NDI method to detect and size cracking. A range of NDE methods was investigated to characterize the damage in the fleet. Electromagnetic, ultrasonic, fluorescent penetrant, thermal, and radiographic techniques were considered. The goal was the development of an appropriate field inspection method capable of detecting the damage prior to full rupture. A comparison of the information obtained from each approach along with an assessment of the suitability for on-aircraft field use will be discussed. The crack sizing capabilities and comparison to a notched reference tube will be discussed for the electromagnetic approach.
**4:50 PM**

**Non-Collinear Wave Mixing for NDE of Titanium Diffusion Bonds**
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Edwill Escobar-Ruiz and Peter Cawley, Imperial College, Mechanical Engineering, London, United Kingdom; Alberto Ruiz, Universidad Michoacana de San Nicolás de Hidalgo, Instituto de Investigaciones Metalúrgicas, Morelia, Mexico; Waled Hassan, Rolls-Royce Corporation, Indianapolis, IN 46225; Ian Collison, Rolls-Royce plc, Derby, United Kingdom; Peter B. Nagy, University of Cincinnati, School of Aerospace Systems, Cincinnati, OH 45221-0070

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Diffusion bonds offer superior mechanical properties compared with conventional joining methods. The full exploitation of these solid-state welds in titanium components is currently limited by a lack of robust Non-Destructive Evaluation (NDE) techniques that can overcome the crystallographic anisotropy of titanium alloys. Advanced ultrasonic techniques based on measuring signal phase have been explored previously, but their sensitivity to material imperfections is limited by the linear acoustic phenomena on which they depend. Non-linear ultrasonic methods have been shown to be significantly more sensitive than their linear counterparts to these types of imperfections, but difficulties in suppressing 'unwanted' non-linearity from that of the diffusion-bond interface has proven somewhat challenging. The work presented here illustrates the major advantages offered by a novel non-collinear wave-mixing system for the inspection of titanium diffusion bonds. A set of samples with varying bond qualities were created and inspected using both conventional and non-linear scanning systems. The interface quality was approximated via the percentage thickness reduction resulting from the diffusion bonding process. Results show that the non-linear ultrasonic scanning system successfully suppresses bulk, system and coupling media non-linearity such that a significant increase in the sensitivity to bond imperfections is obtained compared with conventional linear inspections.
Session 18
SESSION 18  
ICBM-BARKHAUSEN NOISE AND MICROMAGNETIC TESTING  
Robert Fix, Chairperson  
Key Ballroom 9

3:30 PM  Improving the Accuracy of Case Depth Measurements in Carburized Steel by Using a Combination of Electromagnetic Test Methods  
---Robert Meyendorf and Daniel Eylon, University of Dayton, Department for Chemical and Materials Engineering, Dayton, OH 45469

3:50 PM  Case-Depth Verification of Hardened Samples with Barkhausen Noise Sweeps  
---Suvi Santa-aho, Minnamari Vippola, and Toivo Lepistö, Tampere University of Technology, Department of Materials Science, Tampere, Finland; Aki Sorsa and Kauko Leiviskä, University of Oulu, Control Engineering Laboratory, Oulu, Finland; Merja Hakanen, Stresstech Oy, Vaajakoski, Finland

4:10 PM  Case Depth Characterization of Nitrided Steels Using Magnetic Barkhausen Noise  
---B. A. Shaw, C. J. Aylott, M. Davison, and V. Moorthy, Design Unit, Newcastle University, United Kingdom; S. Santa-aho, Tampere University of Technology, Department of Materials Science, Tampere, Finland; L. Suominen, Stresstech Oy, Vaajakoski, Finland

4:30 PM  Detector System for Inclusion Defects in Hot Rolled Steel Plates Using MFLT with Two Different Magnetizing Strengths  
---Junichi Yotsuji, JFE Corporation, Instrument and Control Engineering Research Department, Kawasaki, Kanagawa, Japan

4:50 PM  Detection of the Heat Affected Zone in Welded Steel by Magnetic Barkhausen Emission  
---Mohamed Blaow, University of Misurata, Materials Science and Engineering, AlJazera Street, Misurata, Libya
3:30 PM

**Improving the Accuracy of Case Depth Measurements in Carburized Steel by Using a Combination of Electromagnetic Test Methods**

---Robert Meyendorf and Daniel Eylon, University of Dayton, Department for Chemical and Materials Engineering, Dayton, OH 45469

---Bearing steel components were case hardened by carburization in an industrial facility. Measurements were taken to test the case depth using four independent electromagnetic methods. The four methods have different penetration depths and sensitivity to material properties and thus complement each other. Models to predict the case depth were built by multiple linear regressions. It has been demonstrated that the case depth testing accuracy could be significantly improved by combining measurement data of the two used methods into a single model. The reason was the presence of a thin decarburized layer that distorted the measurements of the deep penetrating method. This distorting effect could be compensated for by using a method with a shallow penetration depth.

3:50 PM

**Case-Depth Verification of Hardened Samples With Barkhausen Noise Sweeps**

---Suvi Santa-aho, Minnamari Vippola, and Toivo Lepistö, Tampere University of Technology, Department of Materials Science, Tampere, Finland; Aki Sorsa and Kauko Leiviskä, University of Oulu, Control Engineering Laboratory, Oulu, Finland; Merja Hakanen, Stresstech Oy, Vaajakoski, Finland

---An interesting topic of recent Barkhausen noise (BN) method studies is the application of the method to case-depth evaluation of hardened components. The utilization of BN method for this purpose is based on the difference in the magnetic properties between the hardened case and the soft core. Therefore, the detection of case-depth with BN can be achieved. The measurements typically have been carried out using low magnetizing frequencies which have deeper penetration to the ferromagnetic samples than the conventional high frequency BN measurement. However, the penetration depth is limited due to eddy current damping of the signal. We introduce here a newly found sweep measurement concept for the case-depth evaluation. In this study sweep measurements were carried out with various magnetizing frequencies and magnetizing voltages to detect the effect of different frequency and voltage and their correspondence to the actual verified case-depth value from destructive characterization. Also a BN measurement device was tested that has an implemented sweep analysis option. The samples were either induction or case-hardened samples and sample geometry contained both rod samples and gear wheel tooth samples. Samples were also further characterized with X-ray diffraction to study the residual stress state of the surface.
Case Depth Characterization of Nitrided Steels Using Magnetic Barkhausen Noise

--- B. A. Shaw, C. J. Aylott, M. Davison, and V. Moorthy, Design Unit, Newcastle University, United Kingdom; S. Santa-aho, Tampere University of Technology, Department of Materials Science, Tampere, Finland; L. Suominen, Stresstech Oy, Vaajakoski, Finland

---Magnetic Barkhausen noise has been widely applied to control the quality of ground, surface hardened components, helping to prevent grinding damage related failures. The method has typically been applied to carburised, induction hardened and through hardened components, but it has not been so widely used on nitrided steels. Nitriding is however increasingly being used for applications where the lower temperature processing results in less distortion related issues (e.g. for thin rim, annulus gears). The use of nitriding is often limited by the maximum attainable case depth and therefore case depth control, especially after subsequent grinding, is of critical importance and current practice relies upon representative, sacrificial samples for destructive examination. This work explores the use of the Barkhausen noise phenomena to give a non-destructive correlation with case depth for a range of nitrided steels, heat treated to generate varying case depths. The study presents and compares the use of moderate and low frequency approaches based upon magnetic voltage sweeps and characterisation of double peak behaviour. Results from the Barkhausen measurements are compared with conventional characterisation of hardness profiles and microstructure. The results show good potential for the Barkhausen method to be used to evaluate the effective case depth of nitrided steels.

Detector System for Inclusion Defects in Hot Rolled Steel Plates Using MFLT with Two Different Magnetizing Strengths

---Junichi Yotsuji, JFE Corporation, Instrument and Control Engineering Research Department, Kawasaki, Kanagawa, Japan

---Recently, steel can manufacturing requires higher quality because otherwise minute non-metal inclusions in thin sheets cause cracks and result in a burst during the pressurization after the pressing process. Quality testing is already installed at the final process in steel plants, but if there is another inspection in an earlier step, at the hot strip mill for example, then the mass manufacture of a nonconforming would be avoided and maintaining quality control would be more efficient. In order to detect inclusion defects in hot-rolled steel plates, MFLT (Magnetic Flux Leakage Testing) using different magnetizing forces is developed. According to analysis of the noise factors in MFLT, it is found that the signals generated from the scale layer on a steel surface are dominant. A different magnetizing force method is the used to decrease this overpowering noise level in MFLT. In this paper, it is confirmed that inclusions, larger than 160um in diameter and less than 0.45mm in depth, can be detected, utilizing the our methods.
Detection of the Heat Affected Zone in Welded Steel by Magnetic Barkhausen Emission

---Mohamed Blaow, University of Misurata, Materials Science and Engineering, ALjazera Street, Misurata, Libya

---The heat affect zone in welded steel sheet was determined by Magnetic Barkhausen emission (MBE). The effect of heat generated in the weld line and the area surrounding it on microstructural and mechanical properties was studied by magnetic Barkhausen emission and hardness test. The magnetic Barkhausen emission measurements generated from the area near the weld line showed increased activity compared with the unaffected areas. The hardness measurements showed a softening effect in the same locations. It was concluded that the magnetic Barkhausen emission could reveal the effect of heat generated by welding on the microstructure in the HAZ caused by heat increase imposed by welding.
WEDNESDAY

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SESSION 19
PROBABILITY OF DETECTION
William Q. Meeker, Chairperson
Key Ballroom 11

8:30 AM Simulation Tools for UT Inspection of Bolthole Cracks
---T. A. Gray and R. A. Roberts, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

8:50 AM Quantile POD Estimation for Nondestructive Inspection with Hit-Miss Data
---Yew Meng Koh and William Q. Meeker, Iowa State University, Center for NDE and Department of Statistics, Ames, IA 50011

9:10 AM Review of Progress in POD Estimation Using Simulation
---Nicolas Dominguez*, Anthony Dubois, Christophe Reboud, and Frederic Jenson, CEA-LIST, DISC, Gif-sur-Yvette, France; *EADS Innovation Works, Toulouse, France; Frederic Reverdy, CEA-LIST, DISC, Toulouse, France

9:30 AM Influence of Sample Characteristics on Probability of Detection Curves
---Charles Annis, Statistical Engineering, Palm Beach Gardens, FL 33418

9:50 AM A Bayesian Approach to Nondestructive Inspection Test Planning with Hit-Miss Data
---Yew Meng Koh and William Q. Meeker, Iowa State University, Center for NDE and Department of Statistics, Ames, IA 50011

10:10 AM Break

10:30 AM Curve Fitting for Probability of Detection Data: A 4-Parameter Generalization
---Floyd W. Spencer, Sfiire, 12312 Haines Avenue N.E., Albuquerque, NM 87112-4924

10:50 AM Probabilistic Modeling and Sizing of Embedded Flaws in Ultrasonic Non-Destructive Inspection for Structural Integrity Assessment
---Xuefei Guan, Jingdan Zhang, and Shaohua K. Zhou, Siemens Corporation, Corporate Technology, 755 College Road East, Princeton, NJ 08540; El Mahjoub Rasselkorde and Waheed A. Abbasi, Siemens Energy Inc., 841 Old Frankstown Road, Pittsburgh, PA 15239-2249

11:10 AM Assessing the Reliability of Nondestructive Evaluation Methods for Damage Characterization
---John C. Aldrin, Computational Tools, Gurnee, IL 60031; Charles Annis, Statistical Engineering, Palm Beach Gardens, FL 33418; Harold A. Sabbagh, Victor Technologies, LLC, Bloomington, IN; Jeremy S. Knopp and Eric A. Lindgren, Air Force Research Laboratory (AFRL/RXCA), Wright Patterson AFB, OH 45433

11:30 AM Probability of Detection and Reliability – Evolution and Paradigm Shift
---Surendra Singh, Honeywell International, Inc., 111 S. 34th Street, Phoenix, AZ 85034

11:50 AM Characterization of a Random Anisotropic Conductivity Field with Karhunen-Loeve Methods
---Matthew R. Cherry², Harold A. Sabbagh³, Adam L. Pilchak¹, and Jeremy S. Knopp¹, ¹Air Force Research Labs, Materials and Manufacturing Directorate, WPAFB, OH 45433-7817; ²University of Dayton Research Institute, Dayton, OH 45469; ³Victor Technologies, Gurnee, IL 60031

12:10 PM Lunch
Simulation Tools for UT Inspection of Bolthole Cracks
---T. A. Gray and R. A. Roberts, Iowa State University, Center for NDE, Ames, IA 50011

Analytical and computer models of UT inspections are coming into wider use as tools to estimate probability of detection (POD) – an application called Model-Assisted POD, or MAPOD. This presentation will detail the current status of a project to develop simulation tools for UT inspection of bolthole cracks in layered civil and military aerospace structures, such as airframes. The work comprises development and implementation of both paraxial, bulk-wave models that have great flexibility in terms of component geometry, as well as more rigorous analytical models that include both bulk and surface/plate modes. The latter models are primarily for benchmarking and testing range of validity for the paraxial versions. The simulation tools will include a full-featured graphical user interface, the ability to import CAD renderings of a component, and batch tools for parametric studies. The project will include comparisons of model predictions to empirical data obtained on realistic test components. This work is funded by AFRL/RXCA and was performed at Iowa State University's Center for Nondestructive Evaluation.

Quantile POD Estimation for Nondestructive Inspection with Hit-Miss Data
---Yew Meng Koh and William Q. Meeker, Iowa State University, Center for NDE and Department of Statistics, Ames, IA 50011

---Probability of detection (POD) is commonly used to measure an NDE inspection procedure's performance. Due to inherent variability in the inspection procedure caused by variability in factors such as technicians and flaw morphology, for some purposes it is important to model POD as a random function. Traditionally, inspection variabilities are pooled and an estimate of the mean POD is reported. In some applications it is important to know how poor typical inspections might be and this question can be answered by estimating a quantile of the POD distribution. This paper shows how to fit a proper model to hit-miss data and considers estimation of the mean POD as well as quantiles of the POD distribution for binary (hit-miss) NDE data. We also show how to compute credible intervals for these quantities using a Bayesian estimation approach.---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 Nondestructive Evaluation.
9:10 AM

**Review of Progress in POD Estimation Using Simulation**
---Nicolas Dominguez, Anthony Dubois, Christophe Reboud, and Frederic Jenson, CEA-LIST, DISC, Gif-sur-Yvette, France; Nicolas Dominguez, EADS Innovation Works, Toulouse, France; Frederic Reverdy, CEA-LIST, DISC, Toulouse, France

---The use of Probability of Detection (POD) for NDT performances demonstration is a key link in products lifecycle management. The POD approach is to apply the given NDT procedure on a series of known flaws to estimate the probability to detect with respect to the flaw size. A POD is relevant if and only if NDT operations are carried out within the range of variability authorized by the procedure. Such experimental campaigns require collection of large enough datasets to cover the range of variability with sufficient occurrences to build a reliable POD statistics, leading to expensive costs to get POD curves. In the last decade research activities have been led in the USA with the MAPOD group and later in Europe with the SISTAE and PICASSO projects based on the idea to use models and simulation tools to feed POD estimations. This paper proposes a synthesis of the work performed on the European side around the CIVA software and shows the progress on two aspects: i) uncertainty analysis and propagation and ii) POD estimation models in the context of simulated-POD. Results are illustrated through concrete POD cases coming from the aeronautical industry. The paper finally provides elements of further progress in the domain.

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9:30 AM

**Influence of Sample Characteristics on Probability of Detection Curves**
---Charles Annis, Statistical Engineering, Palm Beach Gardens, FL 33418

---POD curves are typically constructed as statistical models of responses to known characteristics of the POD demonstration samples. MIL-HDBK-1823A provides some guidance in choosing the number of samples - viz. at least 40 targets for tests that provide a quantitative response (a) and 60 for binary responses (hit/miss) - but says little about the size range or how they should be placed within that range. Here we report on how the number of targets, their size range, and their distribution (uniform, skewed left or right) with respect to a true POD vs. size relationship influences the POD curve that is estimated from these targets. From the parameter estimates we compute confidence bounds to quantify statistical uncertainty. The work is for binary response data and is based on a novel simulation method for estimating the confidence bounds which would prohibitively time-consuming using conventional Monte Carlo methods.
A Bayesian Approach to Nondestructive Inspection Test Planning with Hit-Miss Data

---Yew Meng Koh and William Q. Meeker, Iowa State University, Center for NDE and Department of Statistics, Ames, IA 50011

---Although some useful general guidelines exist for planning nondestructive evaluation studies (e.g., in MIL-HDBK 1823A) statistical tools provide more definitive guidance and to allow comparison among different proposed study plans. It is possible to obtain expressions for estimation precision (e.g., giving the relative width of a confidence interval), providing an assessment and comparison of alternative test plans. One problem is that estimation precision depends on the unknown actual underlying POD function. Engineers generally have some information about the true POD function, based on some combination of knowledge of the physics behind the inspection method or previous experience with the inspection method. If such uncertain information can be described by a probability distribution, it is natural to use a Bayesian method to do the test planning. In this paper we present Bayesian methods to find optimum test plans. Although the optimum plans have practical deficiencies, they provide insight for developing statistically efficient compromise plans that are also developed in our work.---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 Nondestructive Evaluation.

Curve Fitting for Probability of Detection Data: A 4-Parameter Generalization

---Floyd W. Spencer, Sfire, 12312 Haines Avenue N.E., Albuquerque, NM 87112-4924

---The hit – miss data taken from NDE validation and inspector qualification exercises have traditionally been used with logit or probit binary regression models to estimate probability of detection (POD) curves. These models are specified by functions with two parameters that determine location and shape of the resulting POD expressed in terms of an independent flaw size variable. A generalization of these models is discussed in which two additional parameters are added that allow the POD function range to be confined to a subset of the 0 to 1 interval. Thus the POD curve can have a lower asymptote other than zero and an upper asymptote other than one. The additional parameters model naturally occurring inspection phenomena such as detections and misses independent of flaw size. The relationship of the 4 – parameter model to non – parametric POD estimation is also discussed. Determining the need for or the desirability of fitting additional parameters is developed in terms of the statistical significance of the additional parameters. Other strategies for judging the ability of the resultant POD curve from the 4 – parameter fit to more adequately reflect the inspection data are also considered.
10:50 AM

Probabilistic Modeling and Sizing of Embedded Flaws in Ultrasonic Non-Destructive Inspection for Structural Integrity Assessment

---Xuefei Guan, Jingdan Zhang, and Shaohua K. Zhou, Siemens Corporation, Corporate Technology, 755 College Rd. E. Princeton NJ 08540; El Mahjoub Rasselkorde, and Waheed A. Abbasi, Siemens Energy Inc. 841 Old Frankstown Road, Pittsburgh PA 15239-2246

---The paper presents a systematic method and procedure for probabilistic fatigue life prediction using non-destructive testing data under uncertainty. The procedure is developed using uncertainty quantification models for detection, sizing, fatigue model parameters and inputs. The probability of detection model is based on a classical log-linear model coupling the actual flaw size with the NDE reported size. Using probabilistic modeling and Bayes theorem, the distribution of the actual flaw size is derived for both NDE data without flaw indications and NDE data with flaw indications. Fatigue damage and structural integrity assessment is suggested based on the developed method and procedure. A turbine rotor example with realistic NDE inspection data is presented to demonstrate the overall methodology. Calculation and interpretation of the results based on risk recommendations for industrial applications are given. The influence of the NDE detection threshold to the assessment results, and error analysis of the assessment results are discussed in detail.

11:10 AM

Assessing the Reliability of Nondestructive Evaluation Methods for Damage Characterization

---John C. Aldrin, Computational Tools, Gurnee, IL 60031; Charles Annis, Statistical Engineering, Palm Beach Garden, FL; Harold A. Sabbagh, Victor Technologies LLC, Bloomington, IN; Jeremy S. Knopp and Eric A. Lindgren, Air Force Research Laboratory (AFRL/RXCA), Wright-Patterson AFB, OH

---Progress is presented on the development of an approach to evaluate quality metrics on the reliability of NDE characterization capability. Building on this foundation, a comprehensive approach to NDE characterization error (CE) evaluation is presented that follows the framework of the ‘ahat-versus-a’ model evaluation process for probability of detection (POD) assessment. Before characterization error model building is performed, an intermediate step must evaluate the frequency of several possible classes of poor characterization results: due to weak signals from small discontinuities, due to saturated signals, due to conditions exceeding the inversion parameter constraints, ill-posed problems leading to clustering in local minima, and random poor classifications due to a process failure independent of flaw size. The potential application of physics-based models with Bayesian methods for POD and CE evaluation is proposed, following prior work on model-assisted POD evaluation to supplement studies with limited experimental data. A case study is introduced based on the estimation the length, depth and width of surface breaking cracks using eddy current NDE. One key point is that this process is more complex with respect to current POD evaluations and indicates the importance of engineering and statistical expertise in the model-building process to ensure all key effects and interactions are addressed.
**11:30 AM**

**Probability of Detection and Reliability – Evolution and Paradigm Shift**  
---Surendra Singh, NDT Engineering, Materials & Process Engineering, Honeywell Aerospace, Phoenix, AZ 85034

---The subject of Probability of Detection (POD) and NDT Reliability has gone through multiple phases since its humble beginning in the late 1960s. This was followed by a program known as “Have Cracks Will Travel” by US Air Force and Lockheed Georgia during 1974-1978. This led to a series of developments starting from statistical framework by Bernes and Hovey in 1981 for POD estimation to introduction of fracture mechanics, Damaged Tolerance Design (DTD) and subsequent modified inspection criteria, revised MIL-HDBK STD 1823A (2009), and formation of Model Assisted POD (MAPOD) working group. All intended to improve the accuracy of life prediction in components. The accuracy of life prediction depends on the reliability and capability of NDT methods. Therefore, it is essential to have a reliable detection and sizing of large flaws in components. Currently, POD is used for analyzing reliability and capability of NDT methods, though POD data offers no absolute truth regarding NDE reliability and quantifying the human factors. Furthermore, POD and reliability have been reported alike in meaning but POD is not NDT reliability. Instead it is a part of the reliability. Reliability can be expressed in six phases: 1) DOE for sample selection, 2) NDE equipment and its operation and calibration; 3) System evaluation and capability including in-depth statistical analysis such as Gage Repeatability & Reproducibility and ANOVA, 4) Regression curve for NDE system capability, 5) Data acquisition, and 6) Data analysis and POD estimation. In this presentation, the author will provide an overview of all major POD milestones for the last several decades, discuss different statistical tools for capturing the reliability and human factors for estimating POD, use Integrated Computational Materials Engineering (ICME) tools including MAPOD as compliment or replacement for empirical, physical, and extensive study. Another motivation for the author is to list any gaps between “hoped for” versus validated or experienced failed hardware. However, in no uncertain term it is not the author’s intention to decry past achievements.

**11:50 AM**

**Characterization of a Random Anisotropic Conductivity Field with Karhunen-Loeve Methods**  
---Matthew R. Cherry², Harold A. Sabbagh³, Adam L. Pilchak¹, and Jeremy S. Knopp¹, ¹Air Force Research Labs, Materials and Manufacturing Directorate, WPAFB, OH 45433-7817; ²University of Dayton Research Institute, Dayton, OH 45469; ³Victor Technologies, Gurnee, IL 60031

---While parametric uncertainty quantification for NDE models has been addressed in recent years, the problem of stochastic field parameters such as spatially distributed electrical conductivity has been investigated minimally in the last year. In that work, the field was treated as a one-dimensional random process and Karhunen-Loeve methods were used to discretize this process to make it amenable to UQ methods such as ANOVA expansions. In the present work, the field will be treated as an arbitrary two-dimensional random process, and the eigenvalues and eigenfunctions of the integral operator are determined via Galerkin methods. The Karhunen-Loeve method is extended to two dimensions and implemented to represent this process. Several different choices for basis functions are discussed, as well as convergence criteria for each. The methods are applied to correlation functions collected over electron backscatter data from highly microtextured Ti-7Al.
Session 20
8:30 AM Research and Technology Gaps in Development of PHM for Passive aSMR Components

8:50 AM Research in Nondestructive Evaluation Techniques for Nuclear Reactor Concrete Structures
---Dwight A. Clayton, Oak Ridge National Laboratory, Measurement Science and Systems Engineering Division, Oak Ridge, TN 37831-6174; Cyrus M. Smith, Oak Ridge National Laboratory, Computational Sciences and Engineering Division, Oak Ridge, TN 37831-6174

9:10 AM Complementary Single Technique and Multi-Physics Modeling Tools for NDE Challenges
---Nechtan Le Lostec, Bernard Sartre, and S. W. Glass, Areva NDE Solutions, NETEC Chalon sur Saone, France and Lynchburg, VA

9:30 AM Thermographic Inspection of Massive Structures
---Jeremy B. Renshaw, Maria Guimaraes, and David B. Scott, Electric Power Research Institute, Nuclear-Science & Technology Development, 1300 West WT Harris Boulevard, Charlotte, NC 28262

9:50 AM Accurate Modeling of Anisotropic Effects in Austenitic Steel Welds
---Oliver Nowers and David Duxbury, Rolls-Royce Marine, P. O. Box 2000, Raynesway, Derby DE21 7XX, United Kingdom; Alexander Velichko and Bruce Drinkwater, University of Bristol, Mechanical Engineering, Bristol, United Kingdom

10:10 AM Break

10:30 AM Ultrasonic Inspection of Austenitic Stainless Steel Welds with Artificially Produced Stress Corrosion Cracks
---Sandra Dugan and Sabine Wagner, Materials Testing Institute, University of Stuttgart (MPA), NDT in Plant and Mechanical Engineering, 32 Stuttgart, 70569 Germany

10:50 AM Laser Shockwave for Characterizing Diffusion Bonded Interfaces
---James A. Smith, Dave L. Cottle, and Barry H. Rabin, Idaho National Laboratory, Fuel Performance & Design, P. O. Box 1625, Idaho Falls, ID 83415-6188

11:10 AM Radiation Damage Characterization in Reactor Pressure Vessel Steels with Nonlinear Ultrasound
---Kathryn H. Matlack, Georgia Institute of Technology, G. W. Woodruff School of Mechanical Engineering, Atlanta, GA 30332; Jin-Yeon Kim and Laurence J. Jacobs, Georgia Institute of Technology, School of Civil and Environmental Engineering, Atlanta, GA 30332; James J. Wall, Electric Power Research Institute, Charlotte, NC; Jianmin Qu, Northwestern University, Department of Civil and Environmental Engineering, Evanston, IL 60208

11:30 AM Development and Application of Modeling Tools for SFR Inspection
---Florian Le Bourdais, Benoit Marchand, and Vahan Baronian, CEA-LIST, Centre de Saclay, F-91191, Gif-sur-Yvette, France

11:50 AM Design of EMAT Phased Arrays for SFR Inspection
---Florian Le Bourdais and Benoit Marchand, CEA-LIST, Centre de Saclay, F-91191, Gif-sur-Yvette, France

12:10 PM Lunch
8:30 AM

Research and Technology Gaps in Development of PHM for Passive aSMR Components
---Ryan M. Meyer, Jamie B. Coble, Evelyn H. Hirt, Mark R. Mitchell, David W. Wootan, Eric J. Berglin, Charles H. Henager, Jr., and Pradeep Ramuhalli, Pacific Northwest National Laboratory, Richland, WA 99352; Leonard J. Bond, Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA 50011

---Advanced small modular reactors (aSMRs) are among the various options being explored for future reliable nuclear power deployment. It's anticipated that aSMRs can provide advantages over more conventional technologies in the areas of safety and reliability, sustainability, and proliferation resistance. However, aSMRs (as other small reactor concepts) are likely to be impacted by reduced economy-of-scale savings when compared to traditional light water reactors (LWRs).

Prognostics and health management (PHM), particularly for managing degradation in materials, is being considered to ensure safety and improve the economic feasibility of aSMR deployment. A number of factors influence the requirements for PHM of passive components in aSMRs, including proposed new concepts of operation, harsher operating conditions, potentially new degradation mechanisms, etc.

This paper will discuss the research and technology gaps associated with deploying online nondestructive evaluation technologies and PHM systems for passive components in aSMRs based on a set of requirements derived from concepts of operations, operational experience with advanced reactors, and an assessment of the relevant state-of-the-art in PHM.

8:50 AM

Research in Nondestructive Evaluation Techniques for Nuclear Reactor Concrete Structures
---Dwight A. Clayton, Oak Ridge National Laboratory, Measurement Science and Systems Engineering Division, Oak Ridge, TN 37831-6174; Cyrus M. Smith, Oak Ridge National Laboratory, Computational Sciences and Engineering Division, Oak Ridge, TN 37831-6174

---The purpose of the Materials Aging and Degradation (MAaD) Pathway of the Department of Energy’s Light Water Reactor Sustainability (LWRS) Program is to develop the scientific basis for understanding and predicting long-term environmental degradation behavior of material in nuclear power plants and to provide data and methods to assess the performance of systems, structures, and components (SSCs) essential to safe and sustained nuclear power plant operations. The understanding of aging-related phenomena and their impacts on SSCs is expected to be a significant issue for any nuclear power plant planning for long-term operations (i.e. service beyond the initial license renewal period). Management of those phenomena and their impacts during long-term operations can be better enable by improved methods and techniques for detection, monitoring, and prediction of SSC degradation.

The MAaD Pathway R&D Roadmap for Concrete, “Light Water Reactor Sustainability Nondestructive Evaluation for Concrete Research and Development Roadmap”, focused initial research efforts on understanding the recent concrete issues at nuclear power plants and identifying the availability of concrete samples for NDE techniques evaluation and testing. An overview of the research performed by ORNL in these two areas is presented here.
9:10 AM

Complementary Single Technique and Multi-Physics Modeling Tools for NDE Challenges
---Nechtan Le Lostec, Bernard Sartre, and S. W. Glass, Areva NDE Solutions, NETEC Chalon sur Saône, France and Lynchburg, VA

Different modelling software have been used at AREVA NDE Solutions/NETEC for development and simulation tasks. These programs include CIVA for UT methods, PZFlex for UT probes, Flux for ET probes and methods. Each of these various tools and their limitations are described along with some example applications: UT setup design and performance evaluation with CIVA, UT probe design and analysis with PZFlex, electromagnetic probe performance evaluation with Flux. Overcoming the limitations of these software and opening new fields of application is addressed through evolution of the current software and procurement of new ones possibly replacing current tools. In particular the future of finite element simulation is being developed on a one and only multiphysics modelling platform relying on two software: Abaqus for finite element analysis and Isight for process automation and design exploration. The Abaqus solvers provide a complete spectrum of convenient tools for numerical modelling and simulation of classical NDE techniques: piezoelectric ultrasonic transducer, magnetostatic and eddy current probes and methods, as well as techniques and excitation methods based on coupled physics such as inductive and laser thermography, shearography, electromagnetic acoustic transducers, laser ultrasonics. The latter are out of the field of the classical single-technique specific codes. Isight software allows the automation of engineering and design processes and the use of data analysis algorithms to drive the simulation and modelling towards the realization of quantified objectives. However many developments are required to make Abaqus and Isight suitable and efficient for our use, including process formalization and solvers adaptation to NDE specificities. Current state of the multiphysics software development roadmap and the corresponding future NDE applications will be presented along with the ongoing developments to make the classical tools easier to use.

9:30 AM

Thermographic Inspection of Massive Structures
---Jeremy B. Renshaw, Maria Guimaraes, and David B. Scott, Electric Power Research Institute, Nuclear - Science & Technology Development, 1300 West WT Harris Blvd., Charlotte, NC 28262

NDE of large structures has become an increasing concern for the nuclear industry, especially for large concrete structures. Inspecting very large, thick concrete structures such as containment buildings or cooling towers can be very challenging with conventional NDE techniques and extremely time-consuming with spot measurements. The challenge increases for structures with a combination of a metal liner, rebar, and concrete, such as for a containment liner in a containment building. Thermography has shown promise as a rapid screening tool for some applications and research is continuing for the detection of typical as-built defects in massive concrete structures.
Accurate Modelling of Anisotropic Effects in Austenitic Steel Welds

---Oliver Nowers and David Duxbury, Rolls-Royce Marine, P. O. Box 2000, Raynesway, Derby DE21 7XX, United Kingdom; Alexander Velichko and Bruce Drinkwater, University of Bristol, Mechanical Engineering, Bristol, United Kingdom

---The ultrasonic inspection of austenitic steel is challenging due to the formation of highly anisotropic and heterogeneous structures post-welding. This is due to the intrinsic crystallographic structure of austenitic steel, driving the formation of dendritic grain structures on cooling. The anisotropy is manifested as both a 'steering' of the ultrasonic beam and the back-scatter of energy due to the macroscopic granular structure of the weld. However, the quantitative effects and relative impacts of these phenomena are not well-understood. A semi-analytical simulation framework has been developed to allow the study of anisotropic effects in austenitic welds. Frequency-dependent scatterers are allocated to a weld-region to approximate the coarse grain-structures observed within austenitic welds and imaged using a simulated array. The effect on signal-to-noise ratio as a function of array frequency, scatterer density, and elastic stiffness orientation is presented. To simulate beam-steering effects, successive ray-traces are made through a pre-defined anisotropic weld map for a typical inspection of an austenitic weld. Representative weld-maps are supplied by a model of the welding process, and the magnitude of beam-steering investigated. The simulation framework allows the comparison of beam-steering and grain-scatter effects in austenitic welds, and the relative impacts of each degradation mechanism is presented.

Ultrasonic Inspection of Austenitic Stainless Steel Welds with Artificially Produced Stress Corrosion Cracks

---Sandra Dugan and Sabine Wagner, Materials Testing Institute, University of Stuttgart (MPA), NDT in Plant and Mechanical Engineering, 32 Stuttgart, 70569 Germany

---Austenitic stainless steel welds and nickel alloy welds, which are widely used in nuclear power plants, present major challenges for ultrasonic inspection due to the grain structure in the weld. Large grains in combination with the elastic anisotropy of the material lead to increased scattering and affect sound wave propagation in the weld. This results in a reduced signal-to-noise ratio, and complicates the interpretation of signals and the localization of defects. Automated ultrasonic inspection was applied to study austenitic stainless steel test blocks with different types of flaws, including inter-granular stress corrosion cracks. The results show that cracks located in the heat affected zone of the weld are easily detected when inspection from both sides of the weld is possible. In cases of limited accessibility, when ultrasonic inspection can be carried out only from one side of a weld, it may be difficult to distinguish between signals from scattering in the weld and signals from cracks.
10:50 AM

Laser Shockwave for Characterizing Diffusion Bonded Interfaces
---James A. Smith, Dave L. Cottle, and Barry H. Rabin, Idaho National Laboratory, Fuel Performance & Design, P. O. Box 1625, Idaho Falls, ID 83415-6188

---The US National Nuclear Security Agency has a Global Threat Reduction Initiative (GTRI) which is tasked with minimizing the use of high-enriched uranium (HEU) worldwide. A key component of that effort is the conversion of research reactors from HEU to low enriched uranium (LEU) fuels. A novel fuel is being designed to replace HEU. The new LEU fuel is based on a monolithic fuel meat made from a U-Mo alloy foil encapsulated in Al-6061 cladding. In order to support the fuel qualification process, new techniques are needed to characterize the clad-clad and fuel-clad interface strengths. The Laser Shockwave Technique (LST) originally developed to characterize structural adhesion in composites is being employed to characterize interface strength in fuel plates. LST is a non-contact method that uses lasers for the generation and detection of large amplitude acoustic waves, and is well suited for application to nuclear fuel plates. This paper will report on initial characterization results obtained from fuel plates manufactured by different processes, including hot isostatic pressing, friction stir welding and hot rolling.

11:10 AM

Radiation Damage Characterization In Reactor Pressure Vessel Steels With Nonlinear Ultrasound
---Kathryn H. Matlack, Georgia Institute of Technology, G.W. Woodruff School of Mechanical Engineering, Atlanta, GA 30332; Jin-Yeon Kim and Laurence J. Jacobs, Georgia Institute of Technology, School of Civil and Environmental Engineering, Atlanta, GA 30332; James J. Wall, Electric Power Research Institute, Charlotte, NC; Jianmin Qu, Northwestern University, Department of Civil and Environmental Engineering, Evanston, IL 60208

---Nuclear generation currently accounts for roughly 20% of the US baseload power generation. Yet, many US nuclear plants are entering their first period of life extension and older plants are currently undergoing assessment of technical basis to operate beyond 60 years. This means that critical components, such as the reactor pressure vessel (RPV), will be exposed to higher levels of neutron radiation than they were originally intended to withstand. Radiation damage in reactor pressure vessel steels causes microstructural changes such as point defect clusters, precipitates, dislocations, and interstitial loops that leave the material in an embrittled state. The development of a nondestructive evaluation technique to monitor radiation damage in the RPV would enable the assessment of the remaining integrity of the RPV. Recent research has shown that nonlinear ultrasound is sensitive to radiation damage. The physical effect monitored by nonlinear ultrasound is the generation of higher harmonic frequencies in an initially monochromatic ultrasonic wave, arising from the interaction of the ultrasonic wave with microstructural features such as dislocations, precipitates, and their interactions. Current findings relating the measured acoustic nonlinearity parameter to increasing levels of neutron dose for different representative RPV material are presented.
11:30 AM

Development and Application of Modeling Tools for SFR Inspection
---Florian Le Bourdais, Benoit Marchand, and Vahan Baronian, CEA LIST, Centre de Saclay F-91191 Gif-sur-Yvette, France

---To support the development of in-service inspection methods for the Advanced Sodium Test Reactor for Industrial Demonstration (ASTRID) project led by the French Atomic Energy Commission (CEA), several tools that allow situations specific to Sodium cooled Fast Reactors (SFR) to be modeled have been implemented in the CIVA software and exploited. This paper details specific applications and results obtained. For instance, a new specular reflection model allows the calculation of complex echoes from scattering structures inside the reactor vessel. EMAT transducer simulation models have been implemented to develop new transducers for sodium visualization and imaging. Guided wave analysis tools have been developed to permit defect detection in the vessel shell. Application examples and comparisons with experimental data are presented.

11:50 AM

Design of EMAT Phased Arrays for SFR Inspection
---Florian Le Bourdais and Benoit Marchand, CEA LIST, Centre de Saclay, F-91191, Gif-sur-Yvette, France

---A long-standing problem for Sodium cooled Fast Reactor (SFR) instrumentation is the development of efficient under-sodium visualization systems that adapt to the hot and opaque sodium environment. Electromagnetic Acoustic Transducers (EMAT) are potential candidates for a new generation of UT probes well-suited for SFR inspection that can overcome drawbacks of classical piezoelectric probes in sodium environment. Based on the use of new CIVA simulation tools, we have designed and optimized an advanced EMAT probe for under-sodium visualization. This has led to the development of a fully functional L-wave EMAT sensing system composed of 8 elements and a casing for 200° C sodium inspection. Laboratory experiments demonstrated the probe’s ability to sweep an ultrasonic beam to an angle of 15 degrees. Testing in a specialized sodium facility has shown that it was possible to obtain pulse-echo signals from a target under several different angles from a fixed position.
Session 21
### SESSION 21

**NDE AND MONITORING FOR CIVIL ENGINEERING STRUCTURES**  
Laurence J. Jacobs and Pranaam Haldipur, Co-Chairpersons  
Key Ballroom 3

<table>
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<tr>
<th>Time</th>
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| 8:30 AM| **The Effective Damage Characterization by Fusion Technique with Impact-Echo and Flexural Modes for Bridge Deck NDE**  
---Taekeun Oh, Incheon National University, Department of Safety Engineering, Incheon, South Korea; John S. Popovics, University of Illinois, Department of Civil and Environmental Engineering, Urbana, IL 61801 |
| 8:50 AM| **Comparison of Frequency-Modulated Continuous-Wave (FM-CW) Radar and Impact-Echo Data for Detecting Delamination in Concrete Bridge Decks**  
---Reza Zoughi and M. T. Ghasr, Applied Microwave Nondestructive Testing Laboratory (amntl), Electrical and Computer Engineering Department, Missouri University of Science and Technology, Rolla, MO 65409; John S. Popovics and S. Ham, Department of Civil and Environmental Engineering, University of Illinois, Urbana, IL 61801 |
| 9:10 AM| **Evaluation of the Feasibility for Detecting Hidden Corrosion Damage in Multi-Layer Gusset Plates Using Multiple Inspection Techniques**  
---Adam C. Cobb, Charles E. Duffer, and Glenn M. Light, Southwest Research Institute, 6220 Culebra Road, San Antonio, TX 78238 |
| 9:30 AM| **Structural Element Assessments by Dispersive Wave Methods**  
---J. Darrin Holt, FDH Engineering, Inc., Raleigh, NC 27616 |
| 9:50 AM| **Mining of NDT Data in Civil Engineering Applications**  
---Parisa Shokouhi, Markus Stoppel, Andreas Zoega, and Rene Heideklang, BAM-Federal Institute for Material Research and Testing, Berlin, Germany |
| 10:10 AM| Break |
| 10:30 AM| **Stress Wave-Based Nondestructive Testing Methods for Performance Monitoring of Bridge Decks**  
---Hoda Azari, Soheil Nazarian, and Deren Yuan, The University of Texas at El Paso, Center for Transportation Infrastructure Systems, 500 W. University Avenue, El Paso, TX 79968 |
| 10:50 AM| **3D Mapping and Localization of Underground Utilities with Ground Penetrating Radar**  
---Feng Xu, Devendra Tolani, and Xue Qi, Intelligent Automation, Inc., 15400 Calhoun Drive, Suite 400, Rockville, MD 20855; Dave Gibson and Peter Huang, Federal Highway Administration, Turner-Fairbank Highway Research Center, 6300 Georgetown Pike, McLean, VA 22101 |
| 11:10 AM| **The Core Drilling Method for Determining In-Situ Stresses in Concrete – Toward More Practical Field Application**  
---Michael J. McGinnis and Jordan Rey, University of Texas at Tyler, Department of Civil Engineering, 3900 University Boulevard, Tyler, TX 75799 |
| 11:30 AM| **A Novel Wireless Multi-Sensor Network System for Structural Health Monitoring**  
---Xiaoliang (George) Zhao, Tao Qian, Kevin Qi, Gang Mei, An Liu, and Roger Xu, Intelligent Automation, Inc., 15400 Calhoun Drive, Suite 400, Rockville, MD 20855; Regan Zane, Z-Domain Advanced Control, LLC, 411 Opal Way, Superior, CO 80027 |
| 11:50 AM| **Acoustic Emission Intensity Analysis of Corrosion in Prestressed Concrete Piles**  
---William Velez, Fabio Matta, and Paul Ziehl, University of South Carolina, Department of Civil and Environmental Engineering, 300 Main Street, Columbia, SC 29208 |
| 12:10 PM| Lunch |
8:30 AM

The Effective Damage Characterization by Fusion Technique with Impact-Echo and Flexural Modes for Bridge Deck NDE
---Taekeun Oh, Incheon National University, Department of Safety Engineering, Incheon, South Korea; John. S. Popovics, University of Illinois, Department of Civil and Environmental Engineering, Urbana, IL 61801

---The Air-Coupled Impact Resonance (IR) test is a well-established form of non-destructive evaluation (NDE) where the dynamic response of an element resulting from an impact event is measured with air-coupled sensor to make conclusions about the damage characterization accurately as well as rapidly. However, the large amount of data from air-coupled IR tests from bridge decks must be manipulated and presented such that infrastructure engineers can effectively check the condition of the structure. To address this problem, we used the fusion technique with the impact-echo and flexural modes which enables to characterize the area and degree of damage. The basis of the fusion method is introduced, and the practical way how to use the impact-echo and flexural modes for the simulated slabs is studied and experimentally confirmed.

8:50 AM

Comparison of Frequency-Modulated Continuous-Wave (FM-CW) Radar and Impact-Echo Data for Detecting Delamination in Concrete Bridge Decks
---Reza Zoughi and M. T. Ghasr, Applied Microwave Nondestructive Testing Laboratory (amntl), Electrical and Computer Engineering Department, Missouri University of Science and Technology, Rolla, MO 65409; John S. Popovics and S. Ham, Department of Civil and Environmental Engineering, University of Illinois, Urbana, IL 61801

---Reinforced concrete bridge decks are susceptible to early deterioration. A serious problem affecting the service life of the reinforced concrete decks is the formation of a delamination, which is a thin cracked area that lies directly above the steel reinforcement mat within the deck. Since visual inspections are not effective to identify sub-surface delamination, effective nondestructive testing (NDT) methods capable of detecting such delaminations are needed. Here we evaluate the utility of microwave and mechanical wave tests to detect delamination in reinforced concrete bridge deck mock-up samples. The mechanical wave tests comprise air-coupled impact-echo measurements, while the microwave measurements comprise wideband frequency-modulated continuous-wave (FM-CW) field-operable radar system operating in the frequency range of 10-18 GHz. Impact-echo offers excellent sensitivity to near-surface delaminations but is not effective for detecting deeper delaminations. Wideband FM-CW radar offers relatively high-depth resolution in concrete, which makes it particularly suitable for detecting thin delaminations. The trade-off is the depth of penetration in concrete. We present the from both test types in terms of individual pieces of test data as well as images that are built up from those data. Based on a comparison of the results, we evaluate the individual and fused capabilities of each method.
Evaluation of the Feasibility for Detecting Hidden Corrosion Damage in Multi-Layer Gusset Plates Using Multiple Inspection Techniques

--- Adam C. Cobb, Charles E. Duffer, and Glenn M. Light, Southwest Research Institute, 6220 Culebra Road, San Antonio, TX 78238

--- Gusset plates are used to connect the load-bearing members in bridge trusses and they are usually inspected using conventional thickness measurement ultrasonic testing (UT) devices. The damage mechanism of particular concern in gusset plates is corrosion and the regions most susceptible to corrosion damage are on the gusset surface at the chord, diagonal, and vertical member connections from water collecting at the interfaces. In some cases, however, one or more shingle plates are used to reinforce the gusset plate, creating a multi-layer structure. While the areas with corrosion damage remain near the load member connections on the gusset plate, the shingle plates cover the gusset plate and greatly limit the surface access to the gusset plate, making thickness measurement UT impractical. Because of the critical nature of the gusset plates a viable inspection strategy for multi-layer gusset assemblies must be developed. The premise of this research and development effort was to develop viable, field-deployable inspection approaches for this problem area. This paper presents three separate inspection approaches: two ultrasonic-based techniques and one radiographic approach. Each of these techniques was evaluated on the mockup specimens that are representative of bridge structures. Additionally, recommendations on transitioning these techniques from the laboratory to the field will be provided.

Structural Element Assessments by Dispersive Wave Methods

--- J. Darrin Holt, FDH Engineering, Inc. Raleigh, NC 27616

--- Stress wave propagation mechanics is widely used in nondestructive testing (NDT). For civil structures, longitudinal and transverse waves generated by mechanical impact can be used for determining information about a structural element's in-situ condition and size. Longitudinal waves can be used for pile or beam assessments as well as for mapping internal features in walls and slabs. Transverse wave motion, however, is more difficult to use because of the concept of wave dispersion due to an element's geometric configuration. Even though more complex, dispersive wave propagation (DWP) is capable of revealing invaluable information about an element's current state and can be an important addition to an NDT investigation. Slender rod geometries are often used as components in civil structures. Examples of interest are piles supporting bridges and post-tensioned rod anchorages in dams. Due to high slenderness ratios, piles and rods are well-suited for testing by dispersive flexural wave methods. These waves have the ability to provide data about a pile's depth and condition, or the amount of post-tension load in a post-tensioned anchor rod. The DWP method is presented for both of these types of members, along with case histories where it has been successfully applied with verified results.
Mining of NDT Data in Civil Engineering Applications
---Parisa Shokouhi, Markus Stoppel, Andreas Zoëga, and René Heideklang, BAM – Federal Institute for Material Research and Testing, Berlin, Germany

---Two case studies involving NDT data mining are presented. The first example involves mining a multi-sensor NDT dataset automatically collected by a programmable robot. The dataset includes potential measurements, moisture, concrete cover, GPR and ultrasound taken in a parking lot. A number of unsupervised learning algorithms were used to extract the underlying structure in the data. The pre-processing and analysis steps including interpolation, normalization, and attribute selection are discussed. The usefulness of the extracted knowledge was evaluated based on the available ground-truth data. The particular aspects of NDT data mining are pointed out. In the second case study, a supervised learning approach, automatic classification of ultrasonic and impact-echo signals, was used to assert the bonding condition of ceramic tiles. The process of feature selection and extraction is detailed. The model was then applied to field measurements to predict the bonding condition. The automatic classification results were compared against the available expert assessments. The advantages and challenges of NDT data mining in civil engineering applications are discussed.

Stress Wave-Based Nondestructive Testing Methods for Performance Monitoring of Bridge Decks
---Hoda Azari, Soheil Nazarian, and Deren Yuan, The University of Texas at El Paso, Center for Transportation Infrastructure Systems, 500 W. University Avenue, El Paso, TX 79968

---Bridges are one of the most critical nodes in the highway system. Among the concrete bridges’ components, bridge decks deteriorate faster due to environmental factors and traffic loads. Performance monitoring of bridge decks is essential for determining the appropriate timing and the extent of maintenance activities to remedy structural problems and to ensure safety and serviceability. In addition to evaluation of deterioration, there is a need for quantitative quality management of strength and thickness of a new constructed bridge deck. This paper discusses the applicability of two stress wave-based nondestructive testing methods (impact echo, and ultrasonic surface wave) in performance monitoring of concrete bridge decks. To evaluate the potentials and limitations of applications of the two methods, individually and in combination, in detecting and characterizing deterioration in concrete decks, the actual field results of testing a fabricated deck with artificial delaminated areas of varying sizes and depths are included in this paper. The experimental data on the concrete deck are also calibrated with the numerical data. The experimental and numerical results showed that the impact echo and ultrasonic surface wave methods are effective in detecting the deteriorated areas in a concrete deck, especially when the results are evaluated in combination.
10:50 AM

3D Mapping and Localization of Underground Utilities with Ground Penetrating Radar
---Feng Xu, Devendra Tolani, and Xue Qi, Intelligent Automation, Inc. 15400 Calhoun Drive, Suite 400, Rockville, MD 20855; Dave Gibson and Peter Huang, Federal Highway Administration, Turner-Fairbank Highway Research Center, 6300 Georgetown Pike, McLean, VA 22101

---This paper introduces an innovative Ground Penetrating Radar (GPR) system for localization of underground assets and mapping of the utilities network. The system detects underground targets and structure by transmitting EM waves into the ground and sampling the scattered echoes. An Ultra-Wideband (UWB) approach is applied for localizing the GPR antenna array to within 5-10 cm accuracy. Advanced signal processing methods, such as the Synthetic Aperture Radar (SAR) imaging algorithm and inverse scattering algorithm have been developed to improve image resolution and quantify geophysical/electrical/geometric properties of buried targets. The GPR system has been validated with laboratory and field tests over a series of underground structures. 2D and 3D images of the targets were generated. Comparison of the reconstructed targets and the ground truth shows good agreement.

11:10 AM

The Core Drilling Method for Determining In-Situ Stresses in Concrete - Toward More Practical Field Application
---Michael J. McGinnis and Jordan Rey, University of Texas at Tyler, Department of Civil Engineering, 3900 University Boulevard, Tyler, TX 75799

---The core drilling method is a nondestructive technique to evaluate stresses in concrete. In the method, the displacements in the vicinity of a hole drilled in concrete are measured and related to stresses present in the structure via elasticity theory. Water introduced during core drilling causes the concrete to swell; these swelling displacements lead to errors in the estimated stresses. The impact of these displacements has been characterized for 6 inch (150 mm) diameter holes, however, for the method to be more practical, an investigation into drilling smaller diameter holes is underway. This paper determines the water-induced swelling displacements for several smaller hole diameters and provides a means to correct errors introduced by these displacements. The depth of water penetration and the swelling strain due to water exposure are estimated based on values reported in the literature. Finite element modeling is used to estimate the apparent stresses due to ranges of these two parameters for the different hole sizes.
A Novel Wireless Multi-sensor Network System for Structural Health Monitoring
---Xiaoliang (George) Zhao, Tao Qian, Kevin Qi, Gang Mei, An Liu, and Roger Xu, Intelligent Automation, Inc., 15400 Calhoun Drive, Suite 400, Rockville, MD 20855; Regan Zane, Z-Domain Advanced Control, LLC, 411 Opal Way, Superior, CO 80027

---A low cost, small form-factor and low power-consumption wireless multi-sensor network system has been developed to detect and track fatigue cracks in various structures. The system utilizes acoustic emission sensors to monitor the structure responses for damage events such as the growth of a fatigue crack, which then triggers the ultrasonic guided wave sensors for active inspection of the suspected area. The ultrasonic sensors may also perform scheduled inspections if no triggering event occurs for a prolonged time interval. The sensor devices communicate via a Zigbee network to a dedicated gateway node which then process and relay the sensor data to a remote server via the Global System for Mobile communications (GSM) cellular network for further analysis.

Laboratory tests have been conducted on A-36 mild steel compact-tension coupons, carbon fiber reinforced composite samples, and concrete beams for fatigue crack monitoring. Data showed that the system can be used to detect and track the growth of the crack. Initial system testing on a concrete deck, multi-beam steel-girder highway bridge for “web gap” types of crack inspection was also conducted. The results demonstrated good feasibility.

Acoustic Emission Intensity Analysis of Corrosion in Prestressed Concrete Piles
---William Velez, Fabio Matta, and Paul Ziehl, University of South Carolina, Department of Civil and Environmental Engineering, 300 Main Street, Columbia, SC 29208

---Corrosion of steel strands in prestressed concrete bridges may lead to substantial damage or collapse well before the end of the design life. Acoustic Emission (AE) is a suitable nondestructive technique to detect and locate corrosion in reinforced and prestressed concrete, which is key to prioritize inspection and maintenance. An effective tool to analyze damage-related AE data is Intensity Analysis (IA), which is based on the estimation of two data trends, namely Severity (average signal strength of the largest J hits) and Historic Index (ratio of the average signal strength of the latest K hits to the average of all hits). IA criteria for corrosion assessment in prestressed concrete were recently proposed based on empirical evidence from accelerated corrosion tests.

In this paper, AE data from prestressed and non-prestressed concrete pile specimens exposed to salt water wet-dry cycles for over 400 days are used to analyze the relation between Severity and Historic Index and actual corrosion. Evidence of corrosion is gained from the inspection of decommissioned specimens. The selection of suitable J and K parameters for IA is discussed, and an IA chart with updated corrosion criteria for prestressed concrete piles is presented.
Session 22
SESSION 22
ULTRASONIC PHASED ARRAYS I
Martin Spies, Chairperson
Key Ballroom 12

8:30 AM Simulation of the Ultrasonic Array Response from Real Branched Cracks Using an Efficient Finite Element Model
---Maria V. Felice, Alexander Velichko, and Paul D. Wilcox, University of Bristol, Department of Mechanical Engineering, Bristol, United Kingdom; Tim J. Barden and Tony K. Dunhill, Rolls-Royce plc, Bristol, United Kingdom

8:50 AM Ultrasonic Imaging of Closed Crack with Thermal Stress Induced by Global Preheating and Local Cooling
---Yoshikazu Ohara, Koji Takahashi, and Kazushi Yamanaka, Tohoku University, Department of Materials Processing, Sendai, Miyagi, Japan

9:10 AM Matrix Phased Arrays for the Inspection of CFRP-Components
---Marc Kreutzbruck, G. Brekow, D. Brackrock, H.-J. Montag, R. Boehm, and B. Ilerhauser, Federal Institute for Material Research and Testing, NDT Department, Berlin, Germany

9:30 AM Ultrasonic Measurement Models for Imaging with Phased Arrays
---Lester W. Schmerr, Jr.1,2, Brady J. Engle1,2, Alexander Sedov3, and Xiongbing Li4, 1Center for NDE, Iowa State University, Ames, IA, 50011; 2Dept. of Aerospace Eng., Iowa State University, Ames, IA, 50011; 3Dept of Mech. Eng., Lakehead University, Thunder Bay, ON, Canada P7B 5E1; 4CAD/CAM Institute, Central South University, Changsha, Hunan, 410075, P. R. China

9:50 AM Plane Wave Imaging Using Phased Array
---Arno Volker, Stieltjesweg 1, P. O. Box 155, 2600 AD Delft, The Netherlands

10:10 AM Break

10:30 AM Phased Array Performance Evaluation with PhotoElastic Visualization
---Robert Ginzel, Eclipse Scientific, 97 Randall, Waterloo, Ontario, Canada, N2V 1C5; Gavin Dao, Advanced OEM Solutions, 8044 Montgomery Road, Suite 700, Cincinnati, OH 45236

10:50 AM Categorization of Industrial Advanced Phased Array Techniques
---C. Brillon, G. Painchaud-April, J. Zhang, and B. Lepage, Olympus NDT, Solutions and Technology Development, Quebec, Canada

11:10 AM Improve Resolution of Ultrasonic Phased-Array Inspection Using SAFT
---Xuefei Guan, Jingdan Zhang, and Shaohua K. Zhou, Siemens Corporation, Corporate Technology, 755 College Road East, Princeton, NJ 08540; El Mahjoub Rasselkorde and Waheed A. Abbasi, Siemens Energy Inc., 841 Old Frankstown Road, Pittsburgh, PA 15239-2246

11:30 AM Imaging of Transverse Cracks in Austenitic Welds with RT-SAFT

11:50 AM Defects Imaging Method Based on DORT and SAFT in Austenitic Stainless Steel Deep Weld Using Ultrasonic Phased Array
---Qiang Wang and Yongliang Chen, China Jiliang University, College of Quality and Safety Engineering, No. 258, Xueyuan Street, Hangzhou, Zhejiang 310018, China (PRC)

12:10 PM Lunch
8:30 AM

Simulation of the Ultrasonic Array Response from Real Branched Cracks Using an Efficient Finite Element Model
---Maria V. Felice, Alexander Velichko, and Paul D. Wilcox, University of Bristol, Department of Mechanical Engineering, Bristol, United Kingdom; Tim J. Barden and Tony K. Dunhill, Rolls-Royce plc, Bristol, United Kingdom

---Stress corrosion cracks are a serious issue in many industries. They can grow quickly and cause catastrophic failure, so it is imperative to be able to reliably inspect for them. However, the branched nature of these cracks causes difficulties when using ultrasonic testing. In order to efficiently design better ultrasonic inspections, it is necessary to understand the ultrasonic scattering from branched cracks. A lot of work has been done on simulating the scattering from straight cracks. In this paper, the interaction of ultrasound with branched cracks is addressed. A frequency-domain finite element model is described and used to simulate scattering from branched cracks. It is an efficient model because the spatial domain consists of only the crack shape. The model is validated by comparing results to experimental results and to results from a time-domain finite element model in which the crack is modelled within the whole component. The efficient model is then used to simulate ultrasonic scattering from real stress corrosion crack geometries which are obtained by performing X-ray Computed Tomography of parts that have been removed from service. Simulated ultrasonic array data is obtained by using a hybrid model consisting of the efficient finite element model and ray tracing.

8:50 AM

Ultrasonic Imaging of Closed Crack with Thermal Stress Induced by Global Preheating and Local Cooling
---Yoshikazu Ohara, Koji Takahashi, and Kazushi Yamanaka, Tohoku University, Department of Materials Processing, Sendai, Miyagi, Japan

---Crack closure leads to underestimation or overlook in the ultrasonic inspection. A novel imaging method, subharmonic phased array for crack evaluation (SPACE) is effective for measuring closed-crack depths. However, when a short-burst wave is used, not only closed cracks but also linear scatterers appear in the subharmonic image owing to the spectral broadening of input wave. This degrades the selectivity for closed crack. To solve this problem, we have developed the load difference phased array (LDPA), which uses the subtraction of responses at different external loads. However, a practical method applying load is required. On the other hand, the use of thermal stress induced by local cooling (LC) has been proposed. The top surface of specimen is locally cooled by a cooling spray. The vicinity of the top surface thermally contracts, and thereby, tensile thermal stress is applied to the closed crack by a principle similar to that of a three-point bending test. However, LC cannot open tightly closed cracks since the tensile thermal stress cannot be made sufficiently high to open closed cracks owing to the limited cooling temperature determined by cooling medium. To solve this problem, we propose a crack opening method (GPLC) that combines global preheating (GP) and LC, which can readily increase the tensile thermal stress applied to closed cracks. After GP, LC is performed by a cooling spray. Here, the tensile thermal stress applied can be controlled by varying the GP temperature. In this study, we applied GPLC to a tightly closed fatigue crack. As a result, we succeeded in imaging the crack by linear phased array (PA). Furthermore, we examined the thermal bending stress applied to the crack during GPLC on the basis of heat transfer analysis within a specimen. We estimated the crack closure stress comparing the thermal stress and the PA image.
Matrix Phased Arrays for the Inspection of CFRP-Components
---M. Kreutzbruck, G. Brekow, D. Brackrock, H.-J. Montag, R. Boehm, and B. Illerhaus, Federal Institute for Material Research and Testing, NDT Department, Berlin, Germany

---Lightweight components are increasingly used in different industrial sectors such as transportation, energy generation and automotive. This growing field includes different types of CFRP-structures, hybrid materials and glued components showing - compared to their pure metallic counterparts- a significant more complicated structure in terms of internal interfaces and anisotropy of material parameters. In this work we present the use of matrix phased array to increase the amount of obtained information to enhance the inspection quality. We used different types of carbon materials such as 6mm thick uni- and bidirectional prepreg specimens containing impact damages. The latter were introduced with different energy levels ranging from 1.3 to 7.2 J. By scanning a 2.25 MHz matrix array with 6 x 10 elements above the prepreg surface and using different angels of incidence a complete 3D-image was generated which allows the detection of defects as small as 1mm. A comparison with conventional approaches show that the signal-to-noise can be highly increased. This enables us to visualize the region of damage within the impact zone, clearly showing the cone-like damage distribution along increasing material depth. The detection quality allows the estimation of the opening angles of the cone shaped damage, which can be used for further evaluation and quantitation of energy dependent impact damages.

Ultrasonic Measurement Models for Imaging with Phased Arrays
---Lester W. Schmerr, Jr.1,2, Brady J. Engle 1,2, Alexander Sedov3, and Xiongbing Li4, 1Center for NDE, Iowa State University, Ames, IA, 50011; 2Dept. of Aerospace Eng., Iowa State University, Ames, IA, 50011; 3Dept of Mech. Eng., Lakehead University, Thunder Bay, ON, Canada P7B 5E1; 4CAD/CAM Institute, Central South University, Changsha, Hunan ,410075, P.R. China

---Ultrasonic measurement models have been used extensively to simulate NDE inspections. These models are forward models that predict the measured signals seen in NDE tests. Here we will show that by inverting these measurement models one can also use them to develop imaging algorithms for use with phased arrays. Imaging methods based on inversions of measurement models of both the Auld type and the Thompson-Gray type will be described. Unlike many inversions which are based on the weak scattering Born approximation, we will use a physically based method that relies instead on the high frequency Kirchhoff approximation. For the Auld type of measurement models this will lead to imaging algorithms that are generalizations of delay-and-sum methods such as the synthetic aperture focusing technique (SAFT) and the total focusing method (TFM). Inversions of the Thompson-Gray measurement model will produce physical optics far field inverse scattering (POFFIS) style imaging methods. These results provide a rational basis for understanding and quantitatively evaluating the images obtained with ultrasonic phased array systems.---This work was supported for Lester W. Schmerr, Jr., and Brady J. Engle by the National Science Foundation Industry/University Cooperative Research Center program at the Center for NDE, Iowa State University. Alexander Sedov acknowledges support by the National Sciences and Engineering Research Council of Canada, and Xiongbing Li acknowledges support of the National Natural Science Foundation of China (51005252 and 61271356).
9:50 AM

**Plane Wave Imaging Using Phased Array**

---Arno Volker, Stieltjesweg 1, P.O. Box 155, 2600 AD Delft, The Netherlands

---Phased arrays are often used for rapid inspections. Phased arrays can be used to synthesize different wave fronts. For imaging, focused wave fronts are frequently used. In order to build an image, the phased array has to be fired multiple times at the same location. Alternatively, different data acquisition configurations can be designed in combination with an imaging algorithm. The objective of this paper is to use the minimal amount of data required to construct an image. If a plane wave is synthesized, the region of interest is illuminated completely. For plane wave synthesis, all elements in the phase array are fired. This ensures a good signal to noise ratio. Imaging can be performed efficiently with a mapping algorithm in the wavenumber domain. The algorithm involves only two Fourier transforms and can therefore be extremely fast. The obtained resolution is comparable to conventional imaging algorithms.

10:30 AM

**Phased Array Performance Evaluation with PhotoElastic Visualization**

---Robert Ginzel, Eclipse Scientific, 97 Randall, Waterloo, Ontario, Canada, N2V 1C5; Gavin Dao, Advanced OEM Solutions, 8044 Montgomery Road, Suite 700, Cincinnati OH 45236

---New instrumentation and a widening range of phased array transducer options are affording the industry with greater potential. Visualization of the complex wave components using the photoelastic system can greatly enhance understanding of the generated signals. Diffraction, mode conversion and wave front interaction, together with beam forming for linear, sectorial and matrix arrays, will be viewed using the photoelastic system. Beam focus and steering performance will be shown with a range of embedded and surface targets within glass samples. This paper will present principles and sound field images using this visualization system.
Categorization of Industrial Advanced Phased Array Techniques
---C. Brillon, G. Painchaud-April, J. Zhang, and B. Lepage, Olympus NDT, Solutions and Technology Development, Quebec, Qc, Canada

---Phased array technology in its most basic expression consists in a waveform exciting a group of piezoelectric transducers (the emitter) which will vibrate, thus transferring small mechanical vibrations to some material. The generated modes propagate into the material and are recaptured by the same or a second group of piezoelectric transducers (the receiver) transforming the received acoustic signal back into an electrical format. Recording several of such signals (elementary A-Scans) over a period of time makes it possible for them to be recombined a posteriori using different phasing schemes. Some of these recombination schemes have been used for several years and bear names such as synthetic aperture focusing and dynamic depth focusing while others such as volume focusing and full matrix capture have recently started catching the interest of the larger NDT industry. However, how they all relate to each other is still rather subjective. In this paper, Olympus NDT proposes a classification structure based on mathematical formalism to help categorize advanced phased array techniques. Nomenclature and terminology are adopted and results will be shown that illustrate the advantages, tradeoffs and also equivalence for a subset of techniques.

Improve Resolution of Ultrasonic Phased-Array Inspection Using SAFT
---Xuefei Guan, Jingdan Zhang, and Shao Hua K. Zhou, Siemens Corporation, Corporate Technology, 755 College Rd. East, Princeton NJ 08540; El Mahjoub Rasselkorde and Waheed A. Abbasi, Siemens Energy Inc., 841 Old Frankstown Road, Pittsburgh PA 15239-2246

---Ultrasonic Synthetic Aperture Focusing Technique (SAFT) reconstruction method is developed to provide high-resolution images of the inspected areas and volumes. The basic idea of the method is to coherently superimpose multiple A-scan measurements, incorporating the phase information of the sampling points. The method involves multiple several steps: data filtering, data mapping according to time-of-flight (ToF), and local normalizing. Data filtering is an optional step for removing artificial noise elements in the sampling data. Data mapping refers to the process of mapping each of the sampling points to a three-dimensional grid that represents the geometry model of the object being inspected. The value for each cell of the grid is a summation of all sampling points mapped into the cell. Local normalizing refers to normalize a selected region of interest (ROI) for defect visualization and quantification. Lab experiments are performed using multiple phased array ultrasonic probes with different frequencies. The method is used to process the experimental data. Using the developed method, spatial resolution of the flaw sizing is significantly improved comparing with traditional distance-gain-size method. The results indicate that four closely spaced 0.8mm-diameter flat-bottomed holes are clearly identified.
11:30 AM

Imaging of Transverse Cracks in Austenitic Welds with RT-SAFT


---The synthetic aperture focusing technique (SAFT) is an imaging technique commonly used in ultrasonic inspection. In order to apply SAFT to the inspection of austenitic welds, the inhomogeneous anisotropic nature of the weld structure has to be taken into account. A suitable approach to accomplish this, is to couple the SAFT-algorithm with a ray tracing program (RT-SAFT). While SAFT-imaging of cracks in austenitic welds by use of ray tracing has been carried out before, all attempts so far where limited to longitudinal cracks which usually allows a treatment as 2-dimensional problem. In case of transverse cracks, a full 3-dimensional ray tracing is necessary in order to perform a SAFT-reconstruction. In this paper, we give an outline of our attempts to reconstruct images of transverse cracks in austenitic welds, utilizing 3-dimensional ray tracing and a layered structure model derived from an empirical model of grain orientations in welds. We present results of this RT-SAFT on experimental data taken from transverse cracks in different austenitic welds, which show that size and position of the cracks can be estimated with good accuracy, and compare them to images obtained by assuming an isotropic homogeneous medium which corresponds to the application of the classical SAFT-algorithm.

11:50 AM

Defects Imaging Method Based on DORT and SAFT in Austenitic Stainless Steel Deep Weld Using Ultrasonic Phased Array

---Qiang Wang and Yongliang Chen, China Jiliang University, College of Quality and Safety Engineering, No 258, Xueyuan Street, Hangzhou, Zhejiang 310018, China (PRC)

---This paper presents an imaging method for the defects in austenitic stainless steel deep weld using ultrasonic phased arrays technique. Even though most of methods are proposed to find the defects with satisfactory result, a number of issues still need to be addressed. The DORT (Decomposition of the Time Reversal Operator) method can give a roughly delayed law, but it needs a relatively long time and the quality of the defects image is not very high. The SAFT (Synthetic Aperture Focusing Technique) algorithm can improve the image quality but it was difficult to be directly applied in a bad image. So using two methods together can be taken into consideration. In this paper, an austenitic stainless steel deep weld sample was made with several side drilled holes, then the beam steering focus method was used to inspect the defects and the result was restored in the computer. The DORT method was adopted to analyze the restored result and a new delay law was replied to the inspection after calculated. When a new inspection image was acquired, the SAFT algorithm was employed to adjust the result. In the last we can get a high accuracy defects image.
SESSION 23
ULTRASONIC MODELING, PROPAGATION, AND GUIDED WAVES
Cliff Lissenden, Chairperson
Key Ballroom 2

8:30 AM  Split Approach for FEA Simulations of Very Large Wave Propagation Models
---Shivanandan S. Indimath and T. Balasubramanian, National Institute of Technology
Tiruchirappalli, Department of Physics, Tiruchirappalli, Tamilnadu, India; Sandeep Kumar S. R. and
Krishnan Balasubramaniam, Indian Institute of Technology Madras, Department of Mechanical
Engineering, Chennai, Tamilnadu, India

8:50 AM  Compressional Beam Profile Radiated from Waveguide-Generated Dispersive Lamb Wave
---Hyunjo Jeong, Division of Mechanical and Automotive Engineering, Wonkwang University,
Iksan, Jonbuk 570-749, Republic of Korea; Young-Sang Joo, Hoe Woong Kim, and Jong-
Bum Kim, Fast Reactor Development, Korea Atomic Energy Research Institute, 150-1 Dukjin-
Dong, Yuseong, Daejeon, Republic of Korea

9:10 AM  Series Expansions in Acoustic Wave Generation Models
---Kaican Wang, Yakun Wang, Zhichao Li, Guofu Zhai, and Shujuan
Wang, School of Electrical Engineering and Automation, Harbin Institute of Technology, Harbin,
Heilongjiang, China

9:30 AM  Simulation for Air-Coupled Ultrasound Testing Using Time-Domain BEM
---Taizo Maruyama and Sohichi Hirose, Tokyo Institute of Technology, Department of Mechanical
and Environmental Informatics, Meguro-ku, Tokyo, Japan; Takahiro Saitoh, Gunma University,
Division of Environmental Engineering Science, Tenjin, Kiryu, Gunma, Japan

9:50 AM  Simulation of Ultrasonic Surface Waves with Multi-Gaussian and Point Source Beam Models
---Xinyu Zhao, School of Mechanical Engineering, Beijing Institute of Technology, Beijing 100081,
China; Lester W. Schmerr, Jr., Iowa State University, Center for NDE, 1915 Scholl Road, Ames, IA
50011; Alexander Sedov, Lakehead University, Department of Mechanical Engineering; Xiongbing
Li, Iowa State University, Center for NDE, ASC II, 1915 Scholl Road, Ames, IA 50011

10:10 AM  Break

10:30 AM  Guided Wave Mode and Frequency Selection Tips for Reliable Actuator Design
---Joseph L. Rose and Clifford J. Lissenden, Penn State, Department of Engineering Science and
Mechanics, University Park, PA 16802

10:50 AM  Study on Guided Wave Propagation in a Water Loaded Plate with Wavenumber Analysis
Techniques
---Z. Tian and L. Yu, University of South Carolina, Mechanical Engineering Department, Columbia,
SC 29208

11:10 AM  Analysis of Angle-Beam Wavefield Measurements
---Alexander Dawson, Jennifer E. Michaels, Thomas E. Michaels, and Ross M. Levine, Georgia
Institute of Technology, School of Electrical and Computer Engineering, Atlanta, GA 30332-0250

11:30 AM  Inspection of a Part Circumferential Notch in a Pipe by Torsional Waves: Simulations and
Experiments
---Ki Yean Kim, Young Eul Kwon, and Yoon Young Kim, Seoul National University, School of
Mechanical and Aerospace Engineering, Seoul, Republic of Korea; Hoe Woong Kim, Korea Atomic
Energy Research Institute, Fast Reactor Technology Demonstration Division, Daejeon, Republic of
Korea

11:50 AM  Ultrasound Propagation in Heterogeneous Media: Model Study
---Ronald A. Roberts, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915
Scholl Road, Ames, IA 50011

12:10 PM  Lunch
**8:30 AM**

**Split Approach for FEA Simulations of Very Large Wave Propagation Models**  
Shivanandan S. Indimath and T. Balasubramanian, National Institute of Technology Tiruchirappalli, Department of Physics, Tiruchirappalli, Tamil Nadu, India; Sandeep Kumar S. R. and Krishnan Balasubramaniam, Indian Institute of Technology Madras, Department of Mechanical Engineering, Chennai, Tamil Nadu, India

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FEA simulations of wave propagation models become exceedingly larger with increase in frequency of wave, decrease in velocity of sound in the material and/or overall dimensions of the model. This leads to an excessive requirement in terms of computation resources for solving the model and ultimately limits the maximum dimensions of a model that can be solved in a particular computing facility. A new approach has been tried out by splitting the model into smaller parts and solving each part individually, thereby enabling us to solve much larger FE problems with the limited computation resources available, however, with some constraints. The Higher Order Mode Cluster Guided Wave (HOMC-GW) in steel plates using a Plexiglas wedge with 3-D models using the ABAQUS® Explicit FE package was considered here. The complete model including the wedge and the plate consisted of approximately 10 million elements. The model was physically considered into two separate parts; one consisting of the wedge and some portion of the steel plate under the wedge, and the other consisting of the remaining length of the plate. This split model was implemented in the FEA by decomposing the total large model into 3 sub-models; firstly the initialization of the wave in the wedge which forms the HOMC-GW packet in the steel plate. The response of the packet was captured at the end section of the plate and provided as input for the second sub-model comprising of the remaining length of the plate. The wave packet was thus successfully reconstructed in the second sub-model and the response of this reconstructed wave packet from the notch in the plate and the end-wall were captured. This response was then given as input parameters for the third sub-model, whose model is same as the first sub-model; only now working in a reception mode. The responses of the 3 sub-models were stitched to obtain a complete A-Scan. The split-model results were found to be comparable with complete 3D models.

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**8:50 AM**

**Compressional Beam Profile Radiated from Waveguide-Generated Dispersive Lamb Wave**  
Hyunjo Jeong, Division of Mechanical and Automotive Engineering, Wonkwang University, Iksan, Jonbuk 570-749, Republic of Korea; Young-Sang Joo, Hoe Woong Kim, and Jong-Bum Kim, Fast Reactor Development, Korea Atomic Energy Research Institute, 150-1 Dukjin-Dong, Yuseong, Daejeon, Republic of Korea

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Under-liquid inspection applications, waveguide sensors are frequently employed. In these applications, mode conversion occurs from Lamb waves to angled compressional waves in a radiating fluid. In a recent application, a plate-type ultrasonic waveguide sensor using a leaky Lamb wave (A0 mode) has been developed for under-sodium visual inspection of the reactor core and in-vessel structures. In the plate waveguide sensor, the A0 leaky Lamb wave is utilized for the single mode generation and the effective radiation capability in a fluid. In this paper, we further investigate the beam profile of radiating compressional wave, not fully addressed in earlier study. Theoretical treatment is given to simulate the radiation beam field using the multi-Gaussian beam (MGB) model. The MGB model can easily handle a number of input variables for calculating radiation beam fields, for instance, amplitude and waveform variation along the radiating surface, number of pulse cycles, size of radiating surface, etc. We focus on the strong dispersion effect and examine the efficiency of time reversal (TR) process that is applied to compensate for the effect of dispersive Lamb waves.
Series Expansions In Acoustic Wave Generation Models
---Kaican Wang, Yakun Wang, Zhichao Li, Guofu Zhai, and Shujuan Wang, School of Electrical Engineering and Automation, Harbin Institute of Technology, Harbin, Heilongjiang, China

---Currently, analytical models for both compressional and shear wave transducers have been well established to calculate acoustic wave generation. However, the expressions contain infinite integrations and multi singular points which result in complex numerical computation. A series expansion method is proposed, which imposes a homogeneous Dirichlet or Neumann condition for the acoustic potentials at finite boundaries. This method replaces the integration by series operation and avoids the solutions of singular points effectively. As a result, the model’s precision is well controlled and the computation time is considerably reduced. Expressions of the wave field radiated from compressive normal, shear horizontal and shear radial stresses are presented respectively. The validity of the method is verified by finite-element method.
Simulation of Ultrasonic Surface Waves with Multi-Gaussian and Point Source Beam Models
---Xinyu Zhao, School of Mechanical Engineering, Beijing Institute of Technology, Beijing 100081, China; Lester W. Schmerr Jr., Center for NDE, Iowa State University, Ames, IA, 50011; Alexander Sedov, Department of Mechanical Engineering, Lakehead University; Xiongbing Li, Center for NDE, Iowa State University, Ames, IA 50011

---In the past decade, multi-Gaussian beam models have been developed to solve many complicated bulk wave propagation problems. However, to date those models not been extended to simulate the generation of Rayleigh waves. Here we will combine Gaussian beams with an explicit high frequency expression for the Rayleigh wave Green function to produce a three-dimensional multi-Gaussian beam model for the fields radiated from an angle beam transducer mounted on a solid wedge. Simulation results obtained with this model are compared to those of a point source model. It is shown that the multi-Gaussian surface wave beam model agrees well with the point source model while being computationally much more efficient.

Guided Wave Mode and Frequency Selection Tips for Reliable Actuator Design
---Joseph L. Rose and Cliff J. Lissenden, Penn State, Department of Engineering Science and Mechanics, University Park, PA 16802

---Ultrasonic guided waves in nondestructive evaluation and structural health monitoring are receiving significant attention today because of many recent breakthroughs in understanding, computation, and the ability to solve problems with no prior solution potential. Many commercialization efforts are underway. This short talk discusses the critical element of mode and frequency selection from a set of dispersion curves that is essential for inspection success. A hybrid analytical finite element approach to actuator design is discussed and applied to problems in rail, water-loaded structures, pipe, and coating delamination evaluation. Deicing and gas entrapment problems are also examined. Finally, a few examples in tomographic imaging, phased array in plates, ultrasonic vibrations, and nonlinear ultrasonic guided waves are reviewed.
Study on Guided Wave Propagation in a Water Loaded Plate with Wavenumber Analysis Techniques
---Z. Tian and L. Yu, University of South Carolina, Mechanical Engineering Department, Columbia, SC 29208

Guided waves have been increasingly used for long range ultrasonic nondestructive evaluation (NDE) and structural health monitoring (SHM). In this paper, we study the guided wave propagation in a water loaded plate with wavenumber analyses. Experimentally, a surface mounted PZT wafer is used to generate the waves and a non-contact laser Doppler vibrometer is used to measure the time-space wavefield which contains a wealth of information regarding the propagating waves. Characteristic features of the propagating guided waves in the water loaded plate are acquired with three different wavenumber analysis techniques: (i) frequency-wavenumber analysis, (ii) space-frequency-wavenumber analysis, and (iii) time-space-frequency-wavenumber analysis. Using the wavenumber representation, various wave modes such as A0, S0 as well as the quasi-Scholte modes are easily recognized with different wavenumbers. Mode conversions and boundary reflections are also identified at the interface where the plate is in contact with the water. Our results are consistent with previous work and have shown the effectiveness of wavenumber analysis techniques in the study of wave propagation from the perspective of wavenumber domain.

Analysis of Angle-Beam Wavefield Measurements
---Alexander Dawson, Jennifer E. Michaels, Thomas E. Michaels, and Ross M. Levine, Georgia Institute of Technology, School of Electrical and Computer Engineering, Atlanta, GA 30332-0250

Angle-beam ultrasonic testing is a common practice for nondestructively detecting, locating and characterizing a variety of material defects and damage. Greater understanding of both the incident wavefield produced by an angle-beam transducer-wedge combination and the scattering from a variety of defects and damage can contribute to increasing the reliability of angle-beam testing. The focus of this work is analysis of angle-beam wavefields in plates with and without simple reflectors, which will serve as the basis for the development of improved methods for quantitative damage characterization. Wavefields are measured using a Polytec laser vibrometer, mounted on a scanning stage and programmed to move point-to-point on a rectilinear grid. Prior wavefield analysis methods have focused on guided waves, in particular the estimation of dispersion curves and characterization of scattering from defects. Some of these methods, such as frequency-wavenumber filtering, can be applied to angle-beam bulk wave data, but the multiple bounces of incident and scattered bulk waves between the plate surfaces lead to different propagation characteristics than are manifested with guided waves. Here both frequency-wavenumber filtering and Radon transform methods are applied to the analysis of angle-beam wavefield data. These techniques are useful for not only identifying the wave type (mode), direction of propagation and refracted angle, but also have the potential for removing a specific wave mode and direction of propagation.
Inspection of a Part Circumferential Notch in a Pipe by Torsional Waves: Simulations and Experiments

—Ki Yean Kim, Young Eui Kwon, and Yoon Young Kim, Seoul National University, School of Mechanical and Aerospace Engineering, Seoul, Republic of Korea; Hoe Woong Kim, Korea Atomic Energy Research Institute, Fast Reactor Technology Demonstration Division, Daejeon, Republic of Korea

The research aims to estimate the damage extent of a part circumferential notch in a pipe, not only its depth but also length, by sending the first torsional wave mode alone and analyzing the reflected first and second torsional waves modes from a notch. While earlier works on the subject are mostly focused on the evaluation of notch length, our study carries out an extensive study also for notch depth evaluation. Therefore, it is essential to transmit only the first torsional wave mode towards a notch in a pipe at the frequency between the first and second cut-off frequencies and to measure both the first and second torsional wave modes reflected from it. Then, we show how the reflected torsional wave coefficients can be used to estimate quantitatively the notch depth and length. After numerical simulations are carried out, we demonstrate specific relations between the reflected coefficients and the notch damage extent. For experiments, we use a phased array consisting of two magnetostrictive meander transducers, adjust the line interval of each meander coil, and control the time delay between two transducers. The experimental results were found to support the reasoning from the simulation results.

Ultrasound Propagation in Heterogeneous Media: Model Study

—R. A. Roberts, Center for NDE, Iowa State University, Ames IA 50011

This paper reports on a computational study of ultrasound propagation in heterogeneous microstructures, such as granular metals and fiber reinforced composites. Random spatial fluctuations in elastic properties and density over a range of length scales relative to ultrasound wavelength can give rise to scatter-induced attenuation, backscatter noise, and phase front aberration. It is of interest to quantify the dependence of these phenomena on the microstructure parameters, for the purpose of quantifying deleterious consequences on flaw detectability, and for the purpose of material characterization. Previous work by the author employed a scalar wave model to represent a heterogeneous titanium microstructure, which was used to examine backscatter and phase aberration effects on flaw signal-to-noise. Although informative, this previous approach applied an ad hoc translation of material properties into spatial variations of scalar wave velocity, resulting in a compromised quantitative representation. In the present work, the approach is advanced to consider general linear elastic media, in which 21 elastic constants are assumed to have a random spatial dependence. A volume integral equation (VIE) for the strain field is solved using a FFT-based iterative method which exploits the convolutional nature of the VIE kernel. Realizations of random microstructures are specified on the micron scale using statistical property descriptions (e.g., grain size and orientation distributions), which are then spatially filtered to provide rigorously equivalent scattering media on a length scale relevant to ultrasound propagation. Scattering responses from ensembles of media representations are averaged to obtain mean and variance of quantities such as attenuation and backscatter noise levels, as a function of microstructure descriptors. The approach will be summarized, and examples of application will be presented.---This research was funded through the Pratt & Whitney Center of Excellence at ISU.
Session 24
SESSION 24
SENSORS, TRANSDUCERS, AND PROBES
Key Ballroom 9

8:30 AM  Traceable Micro-Force Sensor for Nanoindentation Instrument Calibration
---Dan Xiang, X-wave Innovations, Inc., 407 Upshire Circle, Gaithersburg, MD 20878

8:50 AM  ASTM E127 Reference Standard Material and Measurement Study
---Mark F. A. Warchol and Lyudmila V. Warchol, Texas Research Institute, Austin, TX 78748; MFAW NDT, LLC, 412 Kissing Oak Drive, Austin, TX 78748-4013

9:10 AM  Static Characterization of a Soft Elastomeric Capacitor for Nondestructive Evaluation Applications
---Hussam Saleem and Simon Laflamme, Iowa State University, Department of Science and Technology, Civil, Construction and Environmental Engineering, Ames, IA 50011; Huanhuan Zhang, Randall Geiger, and Nicola Bowler, Iowa State University, Department of Science and Technology, Electrical and Computer Engineering, Ames, IA 50011; Nicola Bowler, Michel Kessler, and Krishna Rajan, Iowa State University, Department of Science and Technology, Materials Science and Engineering, Ames, IA 50011

9:30 AM  Simulation Based Investigation of Focusing Phased Array Ultrasound in Dissimilar Metal Welds
---Hun-Hee Kim, Hak-Joon Kim, and Sung-Jin Song, Sungkyunkwan University, Suwon, Korea; Kyung-Cho Kim and Yong-Buem Kim, Korea Institute of Nuclear Safety, Daejeon, Korea

9:50 AM  RF Moisture Sensor for a High Pressure Gasket Material
---Gene Bogdanov and Reinhold Ludwig, Worcester Polytechnic Institute, Department of Electrical and Computer Engineering, Worcester, MA 01609; Jason Wiggins and Ken Bertagnolli, US Synthetic, Orem, UT

10:10 AM  Break

10:30 AM  Development of a Magnetic Sensor for Detecting and Sizing Paraffin Deposition Inside Pipelines
---M. C. L. Areiza and J. V. Rocha, Non-Destructive Testing, Corrosion and Welding Laboratory – Department of Metallurgical and Materials Engineering COPPE/UFRJ – Federal University of Rio de Janeiro, CEP 21941-596 – Rio de Janeiro, Brazil; Joao M. A. Rebelo, Department of Metallurgical and Materials Engineering COPPE/UFRJ - Federal University of Rio de Janeiro - P.O. Box 68505 CEP 21941-972 - Rio de Janeiro, Brazil

10:50 AM  Principle of Omni-Directional Lamb Wave Generation by Magnetostrictive Patch Transducer
---Yoon Young Kim and Joo Kyung Lee, Seoul National University, School of Mechanical and Aerospace Engineering, 1 Gwanak-ro, Gwanak-gu, Seoul 151-742, Republic of Korea, Korea; Hoe Woong Kim, Korea Atomic Energy Research Institute, Fast Reactor Technology Demonstration Division, Daejeon, Republic of Korea, Korea

11:10 AM  Potential Drop Strain Sensor for In-Situ Power Station Creep Monitoring
---Joseph Corcoran and Peter Cawley, Imperial College, Mechanical Engineering, London, United Kingdom; Peter B. Nagy, University of Cincinnati, School of Aerospace Systems, Cincinnati, OH 45221

11:30 AM  The Characterization and Design of Ultrasonic Phased Arrays for Harsh Environments
---Mike Watkins, Mark Jones, Brett Braatz, Tony Cinson, Mike Larche, Jerry Posakony, David Baldwin, Paul Keller, Royce Mathews, and Matt Edwards, Pacific Northwest National Laboratory, Richland, WA 99352

11:50 AM  Adjourn Session

12:10 PM  Lunch
8:30 AM

Traceable Micro-Force Sensor for Nanoindentation Instrument Calibration
---Dan Xiang, X-wave Innovations, Inc., 407 Upshire Circle, Gaithersburg, MD 20878

---A traceable micro-force sensor that is capable of measuring forces in the range of micronewtons to millinewtons has been developed. This device consists of a pair of parallel electrodes, with one suspended to be active elastically with applied forces, to provide capacitance measurements. In conjunction with a traceable ultrahigh accuracy capacitance bridge, this sensor has been calibrated against the primary forces that are realized with deadweights. As an effort to develop a secondary transfer micro-force standard, this sensor has been used to verify commercial nanoindentation instruments. By comparing the micro-forces measured from the sensor and those recorded from an indentation system, loading errors of that instrument can been determined. The results unfold the fact that significant errors present in the verified commercial nanoindentation instruments when their loading forces are extended to the micronewton range, which is not, and unable to be calibrated directly with current standards.

8:50 AM

ASTM E127 Reference Standard Material and Measurement Study
---Mark F. A. Warchol and Lyudmila V. Warchol, Texas Research Institute, Austin, TX 78748; MFAW NDT, LLC, 412 Kissing Oak Drive, Austin, TX 78748-4013

---The ASTM E 127 “Standard Practice for Fabricating and Checking Aluminum Alloy Ultrasonic Standard Reference Blocks” was developed to assure consistent ultrasonic measurement of suspected discontinuities in wrought aluminum alloy product. The E127 practice established a consensus methodology for the manufacture, metrological limits and ultrasonic response limits from flat bottom hole (FBH) references manufactured in accordance with the practice. This paper will present a brief history of the development of the standard along with problems encountered in the earliest publications. The early issues were resolved, but as instrumentation and materials changed, problems have again arisen with the consistency of the results. Over the past 20+ years the authors have uncovered the causes of many of the inconsistencies associated with establishing measurement that match the original values prescribed in the practice. Over the years, a multitude of measurements were made on various reference standards covering a manufacture range for the mid 50s to the current time. The measurements have uncovered fundamental causes for the inconsistencies related to the material and measuring systems. The uncovered causes along with a proposal for a revision to the practice will be presented.
9:10 AM

**Static Characterization of a Soft Elastomeric Capacitor for Non Destructive Evaluation Applications**

--- Hussam Saleem and Simon Leflamme, Iowa State University, Department of Science and Technology, Civil, Construction and Environmental Engineering, Ames, IA 50011; Huanhuan Zhang, Randall Geiger, and Nicola Bowler, Iowa State University, Department of Science and Technology, Electrical and Computer Engineering, Ames, IA 50011; Nicola Bowler, Michel Kessler, and Krishna Rajan, Iowa State University, Department of Science and Technology, Materials Science and Engineering, Ames, IA 50011

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A large and flexible strain transducer consisting of a soft elastomeric capacitor (SEC) has been proposed by the authors. Arranged in a network setup, the sensing strategy offers tremendous potential at conducting non-destructive evaluation of large-scale surfaces. In prior work, the authors have demonstrated the performance of the sensor at tracking strain history, localizing cracks, and detecting vibration signatures. In this paper, we present a full characterization of the static performance of the proposed SEC. The characterization includes stability of the signal, drift, precision, noise, sensitivity, and temperature and humidity dependences. Tests are conducted by measuring bending strain on a simply supported aluminum beam. The performance of the SEC is compared against an off-the-shelf resistance-based strain gauge (RSG) with resolution of 1 με. Results show that the SEC signal raises above noise beyond the 25 με level when compared against the RSG readings. Additional improvements in the data acquisition system will enable promising sensing applications for the SEC, including monitoring of surface strain and humidity.

9:30 AM

**Simulation Based Investigation of Focusing Phased Array Ultrasound in Dissimilar Metal Welds**

--- Hun-Hee Kim, Hak-Joon Kim, and Sung-Jin Song, Sungkyunkwan University, Suwon, Korea; Kyung-Cho Kim and Yong-Buem Kim, Korea Institute of Nuclear Safety, Daejeon, Korea

--- Dissimilar metal welds (DMWs) are widely used as nozzles of major components in NPPs. These welds have caused significant reliability problems at nuclear power plants. So, phased array ultrasound widely used inspecting surface break cracks and stress corrosion cracks in DMWs. However, inspection of dissimilar metal weld using phased array ultrasound has relatively low probability of detection of cracks, because crystalline structure of welds causes distortion, and noise splitting of the ultrasonic beams which propagates anisotropic medium. So, advanced focusing techniques of phased array ultrasound are needed for improvement in the probability of detection of flaws in DMWs. Thus, in this study, we have investigated focusing and steering phased array ultrasound in dissimilar metal welds through understanding of propagation of ultrasonic waves in anisotropic medium. Also, we will compare focusing techniques such as time reversal technique, adaptive focusing technique, etc., to enhance SNR of phased array ultrasonic signals.--- This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MEST) (No. 2012M5A4A1035227).
**RF Moisture Sensor for a High Pressure Gasket Material**
---Gene Bogdanov and Reinhold Ludwig, Worcester Polytechnic Institute, Department of Electrical and Computer Engineering, Worcester, MA 01609; Jason Wiggins and Ken Bertagnolli, US Synthetic, Orem, UT

---We have previously reported on a moisture monitoring technique for high-pressure gaskets. These gaskets seal the cubical pressure cell as well as transmit pressure within it. It is suspected that too high a moisture content in these gaskets increases the chance of explosive decompressions that shorten the life of the press anvils. A non-destructive, radiofrequency method has been proposed that allows moisture measurements on every gasket. In this paper we report on the sensor design for this moisture monitoring method. Experience with a previous coaxial resonator sensor has shown it to be adequately sensitive to the moisture levels under investigation (0.2%-0.6%). However, fringe fields resulted in significant radiation loss and coupling to the environment. A new sensor has been designed that terminates the coaxial resonator with a circular waveguide operated below cutoff. Although less accessible, this sensor still allows rapid insertion of samples employing a different approach than in the original design. The waveguide termination greatly reduces radiation loss and environmental coupling, permitting accurate measurements. Simulations will show the benefits of the new design.

**Development of a Magnetic Sensor for Detecting and Sizing Paraffin Deposition Inside Pipelines**
---M. C. L. Areiza and J. V. Rocha, Non-Destructive Testing, Corrosion and Welding Laboratory – Department of Metallurgical and Materials Engineering COPPE/UFRJ – Federal University of Rio de Janeiro, CEP 21941-596 – Rio de Janeiro, Brazil; Joao M. A. Rebello, Department of Metallurgical and Materials Engineering COPPE/UFRJ - Federal University of Rio de Janeiro - P.O. Box 68505 CEP 21941-972 - Rio de Janeiro, Brazil

---Controlling paraffin deposition in the internal wall of the pipelines is one of the challenges of oil exploitation. Paraffin is a natural oil product, but it becomes a problem when it deposits in the internal wall of the pipes, due for example to an eventual local temperature lowering. This deposition reduces the flow area preventing the passage of inspection tools inside the pipe. The objective of the present study is to develop a specific sensor to be adapted to the equipment called Pipeline Internal Gate (Pig), for detecting and sizing such paraffin deposition areas. Its basic operational principle consists in creating a constant magnetic field close to the internal wall of the pipe, using a permanent magnet. Finite elements were used to develop the computational model that simulates the magnetic behavior of the paraffin sensor. The magnetic flow lines are measured by a Hall sensor, placed between the magnet and the internal wall of the pipe. The presence of paraffin reduces the density of the flow detected by the Hall sensor. The results obtained indicate that this new magnetic proximity sensor is adequate for use in the nondestructive inspection tools.
10:50 AM

Principle of Omni-directional Lamb Wave Generation by Magnetostrictive Patch Transducer
---Yoon Young Kim and Joo Kyung Lee, Seoul National University, School of Mechanical and Aerospace Engineering, 1 Gwanak-ro, Gwanak-gu, Seoul 151-742, Republic of Korea, Korea; Hoe Woong Kim, Korea Atomic Energy Research Institute, Fast Reactor Technology Demonstration Division, Daejeon, Republic of Korea, Korea

---We present a magnetostrictive patch transducer that can generate the Lamb wave omni-directionally in a plate. The developed transducers, which will be referred to as O-MPT’s, can be used as key elements in forming a phased-array transducer system. To realize omni-directivity by an O-MPT, we fabricated it by using axisymmetric components, namely, a circular magnetostrictive patch, an annular coil providing radial dynamic magnetic field to the patch and a cylindrical magnet located above the center of the patch. Experimental results indicated that the Lamb wave generated by a transmitting O-MPT in a plate has the largest magnitude when its wavelength is approximately equal to two thirds of the patch diameter. To explain the principle of the Lamb wave generation by the O-MPT, a theoretical analysis and a finite element simulation were carried out. The analysis shows that the Lamb wave is actually generated by the second radial extensional eigenmode of a magnetostrictive patch that is un-bonded onto a plate. To demonstrate the effectiveness of the O-MPT’s, a beam-focusing experiment with O-MPT’s is presented.

11:10 AM

Potential Drop Strain Sensor for In-Situ Power Station Creep Monitoring
---Joseph Corcoran and Peter Cawley, Imperial College, Mechanical Engineering, London, United Kingdom; Peter B. Nagy, University of Cincinnati, School of Aerospace Systems, Cincinnati, OH

---Creep is a major high temperature damage mechanism in power station steam pipes. The strain and strain rate develop throughout the entire creep life of a component and so lend themselves as a convenient indicator of creep, informing time to failure calculations. A square arrangement of electrodes allows two perpendicular resistances to be measured using a directional Alternating Current Potential Drop (ACPD) technique. Previously presented work demonstrates the sensitivity of this directional electrical potential drop sensor to strain, relating measured electrical resistance to strain through the use of a gauge factor. The current work further develops this area by extending it to a multiaxial inversion that will be necessary for industry applications. This paper will also present a brief analysis on the magnitude of the influence of creep cavitation on the conductivity tensor. The relative insensitivity of this sensor to creep cavitation compared to the influence of strain will be shown, leading to its effectiveness as a strain sensor. Experimental results from the lab show good agreement with other strain indicators and an on-going site trial will be discussed.
11:30 AM

**The Characterization and Design of Ultrasonic Phased Arrays for Harsh Environments**
---Mike Watkins, Mark Jones, Brett Braatz, Tony Cinson, Mike Larche, Jerry Posakony, David Baldwin, Paul Keller, Royce Mathews, and Matt Edwards, Pacific Northwest National Laboratory, Richland, WA

---The operation and maintenance of liquid metal fast reactors requires the use of high-temperature (approximately 260°C) sensing systems for the in-service inspection, detection of loose parts, and verification of reactor system configuration. An example of such a sensing system involves the use of ultrasonic phased array transducers. In order to advance the state of the art in this area staff at the Pacific Northwest National Laboratory have developed methods to quantify the function and performance of prototypic ultrasonic phased arrays. The results are being used to drive new design and construction concepts using a physics-based approach. This paper will discuss experimental designs and analytical methods that have been developed for characterizing generic prototype performance and reliability in the context of functional requirements and previous work. Design and performance data will be discussed as appropriate.
Session 25
Wednesday, July 24, 2013

SESSION 25
MICROWAVE NDE
Nicola Bowler and Kristen M. Donnell, Co-Chairpersons
Key Ballroom 11

1:30 PM  Microwave and Millimeter Wave Nondestructive and Evaluation Techniques – Evolution and Contributions
---Reza Zoughi, Missouri University of Science and Technology (S&T), Applied Microwave Electrical and Computer Engineering Department, Nondestructive Testing Laboratory (amntl), Rolla, MO 65409

2:10 PM  Materials Characterization of Corrosion-Resistant Thin Film Coatings
---Kristen M. Donnell1 and M. T. Ghasr2, 1Missouri University of Science and Technology, Electrical and Computer Engineering Department, Applied Microwave Nondestructive Testing Laboratory (amntl), 316 Emerson Electric Company Hall, 301 W. 16th Street, Rolla, MO 65409-6524; 2Surender Maddela, 1Missouri University of Science and Technology, Materials Research Center (MRC), Materials Science and Engineering Department, Rolla MO 65409-6524

2:30 PM  3D Millimeter Wave Imaging of Vertical Cracks and Its Application for the Inspection of HDPE Pipes
---M. T. Ghasr and Reza Zoughi, Missouri University of Science and Technology (S&T), Applied Microwave Nondestructive Testing Laboratory (amntl), Electrical and Computer Engineering Department, Rolla, MO 65409

2:50 PM  Evaluation of Hydration Activity in Mortar with and without ASR Gel Using Microwave Dielectric Property Characterization
---Ashkan Hashemi, Kristen M. Donnell, and Reza Zoughi, Missouri University of Science and Technology (S&T), Electrical and Computer Engineering Department, Applied Microwave Nondestructive Testing Laboratory (amntl), Rolla, MO 65409; Kimberly E. Kurtis, Georgia Institute of Technology, School of Civil and Environmental Engineering, 788 Atlantic Drive, Atlanta, GA 30332-0355

3:10 PM  Break

3:30 PM  Electromagnetic Scattering from a Carbon Nanotube Array Embedded in a Dielectric Slab
---Ahmed M. Hassan and Edward Garboczi, National Institute of Standards and Technology, Gaithersburg, MD 20899

3:50 PM  Computational Modeling of the Electromagnetic Characteristics of Carbon Fiber-Reinforced Polymer Composites with Different Weave Structures
---Ahmed M. Hassan, Jack Douglas, and Edward Garboczi, National Institute of Standards and Technology, Gaithersburg, MD 20899-8615

4:10 PM  A Microwave Tomography System Using a Tunable Mirror for Beam Steering
---Amin Tayebi, Junyan Tang, Pavel Roy Paladhi, Lalita Udpa, and Satish Udpa, Michigan State University, College of Engineering, Department of Electrical Engineering, East Lansing, MI 48824

4:30 PM  Image Reconstruction Algorithm for Limited-Angle Diffraction Tomography for Microwave NDE
---Pavel Roy Paladhi, Jacob Klarer, Amin Tayebi, Lalita Udpa, and Satish Udpa, Michigan State University, College of Engineering, Department of Electrical & Computer Engineering, East Lansing, MI 48824-1226
Microwave and Millimeter Wave Nondestructive and Evaluation Techniques – Evolution and Contributions
---Reza Zoughi, Missouri University of Science and Technology (S&T), Applied Microwave Electrical and Computer Engineering Department, Nondestructive Testing Laboratory (amntl), Rolla, MO 65409

---Microwave and millimeter wave techniques are relative newcomers to the field of nondestructive and evaluation (NDT&E), utilizing electromagnetic waves in the frequency range of ~300 MHz-300 GHz. Decades ago, attempts in using these techniques for NDT&E purposes, were limited and they were referred to as “emerging techniques”. However, those involved in the science and engineering of microwave materials characterization, radar remote sensing, and microwave system development have always recognized the utility of these techniques for NDT&E applications. Historically, several prominent factors have helped bringing these techniques to the forefront, namely: the increasing utility of composite structures, availability of large signal bandwidth, plurality of ways by which these waves interact material media, availability of numerous testing probes, and increased availability of critical devices and components. Over the past three decades a significant level of NDT&E-related development has taken place at these frequencies. Two of the broader areas within NDT&E that have significantly benefited from this evolution are: materials characterization and high-resolution and real-time imaging system development. This extended presentation provides for a brief historical background and delves into the evolution and expansion of these techniques for NDT&E with specific examples in several unique areas of contribution and the anticipated future directions.

Materials Characterization of Corrosion-Resistant Thin Film Coatings
---Kristen M. Donnell† and M. T. Ghasr‡, 1Missouri University of Science and Technology, Electrical and Computer Engineering Department, Applied Microwave Nondestructive Testing Laboratory (amntl), 316 Emerson Electric Company Hall, 301 W. 16th Street, Rolla, MO 65409-6524; Surender Maddela, 2Missouri University of Science and Technology, Materials Research Center (MRC), Materials Science and Engineering Department, Rolla MO 65409-6524

---Cerium-based conversion coatings (CeCCs) are viable alternatives to chromate conversion coatings on high strength aluminum alloys used in the automotive and aerospace industries. These coatings are susceptible to micro-cracking/porosity, significantly influencing the corrosion resistance of the coatings. Typical methods to understand the correlation between micro-cracks in the coating and corrosion resistance are currently limited to the laboratory. Microwave nondestructive testing (NDT) has shown tremendous potential as an accurate materials characterization tool. This work highlights the application of a microwave cavity-based surface resistivity measurement tool to nondestructively characterize and evaluate micro-cracking in CeCCs. Measurements of good and poor quality coatings will be presented. A discussion on how these measurements can be correlated quantitatively to the evaluation of micro-cracking and eventually correlated to the corrosion prevention capability of these coatings will be included. Finally, the potential for adapting such a technique for in-situ inspection will also be discussed.
2:30 PM

3D Millimeter Wave Imaging of Vertical Cracks and Its Application for the Inspection of HDPE Pipes
---M. T. Ghasr and Reza Zoughi, Missouri University of Science and Technology (S&T), Electrical and Computer Engineering Department, Applied Microwave Nondestructive Testing Laboratory (amntl), Rolla, MO 65409

---Robust detection of vertical cracks in high-density polyethylene (HDPE) is a challenging task for the majority of nondestructive testing (NDT) techniques. Vertical cracks are specifically referred to as those that occur between two pipe sections when thermally or adhesively joined. This work presents the utility and efficacy of three-dimensional (3D) millimeter wave imaging based on synthetic aperture radar (SAR) algorithm for imaging such cracks. A 3D millimeter wave image can readily represent the type, size, and location of various defects within the structure. Two-dimensional (2D) slices of the 3D image, at different orientations, can represent cross-sectional views of the structure and defects further aiding in identifying and sizing the defect. Imaging results of planner specimen and of curved (pipe section) specimen with machined defects will be presented as well. Polarization of the electric field, incident angle of the wave, and the frequency band are two of parameters that will be studied and optimized for detecting these particular defects (i.e., vertical cracks). These images will be produced using field-portable, small, low-cost, and wideband millimeter-wave reflectometers employing open-ended waveguide antennas.---Authors wish to acknowledge and thank Olympus NDT for providing the HDPE samples.

2:50 PM

Evaluation of Hydration Activity in Mortar With and Without ASR Gel Using Microwave Dielectric Property Characterization
---Ashkan Hashemi, Kristen M. Donnell, and Reza Zoughi, Missouri University of Rolla, Science and Technology (S&T), Electrical and Computer Engineering Department, Applied Microwave Nondestructive Testing Laboratory (amntl), MO 65409; Kimberly E. Kurtis, Georgia Institute of Technology, School of Civil and Environmental Engineering, 788 Atlantic Drive, Atlanta, GA 30332-0355

---Microwave dielectric properties of mortar cast with reactive and non-reactive aggregates have shown distinct and substantial differences related to the presence of alkali-silica reaction (ASR) gel formation in the former. Microwave materials characterization techniques are particularly well-suited for this type of evaluation as they are sensitive to the presence and state of water. It has also been found that post active ASR gel production process and over several months while the mass of several mortar samples (used in those investigations) remained essentially constant, their dielectric properties at S-band (2.6-3.95 GHz) and X-band (8.2-12.4 GHz) underwent a relatively substantial change. It is proposed that this change derives from the formation of additional hydration products, in both the non-reactive and reactive samples, while they were placed in ambient conditions for several (~six) months. In this paper we present the results of these investigations. In addition the development of a first-order dielectric mixing model capable of predicting the complex materials changes in these samples, and suitable for two different microwave frequency bands, will be presented.
Electromagnetic Scattering from a Carbon Nanotube Array Embedded in a Dielectric Slab

---Ahmed M. Hassan and Edward Garboczi, National Institute of Standards and Technology, Gaithersburg, MD 20899

---Carbon nanotubes (CNT) have exceptional electrical and mechanical properties that have fueled extensive research on their incorporation in advanced composite materials. The CNT density and dispersion characteristics have a strong impact on overall composite properties. Electromagnetic waves in the microwave band represent a non-contact and data-rich technique for the NDE of CNT composites. To help understand the NDE of real random composites, ordered composite models can be studied to glean insight into how different CNT configurations produce different microwave responses. In this work, an analytical full wave electromagnetic model of CNT composites is developed. The basis of the model is to implement the composite as an array of infinitesimally thin wires, with the equivalent impedance of CNT, embedded in a dielectric slab. A parametric study is performed to study how the electromagnetic response of the composite is affected by factors such as the radius of the CNT, the filling metal inside the CNT, the spacing between the individual CNTs, and the relative position of the CNT array in the dielectric slab. This analytical work on ordered composites will provide a guide for the interpretation of the microwave NDE of real CNT composites.

Computational Modeling of the Electromagnetic Characteristics of Carbon Fiber-Reinforced Polymer Composites with Different Weave Structures

---Ahmed M. Hassan, Jack Douglas, and Edward Garboczi, National Institute of Standards and Technology, Gaithersburg, MD 20899-8615

---Carbon fiber reinforced polymer composites (CFRPC) are of great interest in the aerospace and automotive industries due to their exceptional mechanical properties. Carbon fibers are typically woven and inter-laced perpendicularly in warps and wefts to form a carbon fabric that can be embedded in a binding matrix. The warps and wefts can be interlaced in different patterns called weaving structures. The primary weaving structures are the plain, twill, and satin weaves, which give different mechanical composite properties. The goal of this work is to computationally investigate the dependence of CFRPC microwave and terahertz electromagnetic characteristics on weave structure. These bands are good candidates for the NDE of CFRPC since their wavelengths are comparable to the main weave features. 3D full wave electromagnetic simulations of the different weaves have been performed using the finite element (FEM) COMSOL simulator, which is able to accurately model the complex weave structure. The computational experiments demonstrate that the reflection and transmission of electromagnetic waves from CFRPC depend sensitively on weave structure. The reflection and transmission spectra calculated in this work can be used to identify the optimal frequencies for the NDE of each weave structure.
A Microwave Tomography System Using a Tunable Mirror for Beam Steering
---Amin Tayebi, Junyan Tang, Pavel Roy Paladhi, Lalita Udpa, and Satish Udpa, Michigan State University, College of Engineering, Department of Electrical Engineering, East Lansing, MI 48824
---Microwave imaging using tomographic reconstruction has shown considerable promise in the fields of medical applications and NDE, particularly for detection of anomalies in dielectric and composite laminate materials. Traditional microwave tomography systems use an array of transceivers placed around the area of interest to collect projection data 360° around the test object. However, the construction of such tomography systems using an array of transceivers is rather complex. This paper presents an alternate system that employs an electrically tunable beam-steering mirror coupled to a single microwave source which generates multi-angle projection data for tomographic reconstruction. The tunable mirror can be built using reflectarray antennas. Reflectarrays are low-profile antennas inheriting the features of both reflector antennas and antenna arrays. The desired radiation pattern is shaped by changing the surface impedance of the array. In case of microstrip reflectarrays one way to do this is to manipulate individual elements(unit cell) of the array, such as physical size. However, to build a tunable reflectarray with beam steering capabilities, the unit cell characteristics should dynamically alter. In this paper, beam steering is achieved by changing the capacitance of individual elements of the array using varactor diodes. Simulation and initial measurements of the mirror will be presented.

Image Reconstruction Algorithm for Limited-Angle Diffraction Tomography for Microwave NDE
---Pavel Roy Paladhi, Jacob Klaser, Amin Tayebi, Lalita Udpa, and Satish Udpa, Michigan State University, College of Engineering, Department of Electrical & Computer Engineering, East Lansing, MI 48824-1226
--- Diffraction tomography using microwaves is an active field of research for the last few decades. Microwave tomography has application in medical imaging as well as non-destructive testing in civil, automotive and aviation industry. Ideally, in conventional tomographic imaging, projection measurements from interrogating waves are taken around the test sample over a range of 360°. However, in many practical problems the angular scan range for obtaining projection measurements of the region of interest (ROI) is physically limited. As this scan angle decreases, the amount of information available becomes progressively limited. With this limited data, reconstructing the ROI becomes a challenge and special schemes for limited angle reconstruction are required. The fundamental principle of diffraction tomography is the Fourier Projection Theorem, which links the 1D–Fourier transform of the scattered field data to the 2D-Fourier transform of the scatterer. In a limited angle situation, the Fourier domain data is highly incomplete. This paper presents a reconstruction technique that takes advantage of the redundancy in Fourier-space of the scattered data that is usually present in a full 360° access of the ROI. An initial reconstructed image is thus generated and then combined with a minimization technique (Total Variation) to generate the final image from limited angle data. Results using simulated data will be presented to validate the approach.
Session 26
SESSION 26
NEW NDE APPLICATIONS
Krishnan Balasubramaniam, Chairperson
Key Ballroom 2

1:30 PM Leaky Guided Waves in Generic Bars: Numerical Prediction and Experimental Validation by Means of Ultrasonic Underwater Testing
---Matteo Mazzotti and Ivan Bartoli, Drexel University, Civil, Architectural & Environmental Engineering Department, 3141 Chestnut St., Philadelphia, PA 19104; Alessandro Marzani, Università degli Studi di Bologna, DICAM, Viale Risorgimento 2, 40136 Bologna, Italy

1:50 PM A Stiffness Reduction Method for Efficient Modeling of Waves in Unbound Media Using Commercially Available Finite Elements Packages
---James Pettit and Michael J. S. Lowe, Imperial College, Mechanical Engineering, London, United Kingdom; Anthony Walker, Rolls-Royce Power Engineering plc, Derby, United Kingdom

2:10 PM Efficient Defect Detections of Elbow Pipes Using Propagation Characteristics of Guided Waves
---Toshihiro Yamamoto and Takashi Furukawa, Japan Power Engineering and Inspection Corporation, NDE Center, Yokohama, Kanagawa, Japan; Hideo Nishino, The University of Tokushima, Graduate School of Advanced Tech. and Science, Tokushima, Tokushima, Japan

2:30 PM Scanning Tone Burst Eddy Current Thermography (S-TBET) for NDT of Carbon Fiber Reinforced Plastic (CFRP) Components
---M. N. Libin, B. W. Maxfield, and Krishnan Balasubramaniam, Indian Institute of Technology Madras, Centre for Nondestructive Evaluation, Chennai, Tamilnadu, India

2:50 PM Rayleigh Wave Interaction and Mode Conversion in a Delamination
---Sunil Kishore Chakrapani1,2, Vinay Dayal1,2, and Jamie Dunt1, Iowa State University, Ames IA 50011; 1Department of Aerospace Engineering; 2Center for NDE

3:10 PM Break

3:30 PM High Speed Ground Penetrating Radar with Adaptive Signal Processing
---Yu Zhang, Anbu Selvam Venkatachalam, and Tian Xia, University of Vermont, School of Engineering, Burlington, VT 05405

3:50 PM Studies of the Influential Factors for Capacitive Imaging Performance Based on the Measurement Sensitivity Distribution
---Xiaokang Yin, Guoming Chen, and Wei Li, China University of Petroleum, Centre for Offshore Engineering and Safety Technology, Qingdao, Shandong, People’s Republic of China, 266580; David A. Hutchins, University of Warwick, School of Eng., Coventry CV4 7AL, United Kingdom

4:10 PM Simulated Parametric Study Based on a Commercial Split D Differential Eddy Current Probe
---Jeremy S. Knopp, (AFRL/RXCA), Wright Patterson AFB, OH, 45433; Ryan D. Mooers and Shamachary Sathish, University of Dayton Research Institute, Structural Integrity Division, NDE Branch, Dayton OH, 45469; John C. Aldrin, Computational Tools, Gurnee IL, 60031

4:30 PM Imaging Techniques in Structural Health Monitoring
---A. Shariati and T. Schumacher, Univ. of Delaware, 758 Christiana Rd., #308, Newark, DE 19713

4:50 PM A Design of Experiments Approach to Uncertainty Assessment of NDE Field Work
---Jeffrey T. Fong, NIST, Applied & Computational Mathematics Division, Gaithersburg, MD 20899-8910; Li Ma, NIST, Metallurgy Division, Gaithersburg, MD 20899-8910; N. Alan Heckert and James J. Filliben, NIST, Statistical Engineering Division, Gaithersburg, MD 20899-8910
**1:30 PM**

**Leaky Guided Waves in Generic Bars: Numerical Prediction and Experimental Validation by Means of Ultrasonic Underwater Testing**

---Matteo Mazzotti and Ivan Bartoli, Drexel University, Civil, Architectural & Environmental Engineering Department, 3141 Chestnut St., Philadelphia, PA 19104; Alessandro Marzani, Universita' degli Studi di Bologna, DICAM, Viale Risorgimento 2, 40136 Bologna, Italy

---Ultrasonic guided waves are used in several non-destructive applications for the inspection of underwater waveguides. As well known, for certain frequency-wavenumber combinations, guided waves leak energy in the surrounding water while propagating along the waveguide (leaky guided waves). Due to a continuous energy radiation in the surrounding media, leaky guided waves are characterized by high attenuation rates. This poses a limit in long range guided waves testing of underwater waveguides and enforces the selection of frequency-mode combinations with minimum loss. To this purpose, in this work the dispersion behavior of guided waves propagating in immersed waveguides of general cross-section is investigated. First, a solid-fluid coupled SAFE-2.5D BEM formulation, recently developed by the authors, is used to compute the frequency-wavenumber spectra of underwater waveguides, where the attenuation spectrum is given by the imaginary component of the wavenumber. Next, a pitch-catch ultrasonic set-up consisting of a dry wideband Pico transducer and a waterproof probe is exploited to generate/receive guided waves with varying pitch/catch distances. Comparisons between numerical and experimental results validate the developed formulation. The results obtained in this paper can be useful for the design of testing conditions in practical applications and to tune experimental set up.

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**1:50 PM**

**A Stiffness Reduction Method for Efficient Modeling of Waves in Unbound Media Using Commercially Available Finite Elements Packages**

---James Pettit and Michael J. S. Lowe, Imperial College, Mechanical Engineering, London, United Kingdom; Anthony Walker, Rolls-Royce Power Engineering plc, Derby, United Kingdom

---A common goal when using Finite Element (FE) modeling in time domain wave scattering problems is to minimize model size by only considering a region immediately surrounding a defect or feature of interest. The model boundaries must simulate infinite space by minimizing the reflection of incident waves. This is a significant and long-standing challenge that has only achieved partial success. Industrial companies wishing to perform such modeling are keen to use established commercial FE packages that offer a thorough history of validation and testing. Unfortunately, this limits the flexibility available to modelers preventing the use of popular research tools such as Perfectly Matched Layers (PML). Unlike PML, Absorbing Layers by Increasing Damping (ALID) have proven successful offering practical implementation into any solver that has representation of material damping. Despite good performance further improvements are desirable. Here, a Stiffness Reduction Method (SRM) has been developed that operates within a significantly reduced spatial domain. The technique is applied by altering damping and stiffness matrices, inducing decay of incident waves. Variables are expressed as a function of known model constants, easing implementation for generic problems. Analytical and numerical solutions have shown that SRM out performs ALID, with results approaching those of PML.
Efficient Defect Detections of Elbow Pipes Using Propagation Characteristics of Guided Waves
---Toshihiro Yamamoto and Takashi Furukawa, Japan Power Engineering and Inspection Corporation, NDE Center, Yokohama, Japan; Hideo Nishino, The University of Tokushima, Graduate School of Advanced Technology and Science, Tokushima, Japan

---In this paper, a novel approach to high sensitivity defect detections in elbow pipes using guided waves was shown. Amplitude of the guided wave propagating in an elbow part takes the distribution due to the shape of the elbow. High sensitive defect detections can be accomplished, if the defect exists in the regions of high amplitude portions. Due to the energy concentration at the defect, much energy must be reflected at the defect. This is the basic principle of the high efficient defect detections in elbow pipes. The distribution also changes as a function of frequency. Therefore, if the frequency can be changed carefully to adjust the high amplitude portion to the pipe location where defects appear frequently, high efficient detections can be accomplished. In the method, the FEM simulations for guided waves propagating in elbow pipes were first carried out in order to obtain the amplitude distributions of the guided waves in elbow pipes. Experimental investigations were performed to confirm the principle described above. It was clearly confirmed that the sensitivities agreed qualitatively well with the amplitude distributions.

2:30 PM

Scanning Tone Burst Eddy Current Thermography (S-TBET) for NDT of Carbon Fiber Reinforced Plastic (CFRP) Components
---M. N. Libin, B. W. Maxfield, and Krishnan Balasubramaniam, Indian Institute of Technology Madras, Centre for Nondestructive Evaluation, Chennai TN India

---The S-TBET technique uses transient eddy current heating inside components and a conventional IR camera for transient heating visualization. This technique has been demonstrated previously for several metals for detection of cracks, corrosion and adhesive dis-bonds. Carbon Fiber Reinforced Plastic (CFRP) material absorbs measurable electromagnetic radiation above 10 kHz. When the surface temperature is observed on the surface that is being heated (slightly to one side of the heating coil), the surface temperature increases with increasing frequency because internal heating increases with frequency. A 2-D anisotropic transient Eddy current heating and thermal conduction model has been developed that provides a reasonable description of the processes described above. The inherent anisotropy of CFRP laminates is included by calculating the heating due to three superimposed, tightly coupled isotropic layers having a specified ply-layup. The experimental apparatus consists of an induction coil and a high frame-rate IR camera with low NETD. The coil is moved over the sample using a stepper-motor controlled manipulator. The IR data recording is synchronized with the motion controller to provide a movie of the surface temperature over time. Several components were evaluated for detection of impact damage, location of stiffeners, etc. on CFRP components.
2:50 PM

Rayleigh Wave Interaction and Mode Conversion in a Delamination
---Sunil Kishore Chakrapani¹,², Vinay Dayal¹,², and Jamie Dunt¹, Iowa State University, Ames IA 50011; ¹Department of Aerospace Engineering; ²Center for NDE

---The interaction of Rayleigh waves with a delamination in a fiber reinforced composite plate was analyzed in the present work. Rayleigh waves interacting with delamination, mode convert into Lamb waves in the delamination zone. These guided Lamb modes have the capability to mode convert back into Rayleigh modes when they interact with the edge of the delamination. Unidirectional glass/epoxy laminate with delamination of known size was fabricated and tested using air-coupled ultrasonics. Finite element models were developed to understand the various mode conversions. Experimental and numerical A-Scans, mode velocities were used to identify each mode. A good correlation between experimental and numerical results was observed.

3:30 PM

High Speed Ground Penetrating Radar with Adaptive Signal Processing
---Yu Zhang, Anbu Selvam Venkatachalam, and Tian Xia, University of Vermont, School of Engineering, Burlington, VT 05405

---In this paper, the development of an air coupled Ultra-Wideband (UWB) Ground Penetrating Radar (GPR) system targeting highway pavements, bridge deck and railroad ballast inspections is described. The hardware component in this GPR system consists of a high voltage pulse generator, a high speed real time data acquisition unit, and a customized field-programmable gate array (FPGA) control element. In comparison with most existing GPR systems with low survey speeds, this system offers surveying at normal highway speed (100km/h) and high horizontal resolution of up to 10 scans per centimeter. In addition, adaptive GPR signal processing algorithms including Curvelet Transform, 2D filtering and exponential scaling are developed to filter out noise and clutter while preserve and enhance subsurface features under test. To test and evaluate our GPR system performance, rebar detection experiments of various configurations are conducted.
Studies of the Influential Factors for Capacitive Imaging Performance Based on the Measurement Sensitivity Distribution
---Xiaokang Yin, Guoming Chen, and Wei Li, China University of Petroleum, Centre for Offshore Engineering and Safety Technology, Qingdao, Shandong, People’s Republic of China, 266580; David A. Hutchins, University of Warwick, School of Engineering, Coventry CV4 7AL, United Kingdom

---The Capacitive Imaging (CI) technique has been successfully used in many NDE applications. Previous work on the CI technique has been focused on exploring the application range of this technique, while the factors that may affect the imaging performance have never been studied systematically. In this work, the influencing factors for the imaging performance of the CI technique on both non-conducting and conducting specimens are discussed and studied based on the measurement sensitivity distribution of the CI probes obtained from Finite Element (FE) models. The studies of the influencing factors are helpful for understanding the relationship between the experiment conditions and the CI performance and may provide indications on how to improve the CI performance.

Simulated Parametric Study Based on a Commercial Split D Differential Eddy Current Probe
---Jeremy S. Knopp, Air Force Research Labs (AFRL/RXCA) Wright Patterson AFB, OH, 45433; Ryan D. Mooers and Shamachary Sathish, University of Dayton Research Institute, Structural Integrity Division, NDE Branch, Dayton OH, 45469; John C. Aldrin, Computational Tools, Gurnee IL, 60031

---The spatial-frequency response of an eddy current probe is very sensitive to certain dimensions of the design. This sensitivity is undesirable when comparing simulated and experimental data. An experimental parametric study can be used to determine the correlation between dimensional changes and the probe response; however, they can have major drawbacks. These experimental studies can be expensive both in material costs and manpower. They can become quite large when the complexity of the probe increases, e.g. when using differential probes. A more economically feasible solution is to supplement the experimental study with modeling and simulation studies. This paper will describe a full parametric study which uses a commercially available split D differential probe. The probe is modeled in VIC 3D(R) and the simulation consist of scanning the probe across an EDM notch in a titanium specimen. Details regarding the variable dimensions, the chosen dimension values, model construction, and data analysis will be presented and discussed. Results will be presented in a variety of ways to illustrate the effects on the probe response. Details will also be given on how to adjust model dimensions to correct for certain minor discrepancies between simulated and experimental data.
4:30 PM

Imaging Techniques in Structural Health Monitoring
---A. Shariati and T. Schumacher, University of Delaware, 758 Christiana Road, #308, Newark, DE 19713

---Various techniques in image processing have been widely studied for Structural Health Monitoring (SHM) purposes. From locating cracks in concrete to measuring surface strains and estimating resulting stresses, image processing techniques have shown great promise for use in the field of structural engineering. An advantage of these techniques is that they are applied non-contact. However, limitations exist in their capabilities with respect to accuracy and reliability. In this paper, an overview of currently used techniques in image and video processing is presented and the capabilities and limitations of these methodologies for SHM applications is reviewed. A novel technique in video processing that shows potential for SHM, Motion Magnification, is particularly discussed in this paper.

4:50 PM

A Design of Experiments Approach to Uncertainty Assessment of NDE Field Work
---Jeffrey T. Fong, NIST, Applied & Computational Mathematics Division, Gaithersburg, MD 20899-8910; Li Ma, NIST, Metallurgy Division, Gaithersburg, MD 20899-8910; N. Alan Heckert and James J. Filliben, NIST, Statistical Engineering Division, Gaithersburg, MD 20899-8910

---For model-based nondestructive evaluation (NDE) field work for finding cracks such as ultrasonic testing (UT) or acoustic emission (AE), it is necessary to have a rigorous method to evaluate the uncertainty of the findings when the field work permits more than one NDE process involving an operator and a machine with hard components and computer software. In this paper, we propose a design of experiments (DEX) approach to analyzing the NDE data in conjunction with the classical inter-laboratory comparison (ILC) consensus mean method (CMM) for arriving at a grand mean and standard deviation of the field-generated NDE measurements. Five groups of uncertainties (U) are identified, namely, (U-1) model uncertainty, (U-2) model parameter uncertainty, (U-3) machine hardware uncertainty, (U-4) computer software uncertainty, (U-5) human factor uncertainty. An example data set based on a UT measurement of a single crack is provided to illustrate the feasibility of this DEX-ILC-CMM approach. Significance and limitations of this NDE field measurement uncertainty quantification approach are included and discussed.
Session 27
SESSION 27
ULTRASONIC METHODS FOR CONCRETE
Parisa Shokouhi, Chairperson
Key Ballroom 3

1:30 PM  Ultrasonic-Based Assessment of the Condition of Concrete Beams
---Ahmet S. Kırlangıç, Giovanni Cascante, and Maria A. Polak, University of Waterloo, 3903 - 151 Street NW, Edmonton AB T6R 1J3, Canada

1:50 PM  Numerical Simulations and Experimental Measurements of Steel and Ice Impacts for Acoustic Interrogation of Delaminations in Bridge Decks
---Brian A. Mazzeo, Anjali N. Patil, and Jeffrey M. Klis, Brigham Young University, Department of Electrical and Computer Engineering, Provo, UT 84602; Randy C. Hurd and Tadd T. Truscott, Brigham Young University, Department of Mechanical Engineering, Provo, UT 84602; W. Spencer Guthrie, Brigham Young University, Department of Civil and Environmental Engineering, Provo, UT 84602

2:10 PM  Estimation of In-Situ Stresses in Concrete Bridge Members Using Polarized Shear Waves
---Andrew H. Chen, Samet Ozturk, and Thomas Schumacher, University of Delaware, Civil and Environmental Engineering, Newark, DE 19716

2:30 PM  ASR Detection in Concrete from Frequency-Related Ultrasonic Attenuation
---Peng Gong, Mark E. Patton, Chang Liu, and Irving J. Oppenheim, Carnegie Mellon University, Department of Civil and Environmental Engineering, Pittsburgh, PA 15213; David W. Greve and Joel B. Harley, Carnegie Mellon University, Department of Electrical and Computer Engineering, Pittsburgh, PA 15213; Mark E. Patton, MEP Limited, Pittsburgh, PA15213

2:50 PM  Air-Coupled Ultrasonic Method for Reconstruction Internal Structure within Reinforced Concrete Elements
---Hajin Choi and John S. Popovics, University of Illinois, Civil and Environmental Engineering, Urbana-Champaign, IL 61801

3:10 PM  Break

3:30 PM  Ultrasonic Investigation of Damage Progression in Concrete
---Parisa Shokouhi and Anna Lorenz, DTU – Technical University of Denmark, BAM – Federal Institute for Material Research and Testing; Gregor Fischer, Lyngby, Denmark

3:50 PM  Characterization of Cracking in Concrete Using a Fully Contactless Scanning Ultrasonic System
---Suyun Ham and John S. Popovics, The University of Illinois at Urbana-Champaign, Civil and Environmental Engineering, Urbana, IL 61801-2352

4:10 PM  Non-Contact Ultrasonic NDT of Concrete Using a Spark Source Focused by an Ellipsoidal Reflector
---Xiaowei Dai, Yi-Te Tsai, and Jinying Zhu, The University of Texas at Austin, Department of Civil, Architectural, and Environmental Engineering, Austin, TX 78681; Michael R. Haberman, The University of Texas at Austin, Applied Research Laboratories, Austin, TX 78681

4:30 PM  Non-Destructive Evaluation of Concrete with Ultrasonic C-Scan and Digital Image Enhancement Techniques
---A. Chukwujekwu Okafor and Amitabha Dutta, Missouri University of Science and Technology, Department of Mechanical and Aerospace Engineering, Rolla, Missouri 65409-0050

4:50 PM  SAFT Reconstruction for Virtual Ultrasonic Array Systems
---Kyle Hoegh and Lev Khazanovich, University of Minnesota, Civil Engineering Department, Minneapolis, MN 55414


**1:30 PM**

Ultrasonic-Based Assessment of the Condition of Concrete Beams
---Ahmet S. Kırlangıç, Giovanni Cascante, and Maria A. Polak, University of Waterloo, 3903 - 151 Street NW, Edmonton AB T6R 1J3, Canada

---The propagation of surface waves provides information about characteristics and condition of the medium. Variations in material conditions can be inferred from changes in phase velocity and attenuation of surface waves. In a homogeneous half space, the dispersion of phase velocity is merely caused by irregularities within the medium. The multichannel analysis of surface waves (MASW) method is a well-established technique used for the determination of the shear-wave velocity profile of near surface soil layers. This method is based on computation of phase velocities; and it is applicable to assess the condition of concrete elements using an appropriate frequency range. Previous studies on detection of surface-breaking cracks in concrete elements, using the dispersion and attenuation of ultrasonic surface waves, were successful; however, a complete damage assessment of the element was not the scope of previous studies. The main objective of this work is to investigate the effectiveness of surface wave methods for the condition assessment of concrete beams. Six laboratory-scale concrete beams (15x10x110 cm) with different damage levels are tested. Damage is introduced by using Styrofoam pellets in the concrete mix. The recorded signals are processed using various time and frequency domain methods, such as 2D Fourier and wavelet transforms. The Rayleigh wave velocity, dispersion behavior, phase velocities and attenuation trend are determined. All the investigated parameters are compared to evaluate the damage level of the beams. The MASW test shows a good potential for the evaluation of damage in concrete beams when the coupling conditions of the transducers are controlled.

**1:50 PM**

Numerical Simulations and Experimental Measurements of Steel and Ice Impacts for Acoustic Interrogation of Delaminations in Bridge Decks
---Brian A. Mazzeo, Anjali N. Patil, and Jeffrey M. Klis, Brigham Young University, Department of Electrical and Computer Engineering, Provo, UT 84602; Randy C. Hurd and Tadd T. Truscott, Brigham Young University, Department of Mechanical Engineering, Provo, UT; W. Spencer Guthrie, Brigham Young University, Department of Civil and Environmental Engineering, Provo, UT 84602

---Delaminations in bridge decks typically result from corrosion of the top mat of reinforcing steel, which leads to a localized separation of the concrete cover from the underlying concrete. Because delaminations cannot be detected using visual inspection, rapid, large-area interrogation methods are desired to characterize bridge decks without disruption to traffic, without the subjectivity inherent in existing methods, and with increased inspector safety. To this end, disposable impactors such as water droplets or ice chips can be dropped using automatic dispensers onto concrete surfaces to excite mechanical vibrations, and acoustic responses can be recorded using air-coupled microphones. In this work, numerical simulations are used to characterize the flexural response of a model concrete bridge deck subject to impactors having various material properties. Multiple simulated vibrational modes of varying intensities are then compared to measured acoustic responses and high-speed imagery of steel and ice impactors used to test decommissioned bridge deck slabs comprising several naturally-formed delaminations.
Estimation of In-Situ Stresses in Concrete Bridge Members Using Polarized Shear Waves

Andrew H. Chen, Samet Ozturk, and Thomas Schumacher, University of Delaware, Civil and Environmental Engineering, Newark, DE 19716

Ultrasonic testing is commonly used to detect flaws, estimate geometries, and characterize material properties. Acoustoelasticity refers to the dependency of stress wave velocity with applied stresses and is a phenomenon that has been known by geophysicists since the 1960s. A way to capitalize on this effect for concrete applications is by using ultrasonic shear waves which are particularly sensitive to applied stresses when polarized in the direction of the applied stress. The authors of this paper conducted an experiment on a 150 x 150 x 305 mm concrete specimen that was loaded in discrete load steps to failure. At each load step two ultrasonic shear waves were transmitted through the specimen, one with the polarization perpendicular and the other transverse to the applied stress. The velocity difference between the two sets of polarized shear waves was found to correlate with the applied stress in the specimen. Two examples of applications for this methodology include evaluation of stresses in pre-stressed concrete bridge girders and investigation of load redistribution in bridge supports after extreme events. This paper introduces the background of this methodology, presents an analysis of the collected data, and discusses the relationship between the recorded signals and the internal stress.

ASR Detection in Concrete from Frequency-Related Ultrasonic Attenuation

Peng Gong, Mark E. Patton, Chang Liu, and Irving J. Oppenheim, Carnegie Mellon University, Department of Civil and Environmental Engineering, Pittsburgh, PA 15213; David W. Greve and Joel B. Harley, Carnegie Mellon University, Department of Electrical and Computer Engineering, Pittsburgh, PA 15213; Mark E. Patton, MEP Limited, Pittsburgh, PA 55213

Alkali silica reaction (ASR) occurs between certain reactive aggregates and the alkaline cement paste in concrete, eventually producing damage such as swelling and cracking. This research uses frequency-related properties of ultrasonic attenuation to detect ASR onset in concrete specimens, with associated study of the influences of specimen size and aggregate size. The test specimens are fabricated in pairs, one specimen typically subjected to an accelerated ASR environment (immersion in a sodium hydroxide solution at 80 degrees Celsius) and the second specimen comparable but not exposed to the accelerated ASR environment. Broadband excitations are used and pitch-catch records are obtained. Signals from ASR specimens show less energy at higher frequencies than the companion (non-ASR) specimen in the pair, but comparable energy at the lower frequencies. Signals from paired non-ASR specimens show comparable energy over the range of frequencies. The presence of ASR in concrete specimens increases ultrasonic attenuation, with characteristics that are recognizable in the frequency domain. The test results also show that the attenuation characteristics are logically related to specimen size and aggregate size.
2:50 PM

Air-Coupled Ultrasonic Method for Reconstruction Internal Structure within Reinforced Concrete Elements
---Hajin Choi and John S. Popovics, University of Illinois, Civil and Environmental Engineering, Urbana-Champaign, IL 61801

---It is important to characterize internal damage within reinforced concrete elements caused by excessive external loads, such as those caused by earthquake. Here we present an air-coupled ultrasonic scanning approach for this purpose. Contactless ultrasonic wave pulse generation is provided by an electrostatic transducer mounted on an automated scanning frame, which maintains constant air gap distance to concrete surface and provides accurate spatial position of the transducer. This system enables many test data to be collected over a large area and in a reasonably short amount of time. Ultrasonic test data are collected through two different types of full-scale steel-reinforced concrete columns: 1) a column containing controlled artificial defects including embedded styrofoam, a pre-cracked concrete block, and de-bonded steel; and 2) a column subjected to simulated earthquake loads across the plastic hinge zone (high damage area) of the column. Internal images are reconstructed from the data in two forms: stacked time signals and tomographs based on velocity and attenuation. The developed images demonstrate that it is possible to detect internal defects and monitor the progression of degradation process and detect internal damage.

3:30 PM

Ultrasonic Investigation of Damage Progression in Concrete
---Parisa Shokouhi and Anna Lorenz, DTU – Technical University of Denmark, BAM – Federal Institute for Material Research and Testing; Gregor Fischer, Lyngby, Denmark

---Ultrasonic measurements were used to monitor progressive damage in concrete specimens subjected to mechanical and thermal loading. Uniaxial compression was applied in small steps over single, multiple and repeating load cycles on concrete specimens. At each step, the loading was held constant and a series of ultrasonic measurements parallel and perpendicular to the loading axis were obtained. The measurements were taken during both the loading and unloading phases. Surface deformation and the evolution of cracks were simultaneously monitored using optical interferometry measurements. The effect of temperature-induced changes in concrete was investigated in a separate series of experiments. Ultrasonic measurements were taken at predefined time intervals, while the temperature was continually increased or decreased. The time scale of the signals was chosen such that the diffuse ultrasonic regime could be recorded in both sets of experiments. Using Coda Wave Interferometry (CWI), the corresponding changes in the velocity of diffuse ultrasonic waves were monitored. The evolution of the slope of the CWI velocity-stress curve is demonstrated. Dynamic Time Warping (DTW) was used to investigate the evolution of signals in both experiments.
3:50 PM

Characterization of Cracking in Concrete Using a Fully Contactless Scanning Ultrasonic System
---Suyun Ham and John S. Popovics, The University of Illinois at Urbana-Champaign, Civil and Environmental Engineering, Urbana, IL 61801-2352

---Ultrasonic techniques provide an effective non-destructive evaluation (NDE) method to monitor concrete structures, but the need to perform rapid and accurate interpretation assessment requires evaluation of hundreds, or even thousands, of measurement data. Use of a fully contactless ultrasonic system can save time and labor through rapid implementation, and can enable automated and controlled data acquisition for example through robotic scanning. This paper describes our efforts to develop a fully contactless ultrasonic surface wave system for non-destructive evaluation of concrete in structures. The developed sensors, controlled scanning system with mobile apparatus and employed signal processing scheme are described. The accuracy, reliability and practicality of the fully contactless system are verified through comparison to data collected using conventional contact sensors on two types of damaged concrete specimens. The results show that reliable surface wave velocity and attenuation data are obtained using the developed system, and furthermore that signal energy loss (attenuation) is a sensitive indicator of single and distributed cracks in concrete.

4:10 PM

Non-Contact Ultrasonic NDT of Concrete Using a Spark Source Focused by an Ellipsoidal Reflector
---Xiaowei Dai, Yi-Te Tsai, and Jinying Zhu, The University of Texas at Austin, Department of Civil, Architectural, and Environmental Engineering, Austin, TX 78681; Michael R. Haberman, The University of Texas at Austin, Applied Research Laboratories, Austin, TX 78681

---Air-coupled ultrasonic non-destructive testing (NDT) of concrete structures is a challenge due to the large impedance contrast between air and concrete. However, because air-coupled sensing offers many advantages such as rapid scanning of large areas and the elimination of part immersion for inspection, there remains strong incentive to find unique methods for air-coupled excitation of wave motion in concrete. In the present paper, we present experimental results of an in-air acoustic source that has been shown to excite wave motion in concrete. The source consists of a spark generator and an ellipsoidal reflector. The spark generator radiates a short-duration, high-amplitude acoustic signal as the result of an electrostatic discharge between two electrodes with high potential difference. Analogous to lithotripter devices, the spark is located at the near focus and generates an outgoing wave that is then focused at the far focus of the reflector which is aligned at the air-solid interface. The air-borne acoustic wave in the free-field and the focused acoustic wave are analyzed. This paper presents applications of the air-coupled system for Rayleigh wave, impact-echo and ultrasonic through transmission tests on a concrete slab.
Non-Destructive Evaluation of Concrete with Ultrasonic C-Scan and Digital Image Enhancement Techniques
---A. Chukwujekwu Okafor and Amitabha Dutta, Missouri University of Science and Technology, Department of Mechanical and Aerospace Engineering, Rolla, Missouri 65409-0050

---This paper presents the results of Nondestructive Evaluation (NDE) of concrete slabs using Ultrasonic C-Scan and image-enhancement algorithms for the detection and extraction of damage information from the raw data. Two fabricated concrete slabs, one undamaged and the other with three rectangular voids were used for the test. Damage was evaluated by using ultrasonic through transmission C-Scan method. A 500 kHz transducer with pulse rates of 100 Hz to 5000Hz was investigated to determine the best pulse rate for scanning concrete. The amplitude scan shows accurately the position of the voids present in the damaged concrete with respect to the reference edge. In addition the results also show the inherent in-homogeneity of the concrete slab due to the presence of air pockets that invariably arise during the fabrication. Three statistical filtering techniques (Median, Mean and Gaussian) and one wavelet filtering technique were comparatively evaluated to enhance the quality of the digital image. The results show clearly the presence of the rectangular voids. Median filtering technique was the best in enhancing the image obtained from the C-Scan in terms of removing noise and preserving the details of the defects. Wavelet filtering technique was good in terms of overall noise reduction, but it resulted in loss of details of the defects producing a comparatively blurred image. This technique can be used to determine the quality of concrete at any stage in its working lifecycle thus making it a useful tool in the field of health monitoring of concrete.

SAFT Reconstruction for Virtual Ultrasonic Array Systems
---Kyle Hoegh and Lev Khazanovich, University of Minnesota, Civil Engineering Department, Minneapolis, MN 55414

---The synthetic aperture focusing technique (SAFT), as applied to elastic wave propagation, can be used to determine precise locations of changes in acoustic impedance when using spatially diverse measurement pairs. While traditional SAFT B-scans are useful for diagnostics of various problems, limited aperture of the self-contained measurement system can cause inaccuracy when the area of interest is at the edge of the ultrasonic array system. Moreover, the area of interest is often greater than the size of the measurement aperture. To address this limitation and add more redundancy, a modified SAFT procedure is proposed. This procedure can handle virtual arrays using associated data fusion and reconstruction techniques. Several practical civil engineering applications were considered and a comparison with forensic verification demonstrated the effectiveness of the proposed method.
Session 28
SESSION 28
ULTRASONIC PHASED ARRAYS II
Alexander Velichko, Chairperson
Key Ballroom 12

1:30 PM  A New Architecture for Fast Ultrasound Imaging
---J. F. Cruza, J. Camacho, J. M. Moreno, and L. Medina, Consejo Superior de Investigaciones Cientificas (CSIC), UMEDIA Group, La Poveda (Arganda del Rey), Madrid, Spain

1:50 PM  Implementation of a GPU Accelerated Total Focusing Reconstruction Method within Civa Software
---Gilles Rougeron, Jason Lambert, and Ekaterina Iakovleva, CEA-LIST, F-91191, Gif-sur-Yvette, France; Lionel Lacassagne, LRI, Universite Paris-Sud, F-91405, Orsay, Cedex, France (Presenter is Nicolas Dominguez)

2:10 PM  Automatic Dynamic Depth Focusing for NDT
---Jorge Camacho, Jorge F. Cruza, Carlos Fritsch, and Jose Miguel Moreno, Consejo Superior de Investigaciones Cientificas (CSIC), UMEDIA Group, La Poveda (Arganda del Rey), Madrid, Spain

2:30 PM  Inspection Design Using 2D Phased Array, TFM, and CueMAP Software
---Jerzy Dziewierz, Ailidh McGilp, Tim Lardner, John Mackersie, and Anthony Gachagan, Centre for Ultrasonic Engineering, University of Strathclyde, Glasgow, United Kingdom

2:50 PM  Multi-Mode TFM Imaging with Artifact Filtering Using CIVA UT Forward Models
---S. Chatillon, E. Iakovleva, P. Bredif, and S. Mahaut, CEA-LIST, F-91191, Gif-sur-Yvette, France

3:10 PM  Break

3:30 PM  Using a Pulsed Array to Determine the Position of a Defect
---Samuel J. Hill, University of Warwick, Department of Physics, Coventry, West Midlands, United Kingdom

3:50 PM  Matrix Phased Array Imaging Technology for Resistance Spot Welds
---Jeong K. Na and Sean Gleeson, Edison Welding Institute, 1250 Arthur E. Adams Drive, Columbus, OH 43221

4:10 PM  In-Situ Weld Quality Inspection with Matrix Phased Array Ultrasonic Technology
---Sean G. Gleeson1, Gavin Dao2, and Jeong K. Na1, 1Edison Welding Institute, 1250 Arthur E. Adams Drive, Columbus, OH 43221; 2Advanced OEM Solutions, Cincinnati, OH 45236

4:30 PM  Heavy Wall Pipe Line Inspection by Phased Array Ultrasonic Test (PAUT) and Comparison with Conventional NDT Methods
---Afshin Yousefi, Iranian Welding Research and Engineering Center, Metallurgy Laboratory, Shahin Shomali, Tehran, Iran; Mahdi Sarlak, Maysun Engineering and Construction Company; Bahram Mirzaiee, Industrial Projects Management of Iran; Arash Yousefi, Ark Engineering and Construction Company
WEDNESDAY, SESSION 28

1:30 PM

A New Architecture for Fast Ultrasound Imaging
--- J. F. Cruza, J. Camacho, J. M. Moreno, and L. Medina, Consejo Superior de Investigaciones Científicas (CSIC), UMEDIA Group, La Poveda (Arganda del Rey), Madrid, Spain

--- Some ultrasound imaging applications require high frame rate, for example 3D imaging and automated inspections in industry. Being the signal-processing throughput of the system the main bottleneck, parallel beamforming is required to achieve hundreds to thousands of images per second. Simultaneous A-scan line beamforming in all active channels is required to reach the intended high frame rate. To this purpose, a new parallel beamforming architecture that exploits the currently available processing resources in state-of-the-art FPGAs is proposed. The work aims to get the optimal resource usage, high scalability and flexibility for different applications. To achieve these goals, the basic beamforming function is reformulated to be adapted to the DSP-cell architecture of state-of-the-art FPGAs. This allows performing simultaneous dynamic focusing on multiple A-scan lines. Some realistic examples are analyzed, evaluating resource requirements and maximum operating frequency. For example, a 128-channel system, with 128 scan lines and acquiring at 20 MSPS, can be built with 4 mid-range FPGAs, achieving up to 18000 frames per second, just limited by the maximum PRF. The gold standard Synthetic Transmit Aperture method (also called Total Focusing Method) can be done in real time at a processing rate of 40 high-resolution images per second (15 cm depth).

1:50 PM

Implementation of a GPU Accelerated Total Focusing Reconstruction Method Within Civa Software
--- Gilles Rougeron, Jason Lambert, and Ekaterina Iakovleva, CEA, LIST, F-91191 Gif-sur-Yvette, France; Lionel Lacassagne, LRI, Université Paris-Sud,F-91405 Orsay Cedex, France (Presenter is Nicolas Dominguez)

--- This paper presents results of a TFM implementation for Full Matrix Capture acquisitions in CIVA, proposed as a post-processing tool for accurate analysis. This implementation has been made on GPU architecture with OpenCL to minimize the processing time and offer computational device flexibility (GPU/CPU). Examples on immersion configurations on isotropic 2D CAD specimen with planar extrusion are proposed to illustrate the performances. Reconstructions on 2D or 3D areas of direct echoes with mode conversion are allowed. Probe scanning can also be taken into account. Reconstruction results and a benchmark explaining the speedup are presented. Further improvements are also reviewed.
2:10 PM

**Automatic Dynamic Depth Focusing for NDT**

---Jorge Camacho, Jorge F. Cruza, Carlos Fritsch, and Jose Miguel Moreno, Consejo Superior de Investigaciones Científicas (CSIC), UMEDIA Group, La Poveda (Arganda del Rey), Madrid, Spain

---Automatic Dynamic Depth Focusing (ADDF) is a feature currently not available in state of the art NDT instruments. It would be a valuable tool to inspect arbitrarily shaped parts or when the part-array geometry is not accurately known. Moreover, ADDF should perform dynamic focusing at all acquired samples, giving the best possible image quality. This work proposes an ADDF method based on a fast procedure that automatically sets up all focusing parameters in an NDT instrument, with the only previous knowledge of the propagation velocities and the array pitch and, typically, in less than 1 second. In a first step, the geometry of the part is estimated by a few trigger shots of selected array elements and evaluation of the round-trim time-of-flight of echoes. Then, a virtual array operating in a single medium is computed, with nearly equivalent time-of-flight than the real array to all the foci in the region of interest. From this virtual array, the parameters required by a real-time dynamic depth focusing hardware are set. This procedure is especially well adapted to inspecting parts of unknown or variable geometry or when the distance and/or alignment of the array probe with the part changes during inspection.

2:30 PM

**Inspection Design Using 2D Phased Array, TFM and CueMAP Software**

---Jerzy Dziewierz, Ailidh McGilp, Tim Lardner, John Mackersie, and Anthony Gachagan, Centre for Ultrasonic Engineering, University of Strathclyde, Glasgow, United Kingdom

---A simulation suite, cueMAP, has been developed to facilitate the design of inspection processes and sparse 2D array configurations. At the core of cueMAP is a TFM imaging algorithm that enables computer assisted design of ultrasonic inspection scenarios, including the design of bespoke array configurations to match the inspection criteria. This in-house developed TFM code allows for interactive evaluation of image quality indicators of ultrasonic imaging performance when utilizing a 2D phased array working in FMC/TFM mode. The cueMAP software uses a series of TFM images to build a map of resolution, contrast and sensitivity of imaging performance of a simulated reflector, swept across the inspection volume. The software takes into account probe properties, wedge or water standoff, and effects of specimen curvature. In the validation process of this new software package, two 2D arrays have been evaluated on 304n stainless steel samples, typical of the primary circuit in nuclear plants. Thick section samples have been inspected using a 1MHz 2D matrix array and a sparse 2D configuration operating at 3MHz. Due to the processing efficiency of the software, the data collected from these array configurations has been used to investigate the influence sub-aperture operation has on the inspection performance.
Multi-Mode TFM Imaging With Artifact Filtering Using CIVA UT Forward Models
---S. Chatillon, E. Iakovleva, P. Bredif, and S. Mahaut, CEA, LIST, F-91191 Gif-sur-Yvette, France

---TFM (Total Focusing Method) is an advanced post-processing imaging algorithm of ultrasonic array data that shows great potential in defect detection and characterization. This technique can be performed using several propagation modes (direct or over skip imaging) and several types of waves (longitudinal or transverse) allowing the imaging of extended defects of complex geometry. However, nonphysical indications can be observed, leading to misinterpretations. These imaging artifacts are due to the coexistence of several contributions involving several mode of propagation and interactions with possible defects and/or the geometry of the part. In several configurations, a simple time of flight criterion is not sufficient for their identification. This paper presents tools based on the forward CIVA UT models which allow to analyze and to filter these artifacts, without any tuning parameters. The performances achieved are compared to those of conventional TFM on experimental and simulated data.

Using a Pulsed Array to Determine the Position of a Defect
---Samuel J. Hill, University of Warwick, Department of Physics, Coventry, West Midlands, United Kingdom

---A one dimensional array of emitters are pulsed simultaneously with a controlled bandwidth to create a two dimensional wave. This generated wave-front is smooth and continuous over a large solid angle, and has a frequency that varies as a function of angle to the array. Analytic and finite element models created to simulate this phenomena have been validated with experimental results using ultrasonic waves in metal samples. This pulsed approach provides a rapid means of flooding a region of space with a wave-front, whereby any wave that scatters or reflects off a body to a detector will have a distinct arrival time and frequency. This method was experimentally verified using a periodic permanent magnetic EMAT array to determine the location of a spherical scatterer in an aluminium sample.
3:50 PM

**Matrix Phased Array Imaging Technology for Resistance Spot Welds**
--- Jeong K. Na and Sean Gleeson, Edison Welding Institute, 1250 Arthur E. Adams Drive, Columbus, OH 43221

---A three-dimensional matrix phased array (MPA) probe has been incorporated with a high speed phased array electronic board to visualize nugget images of resistance spot welds. The primary application area of this battery operated portable MPA ultrasonic imaging system is in the automotive industry which a conventional destructive testing process is commonly adopted to check the quality of resistance spot welds in auto bodies. Considering average of five-thousand spot welds on a medium size passenger vehicle, the amount of time and effort given to popping the welds and measuring nugget size are immeasurable in addition to the millions of dollars’ worth of scrap metals thrown away per plant per year. This wasteful labor intensive destructive testing process has become less reliable as auto body sheet metals transitioning from thick and heavy mild steels to thin and light high strength steels. Consequently, the necessity of developing a non-destructive inspection methodology has become inevitable. In this paper, the fundamental aspects of the current 3-D probe design, data acquisition algorithms, and weld nugget imaging process are discussed.

4:10 PM

**In-Situ Weld Quality Inspection with Matrix Phased Array Ultrasonic Technology**
--- Sean G. Gleeson¹, Gavin Dao², and Jeong K. Na¹, Edison Welding Institute, 1250 Arthur E. Adams Drive, Columbus, OH 43221; ²Advanced OEM Solutions, Cincinnati, OH 45236

---In Oil and Gas industry, it is very common to make welds on pipes in the field. For straight pipes, most of the time, welds are inspected with an automated ultrasonic testing (AUT) system. However, pipes having non-traditional geometric constraints such as a slanted corrugation feature prohibit the use of an AUT method. As an effort to develop a field deployable in-situ weld inspection system, a high-speed MPA circuit board (purchased from Advanced OEM Solutions) has been used to drive 32-element MPA probe operating at 5 MHz. The goal of the most recent phase of this development was to achieve a minimum of 200 inch per minute real-time inspection speed to match a welding process developed simultaneously at EWI. In order to meet the speed requirement, it was necessary to maximize the data acquisition rate as close as to the data transfer rate the MPA circuit board could support. A customized ultrasonic imaging algorithm developed using the Python programming language proved to be effective enough to achieve a maximum of 220 inches per minute inspection speed. In this paper, detailed discussions on the development of imaging algorithm and the results of real-time imaging inspection performed on a test specimen are presented.
4:30 PM

Heavy Wall Pipe Line Inspection by Phased Array Ultrasonic Test (PAUT) and Comparison with Conventional NDT Methods

---Afshin Yousefi, Iranian Welding Research and Engineering Center, Metallurgy Laboratory, Shahin Shomali, Tehran, Iran; Mahdi Sarlak, Maysun Engineering and Construction Company; Bahram Mirzaiee, Industrial Projects Management of Iran; Arash Yousefi, Ark Engineering and Construction Company

---This research paper contains comparative results about defect sizing and monitoring by three different methods: phased array, conventional UT and radiography inspection. NDT inspection is playing important role in defect detection during and after manufacturing industrial structures. Common restrictions in RT & UT analysis such as accuracy limitations by increasing thickness can be overcome by PAUT. Phased array has several advantages compared to conventional UT and RT, especially in thick materials (t > 40 mm). Defects in thick materials can’t be observed clearly by conventional RT. In this research, pipe lines of “Slag Catcher” section in SOUTH-PARS (ASALOUYEH-IRAN) gas refinery has been monitored and inspected by three methods: PAUT, conventional UT and RT. Radiography didn’t show defects obviously and defect sizing accuracy decreases in heavy wall pipes by conventional UT and that process is very time consuming specially in field operation conditions, but PAUT detected and determined the dimensions of internal defects quickly and precisely.
SESSION 29
COMPOSITES AND LAMINATES
Cara Leckey, Chairperson
Key Ballroom 9

1:30 PM Ultrasonic Inspection of Adhesive Joints of Composite Pipelines
---Priscila Duarte de Almeida, Non-Destructive Testing, Corrosion and Welding Laboratory, Department of Metallurgical and Materials Engineering, COPPE/UFRJ – Federal University of Rio de Janeiro, Rio de Janeiro, RJ, Brazil; João Marcos Alcoforado Rebello and Gabriela Ribeiro Pereira, Department of Metallurgical and Materials Engineering, COPPE/UFRJ - Federal University of Rio de Janeiro, Rio de Janeiro, RJ, Brazil; SérgioDamasceno Soares, Petrobras Research Center, CENPES – PETROBRAS, Rio de Janeiro, RJ, Brazil; Roman Fernandez, EXTENDE, Le Bergson, Massy, France

1:50 PM Inherent Acoustic Nonlinearity of Fiber Reinforced Composites
---Sunil Kishore Chakrapani1,2, Daniel Barnard2, and Vinay Dayal1,2, Iowa State University, Ames IA 50011;1Department of Aerospace Engineering, 2Center for NDE

2:10 PM Mode Shape-Based Damage Detection in Composite Laminates
---Zheng Li and Kan Feng, Peking University, College of Engineering, Beijing 100871, China

2:30 PM Visualization Studies of Lamb Wave Propagation and Interactions with Anomalies in Composite Laminates Using Air-Coupled Ultrasonics
---V. S. Sasanka Durvasula, Janardhan Padiyar M, and Krishnan Balasubramaniam, Indian Institute of Technology Madras, Department of Mechanical Engineering, Center for Non-Destructive Evaluation, Chennai, Tamilnadu, India; Vivek Madhavan and N. V. Giridharan, National Institute of Technology, Department of Physics, Tiruchirapalli, Tamilnadu, India

2:50 PM Ultrasonic Time-of-Flight Shift Measurements in Carbon Composite Laminates Containing Matrix Microcracks
---Ajith Subramanian, Vinay Dayal, and Daniel J. Barnard, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

3:10 PM Break

3:30 PM NDE Evidence for the Damage Arrestment Performance of PRSEUS Composite Cube During High-Pressure Load Test
---Patrick H. Johnston and F. Raymond Parker, NASA Langley Research Center, Nondestructive Evaluation Sciences Branch, Hampton, VA 23681

3:50 PM Guided Wave Simulation for Carbon Fiber Reinforced Polymer Composites
---Cara A. C. Leckey, F. Raymond Parker, and Matthew D. Rogge, NASA Langley Research Center, Nondestructive Evaluation Sciences Branch, 3B East Taylor St., Hampton, VA 23681; Lingyu Yu, University of South Carolina, Department of Mechanical Engineering, Columbia, SC 29208

4:10 PM Crack Detection in Single-Crystalline Silicon Wafer Using Laser Generated Lamb Wave
---Min-Kyoo Song, Hyeon Lee, and Kyung-Young Jhang, Hanyang University, Graduate School of Mechanical Engineering, Seoul, Korea

4:30 PM Simulation of Focusing Ultrasound in Multi-Layered Tissues for Improvement of HIFU
---Young-In Hwang, Hak-Joon Kim, and Sung-Jin Song, Sungkyunkwan University, Suwon, Korea
1:30 PM

**Ultrasonic Inspection of Adhesive Joints of Composite Pipelines**

---Priscila Duarte de Almeida, Non-Destructive Testing, Corrosion and Welding Laboratory, Department of Metallurgical and Materials Engineering, COPPE/UFRJ – Federal University of Rio de Janeiro, Rio de Janeiro, RJ, Brazil; João Marcos Alcoforado Rebello and Gabriela Ribeiro Pereira, Department of Metallurgical and Materials Engineering, COPPE/UFRJ - Federal University of Rio de Janeiro, Rio de Janeiro, RJ, Brazil; Sérgio Damasceno Soares, Petrobras Research Center, CENPES – PETROBRAS, Rio de Janeiro, RJ, Brazil; Roman Fernandez, EXTENDE, Le Bergson, Massy, France

---Composite pipelines are an attractive solution when traditional materials are not suitable for this purpose, which happens frequently at aggressive environments and also where the structural weight is a limiting factor. This work studies the application of the ultrasonic technique at the detection of defects as lack of adhesive and lack of adhesion, commonly found in adhesive joints of GFRP pipelines applied at onshore and offshore facilities. Ultrasonic simulations were conducted in CIVA 11 beta version software in order to obtain the best possible configuration for the inspections, applying the pulse-echo technique. Experimental results were compared to these simulations and several transducers were tested. An inspection methodology and reference blocks were developed for the calibration of the inspections. Some samples were selected for cutting in order to compare the ultrasonic results and the real condition of the joints. Results show that experimental data and performed simulations presented similar behavior. Smaller frequencies are suitable for the inspection of this material, being able to detect the proposed defects, and focused probes may present more accurate results.

1:50 PM

**Inherent Acoustic Nonlinearity of Fiber Reinforced Composites**

---Sunil Kishore Chakrapani¹², Daniel Barnard², and Vinay Dayal¹², Iowa State University, Ames IA 50011;¹Department of Aerospace Engineering, ²Center for NDE

---This paper presents the study of inherent acoustic nonlinearity found in fiber reinforced composites. Nonlinear elastic wave methods such as Nonlinear Resonant Ultrasound Spectroscopy (NRUS) and Nonlinear Wave Modulation Spectroscopy (NWMS) have been shown earlier to work successfully for NonDestructive Evaluation (NDE) of various materials. It was observed that applying these techniques to detect damage in composites becomes difficult due to baseline nonlinearity in intact samples. NRUS experiments were conducted on intact and damaged carbon fiber-epoxy samples. In the absence of defect, certain laminates exhibited a nonlinear characteristic which was defined as baseline nonlinearity. With increase in damage, nonlinearity increased beyond the baseline nonlinearity which highlights the importance of understanding the contributions to baseline nonlinearity. This study investigates the cause for the baseline nonlinearity and how it impacts the NDE of composites.
2:10 PM

**Mode Shape-Based Damage Detection in Composite Laminates**
---Zheng Li and Kan Feng, Peking University, College of Engineering, Beijing 100871, China

---Accident impact occurs frequently in engineering structures under work condition, which can severely influence the health of composite structures. In this study an operational damage detection method of composite laminates is presented. A kind of typical carbon fiber reinforced composite laminate is studied as a quasi-isotropic and quasi-homogeneous material. The impact damages were produced by a drop weight acting on the surface of unidirectional stressed laminate. The impact energy can be controlled by adjusting the drop height. A two-dimensional nondestructive damage testing method —2D GSM (Two-Dimensional Gapped Smoothing Method) method, based on operational deflection shapes (ODS), is proposed to locate the delamination of the laminate caused by the impact. Unlike most of the other published study, the procedure here does not require the baseline signal of the undamaged structure as, but only uses the data obtained from the structure with defects. The procedure can show the stiffness varies region in the structure, which indicates that the defect locate. PZTs are arranged as actuators. By controlling the frequencies and the phases of signal inputted into each patch, we can actuate the laminate into different operational deflection shapes. The deflection shapes of the laminate are measured by a Scanning Laser Vibrometer (SLV) system. The result shows that the 2D GSM is an efficient way for the damage detection in composite laminates.

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2:30 PM

**Visualization Studies of Lamb Wave Propagation and Interactions with Anomalies in Composite Laminates Using Air-Coupled Ultrasonics**
---V. S. Sasanka Durvasula, Janardhan Padiyar M, and Krishnan Balasubramaniam, Indian Institute of Technology Madras, Department of Mechanical Engineering, Center for Non-Destructive Evaluation, Chennai, Tamilnadu, India; Vivek Madhavan and N. V. Giridharan, National Institute of Technology, Department of Physics, Tiruchirapalli, Tamilnadu, India

---Understanding ultrasonic Lamb wave propagation and its interaction with defects in the composite laminates can be difficult due to multimode nature and mode conversion. Propagation of Lamb waves in a laminate can be studied numerically or by experimental wave field imaging methods such Schlieren imaging and Laser interferometry which gives visual representations of sound fields. In this study feasibility of using air-coupled transducers as an alternative sensing method to visualize the propagating Lamb waves in a laminate will be discussed. Experimental visualizations of out-plane displacements of S0 and A0 Lamb wave fields in GFRP laminate with delaminations are presented. Effect of type of excitation (shear and pressure) on the relative production of S0 and A0 mode components for the GFRP laminate was studied using ABAQUS models. Directivities of different modes in the GFRP laminate was found out using ABAQUS simulations. CFRP plates with impact damages are also tested experimentally with this method using A0 mode. Possible extension of method to quantitative studies like defect sizing and depth of delaminations will be discussed.
Ultrasonic Time-of-Flight Shift Measurements in Carbon Composite Laminates Containing Matrix Microcracks
---Ajith Subramanian, Vinay Dayal, and Daniel J. Barnard, Iowa State University, Center for Nondestructive Evaluation, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

---Time-of-flight (TOF) shifts are calculated from the fundamental A0 Lamb mode using air-coupled ultrasound. The technique is applied to a carbon/bismaleimide samples containing varying microcrack density along the length of the sample. The phase and group velocity reduction is inferred from the TOF shift data. The relation between group velocity and the crack density is presented. Approximate microcrack densities over several segments of the sample are calculated using a simple constant thresholding algorithm applied to X-ray MicroCT data.---This material is based on work supported by NASA under award NNX07AM15A and is performed at the Center for Nondestructive Evaluation at Iowa State University.

NDE Evidence for the Damage Arrestment Performance of PRSEUS Composite Cube During High-Pressure Load Test
---Patrick H. Johnston and F. Raymond Parker, NASA Langley Research Center, Nondestructive Evaluation Sciences Branch, Hampton, VA 23681

---To approach the light-weight, cost-effective and manufacturable structures required to enable the hybrid wing body aircraft, The Boeing Company and NASA have developed the Pultruded Rod Stitched Efficient Unitized Structure (PRSEUS) concept. At the 2012 AA&S Conference, results were reported from the testing of a PRSEUS pressure cube, developed as a risk reduction test article to examine a new integral cap joint concept as part of a building block approach for technology development of the PRSEUS concept. The overall specimen strength met the 18.4 psi load requirement, and testing resulted in the cube reaching a final pressure load of around 48 psi prior to catastrophic failure. The cube pressure test verified that the joints and structure were capable of sustaining the required loads, and represented the first testing of joined PRSEUS structure. This paper will address the damage arrestment performance of the stitched PRSEUS structure. Following catastrophic failure of the cube, ultrasonic pulse-echo inspection found that the localized damage, surrounding a barely-visible impact damage site, did not change noticeably between just after impact and catastrophic failure of the cube, and did not play a role in the catastrophic failure event. Ultrasonic inspection of the remaining intact cube panels presented three basic types of indications: delaminations between laminae parallel to the face sheets, lying between face sheet and tear strap layers, or between tear strap and flange layers; delaminations above the noodles of stringers, frames or integral caps, lying within face sheet or tear strap layers; and delamination between the laminae in the inner fillets of the integral caps, where pull-off stresses were expected to be highest. Delaminations of all three types were predominantly contained by the first row of stitches encountered. For the small fraction of delaminations extending beyond the first row of stitches, all were contained by the second stitch row.
3:50 PM

Guided Wave Simulation for Carbon Fiber Reinforced Polymer Composites
---Cara A. C. Leckey, F. Raymond Parker, and Matthew D. Rogge, NASA Langley Research Center, Nondestructive Evaluation Sciences Branch, 3B East Taylor St., Hampton, VA 23681; Lingyu Yu, University of South Carolina, Department of Mechanical Engineering, Columbia, SC

---Modeling and simulation are expected to play a significant future role in validating the capabilities and limitations of guided wave based structural health monitoring (SHM) systems. Additionally, it is expected that rapid, realistic nondestructive evaluation (NDE) simulation tools will someday aid in the certification of new aerospace materials and designs; thus shortening the time from material development to use. The current state-of-the-art in ultrasonic NDE/SHM simulation is still far from the goal of simulating damage detection techniques for large scale composite components/vehicles with realistic damage types. This paper discusses the need for incorporating realistic damage types into 3D guided wave simulations for carbon fiber reinforced polymer (CFRP) composites; as well as the need for moving beyond flat-plate simulation geometries. For example, over simplification of CFRP damage may prevent the development of detailed damage characterization methods. Results from CFRP guided wave simulations with complex geometry delamination damage and for non-flat-plate specimens will be presented. Parallel 3D elastodynamic finite integration technique (EFIT) is used for the example simulations, however, the paper will include a broader discussion on the future direction of large scale computational NDE.

4:10 PM

Crack Detection in Single-Crystalline Silicon Wafer Using Laser Generated Lamb Wave
---Min-Kyoo Song, Hyeon Lee, and Kyung-Young Jhang, Hanyang University, Graduate School of Mechanical Engineering, Seoul, Korea

---In the semiconductor industry, with increasing demands for high performance, high capacity, high reliability and compact components, the crack has been one of the most critical issues in accordance with the growing requirement of the wafer-thinning for recent years. Previous researchers presented the crack detection on the silicon wafers with the air-coupled ultrasonic method successfully. However, the high impedance mismatching is not guaranteed in the industrial field. In this paper, in order to detect the cracks, we propose a laser-ultrasonic Lamb wave method which is not only non-contact, but reliable for the data analysis. The laser-ultrasonic generator and the laser-interferometer are used as a transmitter and a receiver, respectively. As a preliminary step to detect the cracks, we firstly verified the identification of the lowest order symmetric and anti-symmetric Lamb wave modes under the thermo-elastic regime. The experimental result shows S0 and A0 modes of Lamb wave are clearly generated and detected. So, the proposed method is expected to make it possible to detect the cracks on the wafer through the data analysis. The performance to detect the cracks will be shown at the conference.
Simulation of Focusing Ultrasound in Multi-Layered Tissues for Improvement of HIFU
---Young-In Hwang, Hak-Joon Kim, and Sung-Jin Song, Sungkyunkwan University, Suwon, Korea

---High-Intensity Focused Ultrasound (HIFU) has been widely used in clinical practice as a therapeutic method that destroys diseased tissue through ablation. This method has a main advantage as it can be performed without incision. So HIFU can be non-invasively applied to some cancer treatments, for example, prostate cancer, uterine leiomyoma, breast cancer, and liver cancer. For the accurate focusing of HIFU to a target such as a tumor, precise ray tracing should be required. However, from skin to the object, human body is complex as it consists of various tissues so it can make unexpected errors. Therefore, before releasing HIFU to human body, the application of HIFU should be simulated for minimizing the necrosis of normal tissues.

By a biological virtualization to each tumor for the simulation of HIFU method, the position of focal point can be imaged and the pressure can be examined on each parts of human body around target. By this information, time-delay values for each transducer in phase array can be calculated and the appropriate geometric shape of HIFU transducer can be set. Thus, in this study, the simulation was performed according to the parameter of HIFU sensor and applied in case of the part surrounded by bones.---This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MEST) (No. 2012R1A1A2044423).
SESSION 30
DAMAGE PRECURSOR CHARACTERIZATION
Sigrun Hirsekorn, Chairperson
Key Ballroom 10

1:30 PM Online Monitoring and Characterization of Fatigue Processes of Carbon Fiber Reinforced Plastics by Ultrasound
---Sigrun Hirsekorn, Miriam Weikert, Ute Rabe, Hans-Georg Herrmann, and Christian Boller, Fraunhofer Institut für zerstörungsfreie Prüfverfahren (IZFP), 66123 Saarbrücken, Germany; Thomas B. Helfen, Lehrstuhl für zerstörungsfreie Prüfung und Qualitätssicherung (LZPQ), Universität des Saarlandes, Saarbrücken, Germany

1:50 PM Noncontact Acousto-Thermal Signatures in Fatigue Damage of Ti-6Al-4V
---Shamachary Sathish1, John Welter, Norm Schehl1, and Kumar V. Jata, Wright Patterson Air Force Base, Air Force Research Laboratory, Materials State Awareness and Supportability Branch, Dayton, OH 45469, 1Univ. of Dayton Research Institute, Structural Integrity Division, Dayton, OH 45469

2:10 PM Modeling the Nonlinear Hysteretic Response of Distributed Damage in a 1D Resonance Experiment
---Claudio Pecorari, Hesjakollen 111, Bergen, Norway; Daniel A. Mendelsohn, The Ohio State Univ., Department of Mechanical Engineering, 201 W. 19th Ave., Columbus, OH 43210

2:30 PM Early Detection of Critical Material Degradation by Means of Electromagnetic Multi-Parametric NDE
---Klaus Szielasko, Ralf Tschuncky, Madalina Rabung, Iris Altpeter, Gerd Dobmann, Hans-Georg Herrmann, and Christian Boller, Fraunhofer Institute for Nondestructive Testing (IZFP), Department WFL, Saarbruecken, Germany; Georg Seiler, Saarland University, Chair of NDT & Quality Assurance, Saarbruecken, Germany

2:50 PM Recent Progress in the NDE of Cast Ship Propulsion Components
---Martin Spies, Hans Rieder, Alexander Dillhoefer, Markus Rauhut, and Kai Taebner, Fraunhofer Institute for Industrial Mathematics ITWM, Image Processing Department, 67663 Kaiserslautern, Germany; Peter Kreier, Innotest AG, 8360 Eschlikon, Switzerland

3:30 PM Acoustic Emission Monitoring of Tensile Testing of Corroded and Un-corroded Clad Aluminum 2024-T3 and Characterization of Effects of Corrosion on AE Source Events and Material Tensile Properties
---A. Chukwujekwu Okafor and Shridhar Natarajan, Missouri University of Science and Technology, Department of Mechanical and Aerospace Engineering, Structural Health Monitoring Laboratory, 327 Toomey Hall, Rolla, Missouri 65409-0050

3:50 PM Verification of Grazing Incidence Ultrasound Microscopy (GIUM) by Comparative Measurements with EBSD
---Bernd Köhler, Martin Barth, and Frank Schubert, Fraunhofer IZFP, Dresden Branch, Dresden, Germany; Maik Müller, Technische Univ. Dresden, Electronic Packaging Lab (lAVT), Dresden, Germany

4:10 PM Symbiosis of Standard B-Scan Imaging and Time Reversal (TR) Based Nonlinear Elastic Wave Spectroscopy (NEWS) Smart Systems for Non Destructive Imaging of Complex Samples
---Serge Dos Santos, Loire Valley University CVL, Engineering School Centre Val de Loire, 3 rue de la Chocolaterie, F-41034 Blois Cedex, France; Marc Kreutzbruck, Federal Institute for Materials Research and Testing, BAM, Uterden Eichen 87, Berlin, 12205, Germany

4:30 PM Fatigue Damage Prognosis Using Affine Arithmetic
---Audrey Gbaguidi and Daewon Kim, Embry-Riddle Aeronautical University, Aerospace Engineering, 600 S. Clyde Morris Blvd., Daytona Beach, FL 32114

4:50 PM A Broad Band and Resonance-Free Airborne Ultrasound Emitter for the Precision Non Destructive Materials Testing
Online Monitoring and Characterization of Fatigue Processes of Carbon Fiber Reinforced Plastics by Ultrasound

---Sigrun Hirsekorn, Miriam Weikert, Ute Rabe, Hans-Georg Hermann, and Christian Boller, Fraunhofer Institut für zerstörungsfreie Prüfverfahren (IZFP), 66123 Saarbrücken, Germany; Thomas B. Helfen, Lehrstuhl für zerstörungsfreie Prüfung und Qualitätssicherung (LZPQ), Universität des Saarlandes, Saarbrücken, Germany

---In industrial applications, lightweight materials as carbon fiber reinforced plastics (CFRP) become more and more important entailing the request for nondestructive testing (NDT) techniques for quality assurance of CFRP components during production and in operation. For this purpose, linear and nonlinear ultrasonic methods are convenient covering materials characterization, defect and damage detection, monitoring and evaluation of ageing phenomena (fatigue) and failure prediction. In order to investigate fatigue of CFRP under cyclic load of 10^9 cycles or more, in a collaborative project with the Institute of Materials Science and Engineering (WKK), University of Kaiserslautern, Germany, a three point bending ultrasonic fatigue testing system combined with online process monitoring was developed. Its operation frequency of 20 kHz is simultaneously used as input for ultrasonic monitoring techniques. Vibrations of small CFRP plates and their sound irradiation into the air during cyclic loading are recorded by a laser vibrometer and a microphone, respectively. The time signals are evaluated by signal processing procedures. Furthermore, the samples are characterized offline by ultrasonic NDT techniques in their pristine state, during loading pauses along the fatiguing process, and after failure. Changes in the vibration signals and in the material properties with progressive ageing are discussed.

Noncontact Acousto-Thermal Signatures in As Received and Fatigue Damaged Ti-6Al-4V

---Shamachary Sathish¹, John Welter, Norm Schehl¹, and Kumar V. Jata, Wright Patterson Air Force Base, Air Force Research Laboratory, Materials State Awareness and Supportability Branch, Dayton, OH 45469, ¹University of Dayton Research Institute, Structural Integrity Division, Dayton, OH 45469

---Interaction of high amplitude acoustic waves with materials produces a small increase in the temperature that can be detected and measured using an IR camera. Although the temperature increase in the sample has been explained using phenomenological approaches, the aim of this paper is to describe the details of the physical mechanisms responsible for conversion acoustic energy to heat. The role of thermoelasticity, sample geometry (finite dimension), microstructure (grain size) and dislocation density in converting acoustic energy to heat are theoretically examined. The theoretically evaluated temperature changes are compared, with experimental measurements on as received and fatigue damaged polycrystalline Ti-6Al-4V samples, measured using high amplitude acoustic waves at a frequency of 20 kHz. The contribution of each of the mechanisms to the overall temperature increase of the sample is discussed in the light of the applicability of the method for non-contact nondestructive evaluation of evolving fatigue damage.
2:10 PM

**Modeling the Nonlinear Hysteretic Response of Distributed Damage in a 1D Resonance Experiment**

---Claudio Pecorari, Hesjakollen 111, Bergen, Norway; Daniel A. Mendelsohn, The Ohio State University, Department of Mechanical Engineering, 201 W. 19th Ave., Columbus, OH 43210

---The resonant response of alloys and geomaterials to a harmonic excitation reveals the existence of hysteretic mechanisms but provides little information, if any, about their nature. A dynamic version of the classical elasto-dynamic technique, on the other hand, seems to be able to discriminate a variety of nonlinear responses, offering a potentially viable avenue to investigate these mechanisms. To this date, however, even disregarding the relative complexity of its setup, lack of theoretical models supporting the interpretation of these results appears to hinder further application of this technique. In this work, the nonlinear hysteretic response of a 1D bar subjected to a longitudinal excitation is investigated theoretically with the aim of advancing the use of resonance-based techniques for characterization purposes. Three types of distributed damage are considered: dislocations, micro-cracks with and without adhesion, and defects leading to hysteretic quadratic nonlinearity at the macroscopic level. Each type of damage is represented by a constitutive relation that captures the essence of the mechanism responsible for the hysteresis of the material. Arbitrary distributions of damage along the bar are allowed. Spectral features characteristic of these distinct forms of damage are predicted, and their use for characterization purposes is discussed.

2:30 PM

**Early Detection of Critical Material Degradation by Means of Electromagnetic Multi-Parametric NDE**

---Klaus Szielasko, Ralf Tschuncky, Madalina Rabung, Iris Altpeter, Gerd Dobmann, Hans-Georg Herrmann, and Christian Boller, Fraunhofer Institute for Nondestructive Testing (IZFP), Department WFL, Saarbruecken, Germany; Georg Seiler, Saarland University, Chair of NDT & Quality Assurance, Saarbruecken, Germany

---With an increasing number of power plants operated in excess of their original design service life an early recognition of critical material degradation in components will gain importance. Many years of reactor safety research allowed for the identification and development of electromagnetic NDE methods which detect precursors of imminent damage with high sensitivity, at elevated temperatures and in a radiation environment. Regarding low-alloy heat-resistant steel grade WB 36 (1.6368, 15NiCuMoNb5), effects of thermal, thermo-mechanical and radiation-induced aging on mechanical-technological properties and several micromagnetic parameters have been thoroughly studied. In particular knowledge regarding the process of copper precipitation and its acceleration under thermo-mechanical load has been enhanced. The Cu-rich WB36 steel is an excellent model material to study and understand aging effects related to neutron radiation without the challenge of handling radioactive specimens in a hot cell. High-cycle fatigue of the austenitic stainless steel AISI 347 (1.4550, X6CrNiN18-10) has been characterized with electromagnetic acoustic transducers (EMATs) at temperatures of 300 °C. Time of flight and amplitude of the transmitted ultrasound signal were evaluated against the number of load cycles applied and observed as an indication of the imminent material failure significantly earlier than monitoring stresses or strains.
2:50 PM

**Recent Progress in the NDE of Cast Ship Propulsion Components**

---Martin Spies, Hans Rieder, Alexander Dillhoefer, Markus Rauhut, and Kai Taeubner, Fraunhofer-Institute for Industrial Mathematics ITWM, Image Processing Department, 67663 Kaiserslautern, Germany; Peter Kreier, Innotest AG, 8360 Eschlikon, Switzerland

---The safe operation of transportation vehicles requires reliable inspection procedures especially for the highly stressed parts and components. While in aerospace industries a high safety standard has been achieved over the years, there is still tremendous potential for improvement of nondestructive inspection techniques in maritime transportation. The failure of propulsion components of ships and ferries can lead to serious environmental as well as economic damage or even the loss of lives. Serious propeller damages in service require the costly docking of ships and a repair by welding. The total failure of a propeller blade is often characterized by fatigue lines on the cracked surface, starting mostly at a deficiency such as a material or weld defect at the trailing edge of the blade or in its interior. In this contribution we concentrate on the detection and quantitative characterization of these damage precursors. For ultrasonic inspection of both the bulk and the weld material we employ mechanized scanning and defect reconstruction using the Synthetic Aperture Focusing Technique (SAFT). Here, the high sound attenuation of the cast Ni-Al bronzes has been identified to be most challenging. For the near-surface inspection we use eddy current techniques to identify open or (partially) covered defects. Visual surface inspection using optical systems and image processing techniques for corrosion-induced deficiencies, open cracks or other damages complements our multi-sensor approach. We show representative results of both laboratory and on-site inspections, report on POD/MAPOD-studies and our planned future activities.

3:30 PM

**Acoustic Emission Monitoring of Tensile Testing of Corroded and Un-corroded Clad Aluminum 2024-T3 and Characterization of Effects of Corrosion on AE Source Events and Material Tensile Properties**

---A. Chukwujekwu Okafor and Shridhar Natarajan, Missouri University of Science and Technology, Department of Mechanical and Aerospace Engineering, Structural Health Monitoring Laboratory, 327 Toomey Hall, Rolla, Missouri 65409-0050

---Corrosion damage affects structural integrity and deteriorates material properties of aluminum alloys in aircraft structures. Acoustic Emission (AE) is an effective nondestructive evaluation (NDE) technique for monitoring such damages and predicting failure in large structures of an aircraft. For successful interpretation of data from AE monitoring, sources of AE and factors affecting it need to be identified. This paper presents results of AE monitoring of tensile testing of corroded and un-corroded clad Aluminum 2024-T3 test samples, and characterization of the effects of strain-rate and corrosion damage on material tensile properties and AE source events. Effect of corrosion was studied by inducing corrosion in the test specimens by accelerated corrosion testing in a Q-Fog accelerated corrosion chamber for 12 weeks. Eight (8) masked dog-bone shaped specimens were placed in the accelerated corrosion chamber at the beginning of the test. Two (2) dog-bone shaped specimens were removed from the corrosion chamber after exposure time of 3, 6, 9, and 12 weeks respectively, and subjected to tension testing till specimen failure along with AE monitoring, as well as two (2) reference samples not exposed to corrosion. Material tensile properties (yield strength, ultimate tensile strength, toughness, and elongation) obtained from tension test and acoustic AE parameters obtained from AE monitoring were analyzed and characterized. AE parameters increase with increase in exposure period of the specimens in the corrosive environment. Aluminum 2024-T3 is an acoustically silent material during tensile deformation without any damage. Acoustic emission events increase with increase of corrosion damage and with increase in strain rate above a certain value. Thus AE is suitable for structural health monitoring of corrosion damage. Ultimate tensile strength, toughness and elongation values decrease with increase of exposure period in corrosion chamber.
3:50 PM

**Verification of Grazing Incidence Ultrasound Microscopy (GIUM) by Comparative Measurements with EBSD**

---Bernd Köhler, Martin Barth, and Frank Schubert, Fraunhofer IZFP, Dresden Branch, Dresden, Germany; Maik Müller, Technische Universität Dresden, Electronic Packaging Laboratory (IAVT), Dresden, Germany

---Grazing Incidence Ultrasound Microscopy (GIUM) is a rather new acoustic near field method for materials microstructure characterization. During the last QNDE conference we presented first GIUM measurements of cross sections of austenitic welds and compared them with optical images of conventionally polished and etched microsections. Meanwhile, we improved the GIUM evaluation by new algorithms and applied it to further microstructures, amongst others dissimilar welds. The results are again compared with optical images of microsections and furthermore with Electron Backscatter Diffraction (EBSD) images. EBSD is a technique yielding quantitative information about the local grain orientation. However, representing a scanning electron microscopy technique it imposes a limitation of the sample size. Moreover it requires a rather large measurement time and in our case also image stitching. While still too cumbersome for practical application, it gives excellent results for basic studies. The comparison of GIUM and EBSD images proves that nearly all GIUM features are coincident with the grain structure across the measured surface. Some deviations between the images are explained by subsurface features not visible in EBSD.

4:10 PM

**Symbiosis of Standard B-Scan Imaging and Time Reversal (TR) Based Nonlinear Elastic Wave Spectroscopy (NEWS) Smart Systems for Non Destructive Imaging of Complex Samples**

---Serge Dos Santos, Loire Valley University CVL, Engineering School Centre Val de Loire, 3 rue de la Chocolaterie, F-41034 Blois Cedex, France; Marc Kreutzbruck, Federal Institute for Materials Research and Testing, BAM, Unterden Eichen 87, Berlin, 12205, Germany

---Acoustic source localization methods are the subject on an ongoing field of study with a broad range of needs in terms of improvement of Non Destructive Imaging applications. The increase of the geometric complexity and the complexity of the internal properties in modern structures like CFRP, concrete or other calibrated calibrated samples, induces a specific need in the modification of current standard B-scan imaging devices. In this paper, ultrasonic imaging of material complexity is investigated experimentally using the concept of symmetry analysis based signal processing, in symbiosis with the Nonlinear Elastic Wave Spectroscopy (NEWS). These concepts have been tested experimentally on several complex media with an advanced smart electronic system. This system exploits Time Reversal (TR) invariance, reciprocity and coded-excitation for an accurate identification of the nonlinear signature of the medium under ultrasonic health monitoring. The experimental feasibility of a focused TR-NEWS method has been improved with a set-up taking into account new advanced chirp-coded excitations. The localization process has been compared with the classical B-Scan system coupled to a angle delay line and the home made COMPASS imaging device. For TR-NEWS methodology, each line of the 16-element probe input has been isolated in the hardware in order to perform TR-NEWS signal processing steps. A chirp-coded signal coding in the 0.6-2 MHz range is used as a compression coding, and with different amplitudes in order to first extract, and second localize nonlinear signatures in the time-domain responses calculated with cross-correlation. Experiments confirms in complex samples that the greater the complexity of the sample, the more efficient TR-NEWS approaches for localization of nonlinear scatterers. This paper is the first example of TR-NEWS methodology including experimentally (as a demonstrating step) a standard imaging device.
Fatigue Damage Prognosis Using Affine Arithmetic
---Audrey Gbaguidi and Daewon Kim, Embry-Riddle Aeronautical University, Aerospace Engineering, 600 S. Clyde Morris Blvd., Daytona Beach, FL 32114

---Among the essential steps to be taken in structural health monitoring systems, damage prognosis would be the least field investigated due to the complexity of the uncertainties. This paper presents the possibility of using affine arithmetic for uncertainty propagation of crack damage in damage prognosis. The structures examined are thin rectangular plates made of titanium and aluminum alloys with central mode I through cracks and a composite plate with an internal delamination caused by mixed mode I and II fracture modes, under a harmonic uniaxial loading condition. The model based approaches for crack growth rates are considered using the Paris-Erdogan law model for the isotropic plates and the delamination growth law model proposed by Kardomateas for the composite plate. The parameters for both models are randomly taken and their uncertainties are considered as defined by an interval instead of a probability distribution. A Monte Carlo method is also applied to check whether affine arithmetic leads to tight bounds on the lifetime of the structures.

A Broad Band and Resonance-Free Airborne Ultrasound Emitter for the Precision Non Destructive Materials Testing

---Commonly used conventional airborne ultrasound transducers are mostly narrow-banded, show long post-oscillations after a short excitation and are therefore not well suited for broad band materials examinations. Moreover, each new task, especially in the research and development of novel materials requires some special, and for each desired frequencies different, ultrasound transducers. Hence, a precision, broad band and resonance free airborne ultrasound source would be of great benefit for the contact free quality control and health monitoring of novel materials and safety relevant components for example for aerospace and automobile industry. In our contribution we will present optimized broad band and resonance free prototypes of airborne ultrasound emitters consisting of an a few nanometer thin electric conductive coating on plastic substrates. Our experimental investigations show that the efficiency of developed thermo-acoustic ultrasound emitters is comparable to those of conventional airborne ultrasound transducers by use of the same ultrasound excitation equipment. Moreover, the novel transducers are capable to generate sound pressure levels more than 140 dB in a full frequency band of airborne ultrasound applications. A full analytical model for exact determination of generated sound pressures and radiated sound fields generated by thermo-acoustic transducers will be presented and compared to experimental results.
THURSDAY

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  Ultrasonics ........................................................... 208
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**Session 36 – POSTERS – 1:30 – 3:10 PM – Key Ballroom 7 and 8**

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SESSION 31
NEW EDDY CURRENT PROBES AND TECHNIQUES
Lalita Udpa and Theodoros Theodoulidis, Co-Chairpersons
Key Ballroom 9

8:30 AM Advances in Design of Eddy Current Probes
---Lalita Udpa and Satish S. Udpa, Michigan State University, East Lansing, MI 48824

9:10 AM Development of a Pulsed Eddy Current Probe for Inspection of Alloy-800 Steam Generator Tubes within SS410 Support Plates Using Finite Element Modelling
---T. W. Krause, P. R. Underhill, and V. K. Babbar, Royal Military College of Canada, Department of Physics, Kingston, ON, Canada

9:30 AM Evaluation of Inverse Exciting Eddy Current Testing for Tube Inspection Insensitive to Defect Orientation

9:50 AM Design and Application of Hybrid Magnetic Field-Eddy Current Probe

10:10 AM Break

10:30 AM Near Electrical Resonance Signal Enhancement (NERSE) of Eddy-Current Crack Detection
---Robert R. Hughes and Steve M. Dixon, University of Warwick, Department of Physics, Gibbet Hill Road, Coventry, CV4 7AL, United Kingdom

10:50 AM Development of Eddy Current Probes Based on Magnetoresistive Sensors Arrays
---Natalia Sergeeva-Chollet and Jean-Marc Decitre, CEA LIST, F-91191 Gif-sur-Yvette, France; Claude Fermon, DSM/IRAMIS/SPEC - CNRS URA 2464, CEA Saclay, F-91191 Gif-sur-Yvette, France; Matthias Pelkner, Verena Reimund, and Marc Kreutzbruck, BAM Federal Institute for Materials Research and Testing, Unter den Eichen 87, 12205 Berlin, Germany

11:10 AM Transient Eddy Currents in Tube and Pipes
---Yi Lu1 and John R. Bowler1,2, 1Iowa State University, Center for NDE, Ames, IA 50011; 2Iowa State University, Department of Electrical and Computer Engineering, Ames, IA 50011

11:30 AM Nonlinear Eddy Current NDE and Theory Based on Vector Preisach Model in the Rayleigh Regime
---Norio Nakagawa, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

11:50 AM Eddy Current System for Inspection of Train Hollow Axles
---Tomasz Chady, Ryszard Sikora, Grzegorz Psuj, Jacek Kowalczyk, and Ireneusz Spychalski, West Pomeranian University of Technology, Faculty of Electrical Engineering, Department of Electrical and Computer Engineering, Szczecin, Poland

12:10 PM Lunch
The design and operation of eddy current probes have evolved over the decades in terms of their ability to gather, process, present and analyze inspection measurements. Advances have been made in new eddy current probe designs to address the varied needs of different applications as well as to improve the performance of existing probes in terms of speed of measurement and accuracy of interpretation. Secondly, access to inexpensive computing has led to development of computational models to simulate inspection of different probe and test geometries. These models serve an important role in design of these eddy current based sensors and systems. The solution of simulation models provide valuable insight into the underlying physics, help visualize the induced fields and currents and their interaction with sample flaws, predict performance of new designs and help optimize sensor design and develop algorithms for accurately interpreting the measured signals. This talk will give an overview of eddy current probe designs, tailored for various applications, to maximize the POD of critical defects.

Support plate degradation and fouling in nuclear steam generators (SGs) can lead to SG tube corrosion and loss of efficiency. Inspection and monitoring of these conditions can be integrated with preventive maintenance programs, thereby advancing station-life management processes. A prototype pulsed eddy current (PEC) probe, targeting inspection issues associated with Alloy-800 SG tubes, which pass through SS410 tube support plates, has been developed using finite element (FE) software. FE modeling was used to identify driver and pickup coil configurations that optimize sensitivity to changes in gap or offset of SG tubes within the holes of 25 mm thick support plates. Experimental measurements, using a probe manufactured based on the modelled configuration, were used to confirm the sensitivity of differential PEC signals to changes in relative position of the tube within the support plate holes. Models and experiments investigated the effect of shift of tube with respect to hole centers. Near hole centers and for small shifts, modeled signal amplitudes from the differentially connected coil pairs were observed to change linearly with tube shift. This was in agreement with experimentally measured PEC coil response. Factors that result in differences between modeled and experimental results will also be considered in the presentation.
9:30 AM

**Evaluation of Inverse Exciting Eddy Current Testing for Tube Inspection Insensitive to Defect Orientation**


---In-service inspection of steam generator (SG) in Pressurized Water Reactor requires high speed and high sensitivity inspection technology. Eddy Current Testing (ECT) which has an ability to scan at high speed and detect defects on surface with high sensitivity is used as an inspection method for SG. On the other hand, sensitivity of an ECT drops when the eddy currents flow in parallel to the direction of defects. This study is aiming at developing the ECT in order to maintain constant sensitivity regardless of the defect direction. As the first step, we developed “Invert Exciting Method” (IEM) that can detect both axial defects (AD) and circumferential defects (CD) at the same sensitivity from the view point of the direction of eddy currents. In order to detect defects inclined to a tube axis (ID) at high sensitivity, in addition, IEM switches the direction of currents symmetrically with respect to a tube axis. We prepared a new ECT probe applicable to IEM and conducted defect detection tests. As a result, we confirmed that the average of the amplitude ratio between AD and CD was improved from 4.6 to 1.3 compared with a traditional ECT probe and IEM had high sensitivity for ID.

9:50 AM

**Design and Application of Hybrid Magnetic Field-Eddy Current Probe**


---The incorporation of magnetic field sensors into eddy current probes can result in novel probe designs with unique performance characteristics. One such example is an electromagnetic probe consisting of a two-channel magneto-resistive sensor with an embedded single strand eddy current inducer recently developed at NASA Langley Research Center. Magnetic flux leakage maps of ferrous materials can be generated in DC operation with no induction current, while AC operation enables high-resolution eddy current imaging. In this work the design and optimization of this probe will be presented, along with an application toward analysis of sensory materials with embedded ferromagnetic shape-memory alloy (FSMA) particles. The sensory material is designed to produce a paramagnetic to ferromagnetic transition in the FSMA particles under strain. Mapping of the stray magnetic field and eddy current response of the sample with the hybrid probe can thereby image locations in the structure which have experienced an overstrain condition. Numerical modeling of the probe response is performed with good agreement to experimental results.
THURSDAY, SESSION 31

10:30 AM

Near Electrical Resonance Signal Enhancement (NERSE) of Eddy-Current Crack Detection
--- Robert R. Hughes and Steve M. Dixon, University of Warwick, Department of Physics, Gibbet Hill Road, Coventry, CV4 7AL, United Kingdom

--- The use of eddy-current arrays (ECAs) for the surface inspection of failure critical components is growing, but the limitations in spatial resolution along with complicated array element interactions can make the detection of sub-millimeter defects above background noise more challenging. In addition, low conductivities in aerospace superalloys mean higher frequencies then are conventionally used should be implemented to remain sensitive to sub-millimeter defects. The effect of operating at frequencies approaching electrical resonance on surface-breaking defect detection in superalloys was investigated. A previously undocumented defect signal enhancement phenomenon at frequencies approaching resonance was observed and characterized. Experimental validation was performed on notch defects in a typical aerospace superalloy. A simple operational approach for raising the sensitivity of conventional industrial eddy-current testing is proposed based on the principles of the observed near electrical resonance signal enhancement (NERSE) phenomenon. The simple procedural change of operating at the NERSE frequency would not require complex probe design or data analysis. It is therefore a potentially valuable avenue of investigation for improving the sensitivity of ECT and ECA techniques in order to achieve greater reliability of detection for critical defects.

10:50 AM

Development of Eddy Current Probes Based on Magnetoresistive Sensors Arrays
--- Natalia Sergeeva-Chollet and Jean-Marc Decitre, CEA LIST, F-91191 Gif-sur-Yvette, France; Claude Fermon, DSM/IRAMIS/SPEC - CNRS URA 2464, CEA Saclay, F-91191 Gif-sur-Yvette, France; Matthias Pelkner, Verena Reimund, and Marc Kreutzbruck, BAM Federal Institute for Materials Research and Testing, Unter den Eichen 87, 12205 Berlin, Germany

--- Eddy Current Technique is a powerful method for detection of surface notches and of buried flaws during inspection of metallic parts. Recent EC array probes have demonstrated a fast and efficient control of large surfaces. Nevertheless, when size of flaws decreases or the defect is rather deep, traditional winding coil probes turn out to be useless. Other technology, like using magnetic sensors as receivers, has to be investigated. These sensors are very attractive for the detection of buried defects that require low frequency because of skin depth effect. An optimization of the probe with magnetoresistive sensors as receiver has been made by simulations using CIVA software and finite elements methods with OPERA in the frames of collaborative project IMAGIC FP7 288381. EC probes for buried flaws detection have been designed. Experimental results have been compared with simulations.
11:10 AM

**Transient Eddy Currents in Tube and Pipes**

---Yi Lu¹ and John R. Bowler¹,², ¹Iowa State University, Center for NDE, Ames, IA 50011; ²Iowa State University, Department of Electrical and Computer Engineering, Ames, IA 50011

---We give a derivation of integral expressions for the frequency-dependent electromagnetic field due to (i) a coil encircling a coaxial uniform pipe and (ii) a bobbin coil inside a coaxial pipe. In each case the coil is driven by a current pulse. To find the corresponding transient field, the integrand has been expanded in the form of asymptotic series and an inverse Laplace transforms carried out on the terms in the series to express the result as a function of time. The results are corroborated using a numerical Fourier transform. The results are used to establish the relationship between the relaxation of the field and its dependence on pipe wall thickness, and the linear material properties of the pipe.

11:30 AM

**Nonlinear Eddy Current NDE and Theory Based on Vector Preisach Model in the Rayleigh Regime**

---Norio Nakagawa, Iowa State University, Center for Nondestructive Evaluation, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

---This paper presents a theory of nonlinear eddy current (NLEC) NDE response, applicable to describe EC NDE measurements involving a ferromagnetic material, treating the nonlinearity at the lowest nontrivial order. The ferrous material in question can be a ferrite core in the typical EC probe to be modeled, or a part material made of steel. At the lowest order, the well-known Rayleigh relation describes the nonlinear constitutive B-H relation (a hysteresis loop behavior), except that it is restricted to the case where the B and H fields are both unidirectional, and where there are no multiple local minima/maxima in the excitation field $H(t)$. To solve prototypical EC NDE problems, we need to overcome this restriction. Namely, the key step for NLEC applications is to extend Rayleigh's formula to vector-valued B and H fields, while maintaining the level of nonlinearity at the lowest order. The paper shows that the vector Preisach model actually provides us with this extension, and in particular that the Rayleigh regime is maintainable by the choice of constant weight functions. As explicit applications, we present solutions to selected NLEC problems, solved by Born approximation and series expansion.---This work was supported by the NSF Industry/University Cooperative Research Program of the Center for Nondestructive Evaluation at Iowa State University.
**Eddy Current System for Inspection of Train Hollow Axles**

---Tomasz Chady, Ryszard Sikora, Grzegorz Psuj, Jacek Kowalczyk, and Ireneusz Spychalski, West Pomeranian University of Technology, Faculty of Electrical Engineering, Department of Electrical and Computer Engineering, Szczecin, Poland

---Evaluation of the axles is one of the most important tasks during the periodic inspection of the railway rolling stock. For the minimization of risk of the danger failures of the wheelsets and secure human life number of inspections have to be carried out during the exploitation of train axles. Most common technique used nowadays in the railway industry for manual inspection is ultrasound testing, but it is insensitive to the surface breaking crack. Therefore, it is not possible to obtain the full rage evaluation of the axles. In this paper an eddy current system for the inspection of the hollow axles is presented and discussed. It is a part of the system containing of two subsystems: electromagnetic for surface breaking cracks detection and ultrasound evaluation of the structural integrity deeper in the material. A new construction of the eddy current differential transducer is proposed and discussed. The structure of the EC system based on lock-in amplifiers will be also presented. The transducer and the whole system was evaluated using samples of axles with artificial defects. The obtained results are very promising from the point of view of detection and identification of the defects.---This work was supported in part by EC sponsored project AxleInspect under the Research for the Benefit of Specific Groups Project (ref: FP7-SME-2011-1-GA- 286573).
Session 32
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<th>Time</th>
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<tr>
<td>8:30 AM</td>
<td>Automated Inspection of Surface Breaking Cracks Using GMR Sensor Arrays</td>
<td>Matthias Pelkner, Verena Reimund, Thomas Erthner, Nicolai Panke, and Marc Kreutzbruck, BAM Federal Institute for Materials Research and Testing, Unter den Eichen 87, 12205 Berlin, Germany</td>
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<td>8:50 AM</td>
<td>Transient Potential Drop Field Measurements Using a Four Point Probe</td>
<td>Y. Ji, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011</td>
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<td>9:10 AM</td>
<td>Accurate Sizing of Closed Crack Using Nonlinear Ultrasound of SPACE with High Voltage Pulser Transformer Technique</td>
<td>Tsuyoshi Mihara and Hatsuzo Tashiro, University of Toyama, Graduate School of Engineering, Gofuku 3190, Toyama, 930-8555, Japan; Goki Konishi and Yusuke Miura, University of Toyama, Japan</td>
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<td>9:30 AM</td>
<td>Surface Wave Acoustic Microscopy (SWAM) for Rapid NDE of Silicon Nitride Balls</td>
<td>Xiaoliang (George) Zhao, Xue Qi, Roger Xu, Fang Li, Wei Chu, Dan Xiang, and Arthur Yang, Intelligent Automation, Inc. 15400 Calhoun Dr., Suite 400, Rockville, MD 20855</td>
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<td>9:50 AM</td>
<td>Phased Array and Ultrasound 2D Camera Technology: A Resolution Study</td>
<td>Bob Lasser, Willard Morris, Steven Ramiro, and David Rich, Imperium, Inc., 5901-F Ammendale Road, Beltsville, MD 20705</td>
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<td>NDT Applications of Non-Contact Thermosonics</td>
<td>Zhi Zeng, Ning Tao, Lichun Feng, and Cunlin Zhang, Capital Normal University, Department of Physics, Beijing 100048, China; Zhi Zeng, Chongqing Normal University, Institute of Physics and Electronic Engineering, 400047, China</td>
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<td>Thermal History Sensors for Non-Destructive Temperature Measurement in Harsh Environments</td>
<td>Christopher C. Pilgrim and Andrew L. Heyes, Imperial College London, London, SW7 2AZ, United Kingdom; Christopher C. Pilgrim, Joerg P. Feist, Pierre Y. Sollazzo, S. Berthier, and Shilpi K. Biswas, Imperial College London, Sensor Coating Systems, Imperial Incubator, Bessemer Building, SW7 2AZ, United Kingdom</td>
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Automated Inspection of Surface Breaking Cracks Using GMR Sensor Arrays
---Matthias Pelkner, Verena Reimund, Thomas Erthner, Nicolai Panke, and Marc Kreutzbruck, BAM Federal Institute for Materials Research and Testing, Unter den Eichen 87, 12205 Berlin, Germany

---We present a prototype for automated magnetic stray field testing of ferromagnetic roller bearings. For this purpose NDE-adapted GMR sensor arrays (giant magneto resistance) are used for the detection of surface breaking cracks. The sensors are miniaturized down to the lower µm-regime to achieve adequate spatial resolution. In doing so, sensor arrays with up to 48 elements are used to inspect the bearing surface within a few seconds only. In contrast to magnetic particle inspection (MPI), where the global magnetization requires a further inspection step and succeeding demagnetization, the presented prototype only locally magnetize the surface area in the vicinity of the GMR Sensors. For the local magnetization, the applied sub-surface magnetic field was simulated and proofed for detecting flaws with a depth of a few 10 µm. By multiplexing the sensor array with an adapted read out electronics we quasi simultaneously detect the normal field component of about 100µm above the surface. The detection of artificial notches with a depth of 40 µm and more could be resolved with a SNR better than 20 dB. The presented testing facility is fast and provides a step towards automated testing of safety relevant steel components.

8:50 AM

Transient Potential Drop Field Measurements Using a Four Point Probe
---Y. Ji, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

--- In this article, transient potential drop measurement using a four-point probe is presented. Transient potential drop measurement requires direct acquisition of excitation current and time-dependent potential drop across the two pick-up pins of a four-point probe, whereas in traditional ACPD measurement, multi-frequency potential drop phasor is obtained by a lock-in amplifier, which is a zero- intermediate frequency superheterodyne receiver in nature. A custom designed instrument is built for the purpose of this experiment. This hardware utilizes a field-programmable gate array (FPGA) based Direct Digital synthesis (DDS) system to generate arbitrary voltage waveform, which is then converted to excitation current to the four-point probe. Data acquisition system composed of cascaded low noise amplifiers and high-resolution analog to digital converters acquires the waveforms of excitation current and time-dependent potential drop in real time. Comparison to analytical results on a thick conductive plate is given and potential application is also discussed.---This work was supported by the NSF Industry/University Cooperative Research Program of the Center for Nondestructive Evaluation at Iowa State University.
9:10 AM

Accurate Sizing of Closed Crack Using Nonlinear Ultrasound of SPACE with High Voltage Pulser Transformer Technique
---Tsuyoshi Mihara and Hatsuzo Tashiro, University of Toyama, Graduate School of Engineering, Gofuku 3190, Toyama, 930-8555, Japan; Goki Konishi and Yusuke Miura, University of Toyama, Japan

---In ultrasonic inspection of the aged structure components, an accurate detecting technique for crack tip must be established for an accurate crack sizing. Especially for the closed crack, conventional ultrasonic inspection method based on linear ultrasound is difficult to detect because incident ultrasound transmit through closed crack. For this case, nonlinear ultrasound have expected to detect even closed crack due to the generation of superharmonic and subharmonic waves at crack. We have been developed subharmonic wave measurement system of SPACE for many cracks in industrial structures. Although SPACE system was useful for some limited closed crack tip detection, subharmonic ultrasound didn't generate for many industrial cracks. In this paper, for the large displacement ultrasonic incident system using special transformer technique have been developed and combine to the SPACE system. Commercial pulser of 350V for excitation voltage of was enhanced to 2000 V at max using the special transformer technique. SPACE system with 1000 V excitation was applied to inspect industrial cracks in stainless steel to investigate the availability comparing usual SPACE measurement. As the results, we can improve the detection ability of a crack tip using SPACE.

9:30 AM

Surface Wave Acoustic Microscopy (SWAM) for Rapid NDE of Silicon Nitride Balls
---Xiaoliang (George) Zhao, Xue Qi, Roger Xu, Fang Li, Wei Chu, Dan Xiang, and Arthur Yang Intelligent Automation, Inc. 15400 Calhoun Dr., Suite 400, Rockville, MD 20855

---Ceramic hybrid bearings have many excellent performance characteristics such as heat resistance, extended life, light weight, low thermal expansion, and electrical non-conductance. However, even a small crack on a ceramic (silicon nitride) ball surface can cause catastrophic bearing failures. We have successfully developed and experimentally verified an innovative Surface Wave Acoustic Microscopy (SWAM) prototype system for rapid and automatic inspection of silicon nitride (SiN) balls for small defects such as C-cracks. The system utilizes two motorized friction wheels of 90 degrees in axial angles to drive the ball following a spiral trajectory, and a high frequency immersion ultrasonic transducer at a defocus distance to generate and receive Surface Acoustic Waves (SAW) on the silicon nitride ball surface. Any defect or inhomogeneity within the effective SAW inspection area will cause wave scattering thus can be detected. The SWAM interrogates a larger surface area at a time than regular ultrasonic C-scan, and inspect the crack from 360 degrees tangential directions simultaneously on the ball surface. 16 SiN balls of 1-inch in diameter with c-cracks ranging from 300 to 600 microns in cord length were inspected, each ball scan takes less than 6 minutes, and nearly 100% of the cracks were detected.
9:50 AM
Phased Array and Ultrasound 2D Camera Technology: A Resolution Study
---Bob Lasser, Willard Morris, Steven Ramiro, and David Rich, Imperium, Inc., 5901-F Ammendale Road, Beltsville, MD 20705

---Imperium has been investigating the quantitative comparisons for spatial resolution between the ultrasound camera produced by Imperium and phased array systems. The Imperium camera utilizes an acoustic lens system and two-dimensional imaging array with 120x120, or 14,400 elements. We will report how this allows for far greater spatial resolution than the electronic beam forming phased array systems. This camera system is used in a variety of industrial settings including for petrochemical and aerospace usage. We have investigated the mathematical comparisons between the two technologies and have taken comparative results. We utilized a graphite epoxy standard with far-side drilled holes to determine the ultimate resolution possible with each technique. The frequency was common for all both techniques. We will report on the results of this investigation including comparative imagery.

10:30 AM
NDT Applications of Non-Contact Thermosonics
---Zhi Zeng, Ning Tao, Lichun Feng, and Cunlin Zhang, Capital Normal University, Department of Physics, Beijing 100048, China; Zhi Zeng, Chongqing Normal University, Institute of Physics and Electronic Engineering, 400047, China

---Thermosonics or SonicIR has been proven an effective NDT method, in which ultrasonic welding horn is pushed against the tested sample under certain force through a piece of coupling material. Due to the mechanical contact between horn and sample, it may damage the contacted surface, especially for some brittle or fragile samples. In this study, the conventional horn in a small size was replaced by a much bigger horn to avoid the direct contact of horn with the sample. The tested sample could be positioned up to several centimeters away from the bottom or beside of the horn, heat is generated at the defect location under the excitation of ultrasonic field, its heating mechanism is similar with contact thermosonics, the infrared camera could be positioned wherever is convenient to monitor the variation of the surface temperature. The presented experimental results show that the non-contact thermosonics has some potential in NDT application.
Highly-Sensitive X-Ray TV Systems Based on CCD-Arrays with Digital Image Processing
---V. A. Troitsky, N. G. Belyi, and V. N. Bukhensky, E. O. Paton Electric Welding Institute of the National Academy of Sciences of Ukraine, Kiev, Ukraine; S. R. Mikhailov, National Technical University of Ukraine “KPI”, Kiev, Ukraine

---X-ray television systems (XRTS) are widely applied to non-destructive testing of materials and products quality in the industry. Such systems have some advantages relative X-radiography concerning productivity and cost of the control, and also over an opportunity of the control of objects both in a statics, and in dynamics. XRTS on the basis of X-ray screens and high-sensitivity CCD-cameras characterized by simplicity of design, have low cost and can effectively be applied to the nondestructive control of mobile objects, providing relative sensitivity of the control 1,5÷2 % in a wide range of steel depth. The further improvement of relative sensitivity of control XRTS is possible due to operation of a CCD-matrixes in a mode of adjustable duration of images accumulation. Results of research developed digital computerized XRTS on the basis of the X-ray screens CsI(Tl) and Gd2O2S(Tb) with television cameras on CCD-matrix SONY corporation with number of active pixels 752×582 or 1360×1024 are considered in the report. The cameras have work possibility in a mode of adjustable duration of accumulation of images on the CCD-matrix (a maximum till 10 minutes). In cameras there is a possibility of cooling of CCD-matrixes to -30 °C concerning the surrounding temperature. The cameras is equipped by zoom lens with a relative hole 1:1. In the developed XRTS the software for digital processing X-ray images is used. The developed XRTS provides relative sensitivity of the control, commensurable with sensitivity film X-radiography.

Thermal History Sensors for Non-Destructive Temperature Measurement in Harsh Environments
---Christopher C. Pilgrim and Andrew L. Heyes, Imperial College London, London, SW7 2AZ, United Kingdom; Christopher C. Pilgrim, Joerg P. Feist, Pierre Y. Sollazzo, S. Berthier, and Shilpi K. Biswas, Imperial College London, Sensor Coating Systems, Imperial Incubator, Bessemer Building, SW7 2AZ, United Kingdom

---The operating temperature is a critical physical parameter in many engineering applications, however, can be very challenging to measure in certain environments, particularly when access is limited or on rotating components. A new quantitative non-destructive temperature measurement technique has been proposed which relies on thermally induced permanent changes in ceramic phosphors. This technique has several distinct advantages over current methods for many different applications. The robust ceramic material stores the temperature information allowing long term thermal exposures in harsh environment to be measured at a convenient time. Additionally, rare earth dopants make the ceramic phosphorescent so that the temperature information can be interpreted by automated interrogation of the phosphorescent light. This technique has been demonstrated by application of the materials as coatings through the air-plasma spray process. A single material can be used to measure temperature over a wide range, namely between 300°C and 900°C. The sensor material has also been embedded in a standard thermal barrier coating which was applied to a combustor tile in a UK power station. The coating was tested for 4,500 hours and after operation the phosphorescent decay time profile indicated an operating temperature map of the component which corroborates with micrograph analysis.
# SESSION 33

**ULTRASONIC MICROSTRUCTURAL BACKSCATTER**

*Joseph A. Turner and Paul D. Panetta, Co-Chairpersons*

**Key Ballroom 10**

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<th>Time</th>
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| 8:30 AM| **Ultrasonic Scattering and Inverse Characterization of Polycrystals with Texture and Microtexture**  
---S. I. Rokhlin, J. Li, and L. Yang, The Ohio State University, Department of Material Science and Engineering, Edison Joining Technology Center, 1248 Arthur E Adams Drive, Columbus OH 43221 |
| 9:10 AM| **Wigner Transforms and Multiple Scattering Expansions for Characterization of Heterogeneous Materials**  
---Joseph A. Turner, Ping Hu, and Christopher M. Kube, University of Nebraska-Lincoln, Mechanical and Materials Engineering, W342 Nebraska Hall, Lincoln, NE 68588 |
| 9:30 AM| **Backscattering and Attenuation Mechanisms in Solids and Solid-Liquid Suspensions**  
---Paul D. Panetta, College of William & Mary, Virginia Institute of Marine Science, Applied Research Associates, Inc., Mail: P.O. Box 1346, Shipping: Route 1208 Greate Road, Gloucester Point, VA 23062 |
| 9:50 AM| **Automated Grain Size Measurements Using Ultrasonic Backscattering**  
---Paul D. Panetta, Applied Research Associates, Inc., Gloucester Point, VA 23062; Leslie Bland, University of Virginia, Charlottesville, VA; Maureen Tracy, Williamsburg, VA; Waled Hassan, Rolls-Royce Corporation, Indianapolis, IN 46225 |
| 10:10 AM| **Break** |
| 10:30 AM| **Attenuation and Dispersion in Stressed Polycrystalline Media**  
---Christopher M. Kube and Joseph A. Turner, University of Nebraska-Lincoln, Department of Mechanical and Materials Engineering, 900 N. 16th, Lincoln, NE 68588 |
| 10:50 AM| **An Experimental Evaluation of Ultrasonic Array Imaging Algorithms for Inspection of a Coarse Grained Power Plant Material**  
---Anton Van Pamel and Michael J. S. Lowe, Imperial College, Mechanical Engineering, London, United Kingdom; Tim Lardner and Minghui Li, University of Strathclyde, Centre for Ultrasonic Engineering, Glasgow, United Kingdom; Colin R. Brett, E.ON New Build and Technology Ltd, Technology Centre, Ratcliffe-on-Soar, United Kingdom |
| 11:10 AM| **Modelling of Ultrasonic Scattering by an Axial Crack in a Pipe**  
---Jacob Rubenson, Chalmers University of Technology, Department of Applied Mechanics, Göteborg, Sweden |
| 11:30 AM| **Rough Surface Reconstruction for Ultrasonic NDE Simulation**  
---Wonjae Choi, Fan Shi, and Michael J. S. Lowe, Imperial College, Mechanical Engineering, London, United Kingdom; Elizabeth Skelton and Richard Craster, Imperial College, Mathematics, London, United Kingdom |
| 11:50 AM| **Modelling the Effect of Roughness on Ultrasonic Scattering in 2D and 3D**  
---Frederic Cegla and Andrew Jarvis, Imperial College, Mechanical Engineering, London, United Kingdom |
| 12:10 PM| **Lunch** |
**Ultrasonic Scattering and Inverse Characterization of Polycrystals with Texture and Microtexture**
---S. I. Rokhlin, J. Li, and L. Yang, The Ohio State University, Department of Material Science and Engineering, Edison Joining Technology Center, 1248 Arthur E Adams Drive, Columbus OH 43221

---Structural materials develop complex microstructures with preferred orientation of nonequiaxed grains because of the thermo-mechanical processes commonly used in their manufacture. In some materials, such as titanium, orientation clustering of crystallites often occurs. Size of the clusters and level of texture may significantly alter mechanical properties of materials and their service life. Ultrasonic scattering in polycrystals depends on the length scale of the grains and their preferred orientation, so ultrasonic characterization may provide nondestructive means to determine the different aspects of material microstructure and anomalies important for material serviceability. This paper overviews recent theoretical and experimental results for characterization of complex polycrystalline microstructures from measurements of ultrasonic attenuation and backscattering. Three-dimensional microtexture results in orthotropic symmetry of elongated clusters; this necessitates scattering models suitable for this crystallographic symmetry; such models are also valuable to determine when different simplifying assumptions and approximations may be warranted. Such simplifications are essential for reduction of the number of microstructure parameters to be found by inverse determination from ultrasonic measurements. It is shown that to characterize microstructure properties it is advantageous to decouple elastic and geometrical properties by a special series of measurements and data inversion.

---Wigner Transforms and Multiple Scattering Expansions for Characterization of Heterogeneous Materials
---Joseph A. Turner, Ping Hu, and Christopher M. Kube, University of Nebraska-Lincoln, Mechanical and Materials Engineering, W342 Nebraska Hall, Lincoln, NE 68588

---Recent research associated with elastic wave scattering in heterogeneous materials has included two main developments that are discussed in this presentation. First, the statistical approaches that are employed to model scattering experiments demonstrate that the transducers should be included in these models through their corresponding Wigner transforms. The four-fold Wigner distribution function describes the combined time-frequency, space-wave vector domains simultaneously for the transducer beam pattern. Examples of the expected energy distributions within a heterogeneous solid are shown with respect to the angle of incidence, surface curvature and sample properties using a single-Gaussian beam model. Secondly, the statistical expansions used in the models provide a rational strategy for inclusion of any level of multiple scattering. The impact of double scattering is first discussed in detail with a focus on its role in experiments that are assumed to satisfy a single scattering limit. Then the full multiple scattering expansion that leads to a radiative transfer equation is examined. The goal of this work is to use single scattering measurements to make predictions of experiments that involve multiple scattering. Although the focus of the example results presented is on polycrystalline materials, the application to other heterogeneous media will also be examined.
Backscattering and Attenuation Mechanisms in Solids and Solid-Liquid Suspensions
--- Paul D. Panetta, College of William & Mary, Virginia Institute of Marine Science, Applied Research Associates, Inc., Mail: P.O. Box 1346, Shipping: Route 1208 Greate Road, Gloucester Point, VA 23062

---To help minimize the effects of oil spills on marine environments, chemical dispersants are used to disperse the oil in the water column so the oil can be consumed by naturally occurring bacteria. During the Deepwater Horizon incident, 1.1 million gallons of chemical dispersant were injected directly into the flowing plume of oil and natural gas over 1500 meters deep. Dispersants main effect is to decrease the surface tension at the oil-water interface causing the oil to form droplets smaller than ~70 microns so they can remain in the water column. Currently the efficacy of aerial applied dispersants to treat surface slicks is determined by measuring the droplet size decrease using a Laser In-Situ Scattering Transmissometer (LISST) or by detecting the oil in the water column using fluorometers. LISST instruments are limited to dilute mixtures, below ~500 ppm, because the signal is saturated for concentrated mixtures, and their windows can become occluded by oil and biofilms. Fluorometers only measure oil concentration; thus they cannot distinguish between naturally dispersed oil droplets, which will float back to the surface, from chemically dispersed oil droplets, which will remain in the water column. When gas is present as was the case in the Deepwater Horizon incident, the plume consisted of ~22% natural gas, the LISST cannot distinguish between oil droplets and gas bubbles and thus is not able to track the effectiveness of dispersants on oil in the presence of gas. We have developed methods to determine the oil droplet size using acoustic measurements. We are using the resonance behavior of the gas bubbles to separate their contribution to the measured scattering as a function of dispersant applications. We will report on results using acoustic scattering and resonance to track the size of oil droplets in the presence of gas during subsurface releases in our lab as well as in a large wave tank.

Automated Grain Size Measurements Using Ultrasonic Backscattering
--- Paul D. Panetta, Applied Research Associates, Inc., Gloucester Point, VA 23062; Leslie Bland, University of Virginia, Charlottesville, VA; Maureen Tracy, Williamsburg, VA; Waled Hassan, Rolls-Royce Corporation, Indianapolis, IN 46225

---The grain size of metal alloys is one of the key material properties that controls mechanical strength. The grain size is carefully controlled during processing to create the desired mechanical properties and reliability in a final component. Traditional metallographic grain size measurements are destructive, time consuming and labor intensive. In addition they only sample a small region of a component and cannot be performed on every component. Ultrasonic scattering measurements are excellent at probing metal microstructures and providing grain size if appropriate theories exist. However, the ultrasonic backscattering can only be used if the measurement provides the same backscattering coefficient predicted from wave propagation theories and if it is independent of the measurement system. We developed a software tool that unifies the entire process including the data collection, backscattering coefficient calculation, theoretical predictions, grain size calculation and visualization. We tested the tool on nickel super alloys including IN718, Waspaloy, Udimet 720, and Rene 88. We also measured the grain size in an alloy 10 disk with grain sizes ranging from ~8 microns in the bore to ~30 microns at the rim designed to alleviate fatigue and creep respectively. This tool represents a practical application of the many years of scattering research that has been ongoing by many talented scientists. It provides the NDE and materials community the ability to quickly map the grain size test various theories and to predict the measured backscattering coefficient in one software platform for the first time. We will apply the ultrasonic backscattering to other alloys including titanium alloys with equiaxed grains, elongated grains, and duplex microstructures using existing and new theories if needed.
Attenuation and Dispersion in Stressed Polycrystalline Media
---Christopher M. Kube and Joseph A. Turner, University of Nebraska-Lincoln, Department of Mechanical and Materials Engineering, 900 N. 16th, Lincoln, NE 68588

---Acoustoelasticity may be formulated using stress-dependent effective elastic moduli in order to model acoustic wave speeds in stressed materials. Recently, the effective moduli have been used within wave scattering models in an effort to measure an unknown material stress state. Present efforts have been undertaken to derive theoretical estimates of stress-dependent attenuations and wave speeds. The approach follows the perturbation techniques employed by Stanke and Kino to model wave propagation in polycrystals. In this case, the perturbation is due to the stress-induced anisotropy along with the intrinsic material anisotropy. Stress-dependent attenuation and wave speed are determined for longitudinal and shear wave propagation without limiting the frequency range through the Born approximation. These results are given for the cases of wave propagation both perpendicular and parallel to a uniaxial loading direction. Results are also given for wave propagation in a material under hydrostatic loading. This work may result in new applications for NDE stress monitoring and improved wave propagation models.---Research supported by FRA.

An Experimental Evaluation of Ultrasonic Array Imaging Algorithms for Inspection of a Coarse Grained Power Plant Material
---Anton Van Pamel and Michael J. S. Lowe, Imperial College, Mechanical Engineering, London, United Kingdom; Tim Lardner and Minghui Li, University of Strathclyde, Centre for Ultrasonic Engineering, Glasgow, United Kingdom; Colin R. Brett, E.ON New Build and Technology Ltd, Technology Centre, Ratcliffe-on-Soar, United Kingdom

---Improving ultrasound inspection capability of coarse grain metals has been of longstanding interest to industry and the NDE research community and is expected to become increasingly important for next generation power plants. A test sample of coarse grained Inconel 625 which is representative of future power plant materials has been manufactured to test the detectability of different inspection techniques. Conventional ultrasonic scans showed the sample to be extraordinarily difficult to inspect due to its scattering behavior. However, in recent years, array probes and Full Matrix Capture (FMC) imaging algorithms, which extract the maximum amount of information possible, have unlocked exciting new possibilities for improvements. This article evaluates the capabilities of different FMC imaging algorithms for inspection of this sample. The imaging targets are side-drilled-holes of 5mm diameter at various depths. The data is captured in pulse-echo mode using 128 element array probes at a range of frequencies between 1MHz and 10MHz.
11:10 AM

Modelling of Ultrasonic Scattering by an Axial Crack in a Pipe
---Jacob Rubenson, Chalmers University of Technology, Department of Applied Mechanics, Göteborg, Sweden

---Modelling of ultrasonic scattering by an internal, infinitely long, axial crack in a thick-walled pipe is considered. The problem is formulated as a hypersingular integral equation for the crack-opening displacement (COD). The COD is expanded in Chebyshev functions which have the correct square-root singularity along the crack edges, thereby regularizing the integral equation. To discretize the integral equation it is likewise projected onto the same Chebyshev functions. A model of an ultrasonic rectangular contact probe is developed, and the signal response is calculated using a reciprocity argument. Some numerical examples demonstrate the possibilities of the method.

11:30 AM

Rough Surface Reconstruction for Ultrasonic NDE Simulation
---Wonjae Choi, Fan Shi, and Michael J. S. Lowe, Imperial College, Mechanical Engineering, London, United Kingdom; Elizabeth Skelton and Richard Craster, Imperial College, Mathematics, London, United Kingdom

---The reflection of ultrasound from rough surfaces is an important topic for the NDE of safety-critical components, such as pressure-containing components in power stations. The specular reflection from a rough surface of a defect is normally lower than it would be from a flat surface, so it is typical to apply a safety factor in order that justification cases for inspection planning are conservative. The study of the statistics of the rough surfaces that might be expected in candidate defects according to materials and loading, and the reflections from them, can be useful to develop arguments for realistic safety factors. This paper presents a study of real rough crack surfaces that are representative of the potential defects in pressure-containing power plant. Two-dimensional (area) values of the height of the roughness have been measured and their statistics analyzed. Then a means to reconstruct model cases with similar statistics, so as to enable the creation of multiple realistic realizations of the surfaces, has been investigated, using random field theory. The reconstructed and original surfaces have been compared and examples of ultrasonic reflections from them assessed. Additionally, results for these two-dimensional descriptions of real surfaces have been compared with those from the conventional model based on a one-dimensional Gaussian distribution.
Modelling the Effect of Roughness on Ultrasonic Scattering in 2D and 3D
---Frederic Cegla and Andrew Jarvis, Imperial College, Mechanical Engineering, London, United Kingdom

---With the advances of ultrasonic sensor technology, permanent installation of sensors and/or automation of scanning equipment the effect of human errors in NDE can be reduced and it is the unknown boundary conditions of the physics that determine the underlying scatter of the response of a sensor system. The authors have developed a fast and efficient acoustic model that predicts the scatter from rough boundaries and calculates the resultant ultrasonic signal. The predicted responses have been experimentally validated and show good agreement between theory and experiment. A statistical approach is needed to evaluate the response distribution for many different setups and simulation times in 3D can be prohibitive. Therefore a simplification approach that allows description of the 3D response by a 2D model is described for a particular application. This allows the simulation of full statistical distributions of defect populations in a few minutes.
SESSION 34
LASER ULTRASONICS
Daniel Levesque, Chairperson
Key Ballroom 11

8:30 AM Laser Ultrasonic Imaging Using Multiple Wave Modes
---Hao Wang and WenXiang Hu, Tongji University, Institute of Acoustics, 1239 Siping Road, Shanghai 200092, China (PRC)

8:50 AM Effects of Branched Defect Geometry on the Propagation of Rayleigh Waves
---Francisco Hernandez-Valle, Rachel S. Edwards, Andrew R. Clough, and B. Dutton, University of Warwick, Department of Physics, Coventry, West Midlands, CV4 7AL, United Kingdom

9:10 AM Investigation of Surface Acoustic Wave Scattering for Local Mapping of Sub-Surface Defects
---Xiang Chen and Phillip Ahn, Northwestern University, Mechanical Engineering Department, Evanston, IL 60208; Oluwaseyi Balogun, Northwestern University, Department of Civil and Environmental Engineering, Evanston, IL 60208

9:30 AM Application of Gas-Coupled Laser Acoustic Detection to Gelatins and Underwater
---James N. Caron, Quarktet, Silver Spring, MD 20706; Pratima Kunapareddy, Research Support Instruments, Lanham, MD 20706

9:50 AM Laser Ultrasonic Improvements for Industrial Composites
---Kenneth R. Yawn, PaR Systems, Inc., c/o Lockheed Martin Aeronautics, 1 Lockheed Blvd., Fort Worth, TX 76108

10:10 AM Break

10:30 AM Laser-Ultrasonic Inspection of Hybrid Laser-Arc Welds
---Daniel Levesque, Guy Rousseau, and Jean-Pierre Monchalin, National Research Council Canada, Boucherville, Qc, Canada; Priti Wanjara and Xinjin Cao, National Research Council Canada, Montreal, Qc, Canada

10:50 AM Weld Quality Inspection Using Laser-EMAT Ultrasonic System and C-Scan Method
---Lei Yang and I. Charles Ume, Georgia Institute of Technology, G. W. Woodruff School of Mechanical Engineering, 813 Ferst Drive NW, Atlanta, GA 30332-0405

11:10 AM Fundamental Study of Microelectronic Chip Response Under Laser Ultrasonic-Interferometric Inspection Using C-Scan Method
---Lei Yang, Jie Gong, and I. Charles Ume, Georgia Institute of Technology, G. W. Woodruff School of Mechanical Engineering, 813 Ferst Drive NW, Atlanta, GA 30332-0405

11:30 AM Full-Field Mechanical Property Reconstruction System Based on Quantitative Laser Ultrasound Visualization System
---Chia Han Wu and Che-Hua Yang, National Taipei University of Technology, Institute of Mechanical and Electrical Engineering, No. 1, Sec. 3, Zhongxiao E. Rd. Da’an Dist.,Taipei City 106, China (ROC)

11:50 AM Damage Detection by Measuring Laser-Based Mechanical Impedance
---Hyeonseok Lee and Hoon Sohn, Korea Advanced Institute of Science and Technology, Department of Civil and Environmental Engineering, Yuseong-gu, Daejeon, Korea

12:10 PM Lunch
8:30 AM

**Laser Ultrasonic Imaging Using Multiple Wave Modes**
---Hao Wang and WenXiang Hu, Tongji University, Institute of Acoustics, 1239 Siping Road, Shanghai 200092, China (PRC)

---Different wave mode can be generated by pulsed laser in material, such as compressional wave, shear wave and their converted modes. Each wave mode may carry the information of the materials under inspection. In this paper, Kirchhoff migration method was applied to these waves respectively to image the inspected materials, then all of the images are stacked to improve signal noise ratio. An experiment is carried out on an aluminum sample machined with side-holes. The acquired waveforms were processed and the result image shows that these holes can be seen clearly. Furthermore, simulated waveforms from FEM were also processed using the same methods, both processing results are in good agreement. The multiple wave migration method was validated.

8:50 AM

**Effects of Branched Defect Geometry on the Propagation of Rayleigh Waves**
---Francisco Hernandez-Valle, Rachel S. Edwards, Andrew R. Clough, and B. Dutton, University of Warwick, Department of Physics, Coventry, West Midlands, CV4 7AL, United Kingdom

---Rayleigh waves can be used for characterization of surface-breaking defects, giving a measure of the depth and the angle of propagation of a defect with simple (i.e., single crack) geometry. However, surface breaking defects will often grow with a more complicated geometry. We present here results of experimental measurements using laser generated and detected Rayleigh waves on aluminum samples containing machined slots with varied branched geometries. The signal enhancement found in the near-field, the reflection and transmission coefficients can be used to position the defect and gain an idea of its geometry. Additional insight is gained through a 2D finite element simulation, which is used to better understand the contributions of different wavemodes to the enhancement when the branch varies in position and/or length. This research can be applied to monitor components prone to developing stress corrosion cracking (branched-like defects); results are shown of the near-field interactions of Rayleigh waves with this type of cracking in stainless steel pipe samples, in order to resolve the spatial extent and geometric alignment of those defects. Both laser ultrasonics and electromagnetic acoustic transducers (EMATs) have been used.
Investigation of Surface Acoustic Wave Scattering for Local Mapping of Sub-Surface Defects
---Xiang Chen and Phillip Ahn, Northwestern University, Mechanical Engineering Department, Evanston, IL 60208; Oluwaseyi Balogun, Northwestern University, Department of Civil and Environmental Engineering, Evanston, IL 60208

The scattering of surface acoustic waves from sub-surface defects is an important problem in nondestructive evaluation and near-surface defect metrology. Surface acoustic waves are elastic waves that propagate in the near-surface region of a solid and their penetration depth increases with wavelength (or inverse frequency). The interaction of surface acoustic waves with surface defects such as cracks have been widely investigated, and results in the literature show an enhancement in the surface wave amplitude in the vicinity of the defect due to wave scattering and interference effects. In this work, we study the interaction of high frequency surface acoustic waves with subsurface defects (voids and inclusions), particularly in the local near-field of the defects. To facilitate the study, a pulsed laser source is used for thermo-elastic generation of broadband surface acoustic waves. The surface waves are detected with a nanofocusing optical probe that was recently developed to overcome the classical diffraction limit on the optical spatial resolution while maintaining the high temporal resolution of optical based detection techniques. We present preliminary experimental results showing time-resolved detection of broadband (~1GHz) surface acoustic waves and scattering from buried defects with nanoscale spatial resolution. In addition, we validate the experimental results through comparison to analytical modeling and numerical simulation results. This work has the potential to elucidate the feasibility of surface acoustic wave based methods for detection of submicron defects, which would have great impact in nondestructive defect metrology of microelectronic devices.

Application of Gas-Coupled Laser Acoustic Detection to Gelatins and Underwater
---James N. Caron, Quarktet, Silver Spring, MD 20706; Pratima Kunapareddy, Research Support Instruments, Lanham, MD 20706

Gas-coupled Laser Acoustic Detection (GCLAD) is has been used a method to sense ultrasound waves in materials without contact of the material surface. To sense the waveform, a laser beam is directed parallel to the material surface and displaced or deflected when the radiated waveform traverses the beam. We present recent tests that demonstrate the potential of using this technique for detecting ultrasound in gelatin phantoms and underwater. As opposed to interferometric detection, GCLAD operates independently of the optical surface properties of the material. This allows the technique to be used in cases where the material is transparent or semi-transparent. We present results on sensing ultrasound in gelatin phantoms that are used to mimic biological materials. As with air-coupled transducers, the frequency response of GCLAD at high frequencies is limited by the high attenuation of ultrasound in air. In comparison, water has a much lower attenuation. The frequency response of the system would only be limited by the system electronics and the width of the beam at the detection point. Thus, a GCLAD system can be used in an immersion tank to sense higher frequencies while maintaining a broadband frequency response.
Laser Ultrasonic Improvements for Industrial Composites
---Kenneth R. Yawn, Par Systems, Inc., c/o Lockheed Martin Aeronautics, 1 Lockheed Blvd., Fort Worth, TX 76108

---LaserUT®, the Lockheed Martin (LM) developed implementation of Laser Ultrasound for composite structures, has been used to perform non-destructive inspections of over 40,000 production parts from a wide variety of aircraft programs. Inspection of complex-shaped composite aircraft parts can be very difficult and time consuming with conventional Ultrasonic NDI systems. For the most complex of these structures, Laser Ultrasound can be up to 10 times faster than state-of-the-art conventional UT systems and at times allows the inspection of parts previously thought un-inspectable by automated systems [1]. The designs and material systems for some applications can present severe NDI challenges. Large assemblies, complex shapes, and unusual or attenuative materials can make implementation of Laser Ultrasound difficult. Some recent programs at Par Systems have highlighted the need for improved techniques and equipment [1, 2]. Several topics will be touched on: recent CO2 generation laser improvements, work in mid-IR laser development for improved generation of ultrasound in composites, detection system enhancements, and analytical techniques for defect detection in thick and attenuative composites. This paper will give a brief overview of LaserUT for composites, applications, and results from several types of material systems, and highlight some of the current research and the path forward.

Laser-Ultrasonic Inspection of Hybrid Laser-Arc Welds
---Daniel Levesque, Guy Rousseau, and Jean-Pierre Monchalin, National Research Council Canada, Boucherville, QC, Canada; Priti Wanjara and Xinjin Cao, National Research Council Canada, Montreal, QC, Canada

---Conventional shipbuilding is labor intensive and hence automated and optimized manufacturing processes can increase the production efficiency. Robotized production using hybrid laser-arc welding (HLAW) is becoming one of the key manufacturing approaches. The HLAW process is a relatively low heat input joining technology that combines the synergistic qualities of both the high energy density laser beam for deep penetration and the arc for wide fit-up gap tolerance. Therefore, this process is especially suitable for the shipbuilding industry where thick-gauge section, long steel plates have been widely used in a butt joint configuration for manufacturing. To detect and visualize the welding defects, we have explored the use of laser ultrasonics combined with the synthetic aperture focusing technique (SAFT). Results obtained on 9 mm thick butt-welded HSLA-65 steel plates show that the laser-ultrasonic SAFT inspection technique can successfully detect and visualize the presence of inclusions and linear defects. This was further confirmed by X-ray digital radiography. The results obtained clearly show the potential of using the laser-ultrasonic technology for the automated inspection of hybrid laser-arc welds.
10:50 AM

**Weld Quality Inspection Using Laser-EMAT Ultrasonic System and C-scan Method**

---Lei Yang and I. Charles Ume, Georgia Institute of Technology, G. W. Woodruff School of Mechanical Engineering, 813 Ferst Drive NW, Atlanta, GA 30332-0405

---Laser/EMAT ultrasonic technique has attracted more and more interests in weld quality inspection because of its non-destructive and non-contact characteristics. When ultrasonic techniques are used to detect welds joining relative thin plates, the dominant ultrasonic waves present in the plates are Lamb waves, which propagate all through the thickness. Traditional Time of Flight (ToF) method loses its power. The broadband nature of laser excited ultrasound plus dispersive and multi-modal characteristic of Lamb waves make the EMAT acquired signals very complicated in this situation. Challenge rises in interpreting the received signals and establishing relationship between signal feature and weld quality. In this paper, the laser/EMAT ultrasonic technique was applied in a C-scan manner to record full wave propagation field over an area close to the weld. Then the effect of weld defect on the propagation field of Lamb waves was studied visually by watching a movie resulted from the recorded signals. This method was proved to be effective to detect the presence of hidden defect in the weld. Discrete wavelet transform (DWT) was applied to characterize the acquired ultrasonic signals and ideal band-pass filter was used to isolate wave components most sensitive to the weld defect. Different interactions with the weld defect were observed for different wave components. Thus this C-Scan method, combined with DWT and ideal band-pass filter, proved to be an effective methodology to experimentally study interactions of various laser excited Lamb Wave components with weld defect. In this work, the method was demonstrated by inspecting a hidden local incomplete penetration in weld. In fact, this method offered promise in studying Lamb Wave interactions with any type of structural inconsistency. This work also proposed an ideal filter based method to effectively reduce the total experimental time.

11:10 AM

**Fundamental Study of Microelectronic Chip Response Under Laser Ultrasonic-Interferometric Inspection Using C-Scan Method**

---Lei Yang, Jie Gong, and I. Charles Ume, Georgia Institute of Technology, G. W. Woodruff School of Mechanical Engineering, 813 Ferst Drive NW, Atlanta, GA 30332-0405

---In modern surface mount packaging, such as flip chips, chip scale packages, and ball grid arrays (BGA), chips are attached to the substrates/printed wiring board (PWB) using solder bumps. The quality of solder bumps between the chips and the substrate/board is difficult to inspect. Laser ultrasonic-interferometric technique was proved to be a promising approach for solder bump inspection because of its noncontact and nondestructive characteristics. Different indicators extracted from received signals have been used to predict the potential defects, such as correlation coefficient, error ratio, frequency shifting, etc. However, fundamental understanding of the chip behavior under laser ultrasonic inspection is still missing. Plus, it is found that the received signals are chip dependent. Both challenges impede the interpretation of signals. In this paper, a C-scan method was proposed to study the underlying phenomenon during laser ultrasonic inspection. The full chip was inspected. The response of the chip under laser excitation was visualized in a movie resulted from the recorded signals. By characterizing signals using discrete wavelet transform (DWT), both ultrasonic wave propagation and vibration were observed. Separation of them was successfully achieved using ideal band-pass filter and visualized in movies, too. The ultrasonic wave types were identified and their respective speeds were measured by applying 2-D FFT. The C-scan method, combined with different digital signal processing techniques, was proved to be a very effective methodology to learn the behavior of chips under laser excitation. This general procedure can be applied to any unknown chip before inspection. A wealth of information can be provided by this learning procedure, which greatly benefits the interpretation of inspection signals.
Full-Field Mechanical Property Reconstruction System Based on Quantitative Laser Ultrasound Visualization System
---Chia Han Wu and Che-Hua Yang, National Taipei University of Technology, Institute of Mechanical and Electrical Engineering, No. 1, Sec. 3, Zhongxiao E. Rd. Da’an District, Taipei City 106, China (ROC)

---This research employs a quantitative laser ultrasound visualization system (QLUVS) for the reconstruction of full-field mechanical properties. The QLUVS uses a pulsed laser to generate acoustic waves which can be detected either with optical probe or piezoelectric transducer. With dual axis gyro-scanning, two-dimensional full-field waveform data are collected in a fast way. Existing reports based laser ultrasound visualization is either primarily for waveform visualization or dealing with full-field mapping of mechanical properties with limited accuracy and very low speed. In this paper, innovated fast and accurate algorithms are integrated with the QLUVS for full-field mechanical property mapping with high accuracy and relatively satisfactory speed. This study demonstrates the QLUVS in two aspects: first for qualitative wavefield visualization and second for quantitative reconstruction of mechanical properties under the aid of newly developed algorithms. The developed technique is applied to some useful cases, including property mapping of plates with defects, mapping of temperature distribution and mapping of inhomogeneous properties in thermal sprayed samples.

Damage Detection by Measuring Laser-Based Mechanical Impedance
---Hyeonseok Lee and Hoon Sohn, Korea Advanced Institute of Science and Technology, Department of Civil and Environmental Engineering, Yuseong-gu, Daejeon, Korea

---This study proposes a measurement technique for mechanical impedance using noncontact laser ultrasound. The measurement of mechanical impedance has been of great interest in nondestructive testing (NDT) and structural health monitoring (SHM) since the mechanical impedance is sensitive even to small structural defects. Conventionally, the mechanical impedance is indirectly measured via the electromechanical coupling of the target structure with a contact-type piezoelectric transducer. However, these surface-mounted transducers are susceptible to electromagnetic inference, long term deterioration of the bonding layer, and not applicable to high temperature environments. This study aims to tackle the limitations of the conventional EMI measurement technique by proposing a laser-based mechanical impedance (LMI) measurement technique. The LMI response is generated by shooting a pulse laser beam to a target structure and measuring the out-of-plane velocity using a laser vibrometer. The LMI response is simulated through a thermo-mechanical finite element analysis, and compared with the mechanical impedance. The applicability of the LMI technique to damage detection is experimentally verified using a pipe specimen under high temperature environments.
Session 35
SESSION 35
THERMOGRAPHY AND THERMOSONICS I
Xiaoyan Han and Stephen D. Holland, Co-Chairpersons
Key Ballroom 12

8:30 AM  A Short History of Thermal NDE
           ---Lawrence D. Favro, Wayne State University, Department of Physics, 666 W. Hancock, Detroit, MI 48202

9:10 AM  Computational Improvement of Thermographic Characterization of Flaws in Graphite Polymer Composites
           ---William P. Winfree, Patricia A. Howell, and Joseph N. Zalameda, NASA Langley Research Center, Hampton, VA 23681

9:30 AM  A Quantitative Comparison of the Defect Detection Capabilities of Long and Short Pulse Stimulated Thermographic NDE Techniques
           ---Darryl P. Almond and Simon G. Pickering, University of Bath, Department of Mechanical Engineering, Bath, United Kingdom

9:50 AM  Influence of the Acquisition Parameters on the Performance of Laser-Thermography for Crack Detection in Metallic Components
           ---P. Myrach, M. Ziegler, C. Maierhofer, and M. Kreutzbruck, Federal Institute for Materials Research and Testing, Division 8.4 Acoustical and Electromagnetic Methods, Berlin, Germany

10:10 AM  Break

10:30 AM  Thermographic Investigation of Damage in Ceramic Matrix Composites
           ---Z. Ouyang1, I. Smyth1, G. Ojard2, U. Santhosh3, and Y. Gowayed4, 1Pratt & Whitney, East Hartford, CT 06108; 2United Technologies Research Center, East Hartford, CT 06108; 3Structural Analyticas, Inc., Carlsbad, CA; 4Auburn University, Auburn, AL 36849

10:50 AM  Identification of Heat Source Distribution in Vibrothermography
           ---Jyani S. Vaddi and Stephen D. Holland, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

11:10 AM  Sonic Infrared Imaging Assessment on Impact Damages in Composite Structures
           ---X. Han, M. C. Jackson, J. M. Ar-Rasheed, D. Zhang, and A. Lubowicki, Wayne State University, Electrical and Computer Engineering, Detroit, MI 48202; L. Favro, Wayne State University, Physics Department, Detroit, MI 48202; G. Newaz, Wayne State University, Mechanical Engineering, Detroit, MI 48202

11:30 AM  Adjourn Session

12:10 PM  Lunch
8:30 AM

**A Short History of Thermal NDE**
---Lawrence D. Favro, Wayne State University, Department of Physics, 666 W. Hancock, Detroit, MI 48202

---Thermal NDE has come a long way since the early days of laser heating and detection, scanned single infrared detectors, photoacoustic cells, etc. Modern thermal NDE methods typically use infrared cameras, many of which are ITAR-controlled, and some of which cost more than $100k. These cameras can be used either as passive thermal detectors, or as part of an active system in which the target is subjected to some external stimulation. We will discuss the evolution of these methods, and the physical mechanisms responsible for their ability to detect flaws in materials.

9:10 AM

**Computational Improvement of Thermographic Characterization of Flaws in Graphite Polymer Composites**
---William P. Winfree, Patricia A. Howell, and Joseph N. Zalameda, NASA Langley Research Center, Hampton, VA 23681

---Flaw detection and characterization with thermographic techniques in graphite polymer composites are often limited by localized variations in the thermographic response. Variations in properties such as acceptable porosity, fiber volume content and surface polymer thickness result in changes in the thermal response that in general cause significant variations in the initial thermal response. These result in a “noise” floor that increases the difficulty of detecting and characterizing deeper flaws. A method is presented for computationally removing a significant amount of the “noise” from near surface porosity by diffusing the early time response, then subtracting it from subsequent responses. Simulations of the thermal response of a composites are utilized in defining the limitations of the technique. This method for reducing the data is shown to give a considerable improvement characterizing both the size and depth of damage. Examples are shown for data acquired on specimens with fabricated delaminations and impact damage.
9:30 AM

A Quantitative Comparison of the Defect Detection Capabilities of Long and Short Pulse Stimulated Thermographic NDE Techniques.

---Darryl P. Almond and Simon G. Pickering, University of Bath, Department of Mechanical Engineering, Bath, United Kingdom

---Thermographic inspection employing short pulse excitation by an optical flash lamp is the most widely used thermographic NDE (TNDE) technique. Its defect detection capabilities have been established by numerous experimental and theoretical/numerical modelling investigations. It is, however, well known that long pulse excitation, achieved by inexpensive lamps or hot air blowers, can produce similar results to the short pulse technique in some applications. Surprisingly, there has been little detailed analysis of long pulse TNDE. An analytical analysis of long pulse TNDE will be presented that is an extension of a recent analytical analysis of short pulse TNDE. It will be shown that long pulse TNDE has a similar defect detection performance to the short pulse technique where the latter’s contrast peaks occur at times similar to the long pulse excitation time, i.e. seconds. Experimental comparisons of the two techniques’ defect detection performances across a range of materials will be presented. These results show the long pulse technique to compare favorably for certain applications, in agreement with the analytical analysis and numerical modelling. The role of long pulse TNDE as a simple and inexpensive alternative to short pulse TNDE will be discussed.

9:50 AM

Influence of the Acquisition Parameters on the Performance of Laser-Thermography for Crack Detection in Metallic Components

---P. Myrach, M. Ziegler, C. Maierhofer, and M. Kreutzbruck, Federal Institute for Materials Research and Testing, Division 8.4 Acoustical and Electromagnetic Methods, Berlin, Germany

---We present results of a systematic study on the performance of laser-thermography for the detection of surface cracks in metallic components. Scanning a metallic surface with laser causes local heating that is mapped simultaneously by an IR-camera and allows identifying cracks with sub-µm openings. The detectability, however, depends on a number of acquisition parameters (e.g., scanning speed, laser power, IR-camera resolution) that typically relate on each other. We investigated these dependencies and concluded rules to provide a first, simple estimation for the performance of the method for a number of specific testing problems. Most importantly, the crack-sensitivity is given by a particular combination for the acquisition parameter values. As a result, this sensitivity is adaptable within wide ranges allowing to detect cracks with openings ranging from 200 to 0.1µm at testing speeds of 100 to 0.05 cm²/s. By examining artificial as well as fatigue cracks, we demonstrate that the method can be even applied to shiny surfaces with no need of pretreatments, which makes it an entirely contactless, remote and automatable NDE technique. A comparison with magnetic particle and penetration testing shows that laser-thermography has the potential to become a strong competitor to conventional surface inspection methods in the future.
10:30 AM

**Thermographic Investigation of Damage in Ceramic Matrix Composites**
---Z. Ouyang\(^1\), I. Smyth\(^1\), G. Ojard\(^2\), U. Santhosh\(^3\), and Y. Gowayed\(^4\), \(^1\)Pratt & Whitney, East Hartford, CT; \(^2\)United Technologies Research Center, East Harford, CT; \(^3\)Structural Analyticas, Inc., Carlsbad, CA; \(^4\)Auburn University, Auburn, AL

---As the engineering application of ceramic matrix composites progresses, a key part of the insertion effort is non-destructive characterization. While most non-destructive evaluation is focused on the initial state based on the presence of defective conditions, the evolution of damage or change with exposure is relevant to composite lifing. Thermography offers the benefit of fast inspection times with the option of finding defects or material changes based on the diffusivity of the material. A series of ceramic matrix composite samples were inspected by thermography. Some samples were in the as-fabricated condition while others were exposed to different conditions of temperature, stress and time. The results of this testing along with mechanical testing and analysis will be presented and trends discussed.

10:50 AM

**Identification of Heat Source Distribution in Vibrothermography**
---Jyansi S. Vaddi and Stephen D. Holland, Iowa State University, Center for Nondestructive Evaluation, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

---Vibrothermography is a nondestructive evaluation method for finding cracks in materials using vibration induced heat generation. The specimen is subjected to high energy resonant vibrations and the heat generated at the crack is imaged with an infrared camera. Because of the uneven crack face morphology and closure stresses, the heat generation is not uniform across the crack length. Additionally, thermal diffusion in solids blurs the image and makes the heat source identification even harder. Therefore, the quantification of ‘crack heating’ in vibrothermography is highly subjective. Some researchers define it as a measure of temperature rise, some use the infrared camera reading in arbitrary units to define it and some use the total power dissipated at the crack. In this presentation, we propose an algorithm that hypothesizes the crack as a series of arbitrarily located line sources and estimates the locations and intensities of each of these sources. We calculate the radius and amplitude at every point in the heated region using a curve fitting procedure and feed this as the input to our algorithm, which then estimates the source locations and intensities. The algorithm uses non-linear least squares optimization to minimize the mean square error between estimated and measured temperature distribution. The resulting source distribution can be used to estimate the thermal power dissipated in heating the crack.---This material is based on work supported by the Air Force Research Laboratory under Contract #FA8650-10-D-5210, Task Order #023, and performed at Iowa State University.
Sonic Infrared Imaging Assessment on Impact Damages in Composite Structures
---X. Han, M. C. Jackson, J. M. Ar-Rasheed, D. Zhang, and A. Lubowicki, Wayne State University, Electrical and Computer Engineering, Detroit, MI 48202; L. Favro, Wayne State University, Physics Department, Detroit, MI 48202; G. Newaz, Wayne State University, Mechanical Engineering, Detroit, MI 48202

---Sonic IR imaging combines ultrasound excitation of a short pulse (typically a fraction of a second) and infrared imaging. It has been shown its advantages as a fast, wide-area NDE technology to detect defects such as cracks, delamination, and disbonds in materials and structures. WSU researchers have been studying impact damages in composite structures with Sonic Infrared Imaging. Damage in laminated composites from external loads in service can occur between different plies depending on the external loading. Composite ply configuration and structure also play important roles in the degree of impact damage. In this paper, we will present our study on composite panels containing structures such as doublers and stiffeners, which were subjected to impacts from varying energy projectiles.---This work was sponsored by the Federal Aviation Administration William J. Hughes Technical Center under Contract Number DTFACT-08-C-00043 with Agency Contract Number 437-65061, and in part by Wayne State University. The impact samples were provided by Robert Barry from Bell Helicopter.
Session 36
NDE Sensors and Systems

Progress in Quantitative GPR Development at CNDE
---David Eisenmann, Frank Margetan, Chien-Ping T. Chiou, Ron Roberts, and Scott Wendt, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Rd., Ames, IA 50011

Complex Surface Ultrasonic Detection Technology Based on Joint Robot
---Juan Hao, Chunquang Xu, and Lan Zhang, Beijing Institute of Technology, School of Mechanical Vehicle, No. 5 Zhongguancun South Street, Haidian District, Beijing, China

Evaluation of Hydrogen Embrittlement of API X70 Pipeline Steel by Electrical Resistivity
---Young-Hyun Nam, Un-Bong Baek, Jeon-Hong Kang, and Seung-Hoon Nahm, Korea Research Institute of Standards and Science, Center for Material Measurement, 267 Gajeongro, Yuseong, Daejeon 305-340, Republic of Korea

Investigations Into the Negative Measurement Sensitivity Values of Planar Capacitive Imaging Probes
---Xiaokang Yin, Guoming Chen, and Wei Li, China University of Petroleum, Centre for Offshore Engineering and Safety Technology, Qingdao, Shandong, People’s Republic of China, 266580; David A. Hutchins, School of Engineering, University of Warwick, Coventry CV4 7AL, United Kingdom

Detecting the Defect in the Cold-Rolled Steel Strip Using Linear Hall Array Sensor Based on MFL
---Sang-Woo Choi, JuSeung Lee, and Ho-Moon Bae, POSCO, System Engineering Research Group, Pohang, Gyeongsangbuk-do, Korea; SeHo Choi, POSCO, Process Engineering Research Group, Pohang, Gyeongsangbuk-do, Korea

Synergistic Smart Fuel for Microstructure Mediated Measurements
---James A. Smith and Dale K. Kotter, Idaho National Laboratory, Fuel Performance & Design, Idaho Falls, ID 83415-6188; Steven L. Garrett, Penn State, Graduate Program in Acoustics and Applied Research Laboratory, State College, PA 16802

THz Methods for Corrosion Detection in Steel-Reinforced Concrete

New Customizable Phased Array UT Instrument Opens Door for Furthers Research and Better Industrial Implementation
---Gavin Dao, Advanced OEM Solutions, 8044 Montgomery Road 700, Cincinnati, OH 45236

Modular Instrument for Eddy Current Testing with Magnetic Field Sensors
---Nikolaos Poulakis, Technological Educational Institute of Western Macedonia, Department of Electrical Engineering, Kozani, Greece; Charitini Voulgaraki and Theodoros Theodoulidis, University of Western Macedonia, Department of Mechanical Engineering, Kozani, Greece
Fully Contactless Ultrasonic System to Characterize Concrete Structures with a Guided Wave Approach
---Suyun Ham and John S. Popovics, The University of Illinois at Urbana-Champaign, Civil and Environmental Engineering, Urbana, IL 61801-2352

Alternating Current Potential Drop Crack Measurements Using Four Point Probes
---Y. Ji and Y. Lu, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

Design of Encircling Send-Receive Type Pulsed Eddy Current Probe
---Young-Kil Shin, Kunsan National University, Department of EE, Kunsan, Chonbuk, South Korea

Developing and Testing of a Novel Portable ACFM Intelligent Instrument
---W. Li, G. Chen, C. Zhang, X. Yin, and T. Liu, China University of Petroleum, Centre for Offshore Engineering and Safety Technology, Qingdao, Shandong, China

Integration of Microwave and Thermographic NDT Methods for Corrosion Detection
---Kristen M. Donnell and M. T. Ghasr, Missouri University of Science and Technology, Electrical and Computer Engineering Department, Applied Microwave Nondestructive Testing Laboratory (amnl), 216 Emerson Electric Company Hall, 301 W. 16th Street, Rolla, MO 65409-6524; Edward Kinzel, Missouri University of Science and Technology Mechanical and Aerospace Engineering Department, Rolla, MO 65409-6524

Review of Progress in MPI
---Dave Eisenmann, Darrel Enyart, and Chester Lo, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

Non-Destructive Evaluation of Adhesive in Composite Material Tube by 3D Microcomputed Tomography
---I. Lima, D. de Oliveira, and R. T. Lopes, Nuclear Instrumentation Laboratory, PEN/COPPE/UFRJ, P. O. Box 68.509, Zip Code: 21941-972 – Rio de Janeiro, Brazil; D. de Oliveira, Physics Institute, UERJ – Rio de Janeiro - Brazil

Reinforced Concrete Inspection
---I. Lima, A. Machado, and R. T. Lopes, Federal University of Rio de Janeiro, Nuclear Engineering Program, Rio de Janeiro, Brazil

Handheld System for Non-Destructive Temperature Profiling of Hot Surfaces for Critical Components
---Christopher C. Pilgrim, Joerg P. Feist, Pierre Y. Sollazzo, Stephane Berthier, and Shilpi K. Biswas, Imperial College London, Sensor Coating Systems, Imperial Incubator, London, United Kingdom

Ultrasonics

Welding for Testability: An Approach Aimed to Improve the Ultrasonic Testing of Thick-Walled Austenitic and Dissimilar Welds
---Sabine Wagner and Sandra Dugan, Materialprüfungsanstalt, Universität Stuttgart, ZFP in Anlagen und Maschinenbau, Stuttgart, Germany; Martin Barth, Frank Schubert, and Bernd Köhler, Fraunhofer IZFP, Dresden Branch, Dresden, Germany

A Coupled Finite Element Model for Meander Coil Electromagnetic Acoustic Transducer-Receiver Systems
---Zhichao Li, Weiting Zhai, Pengzhan Li, Riliang Su, and Guofu Zhai, Harbin Institute of Technology, School of Electrical Engineering and Automation, Harbin, China
Nonlinear Acoustics Experimental Characterization of Microstructure Evolution in Alloy 617
---Xiaochu Yao, Yang Liu, and Clifford J. Lissenden, The Pennsylvania State University, Department of Engineering Science and Mechanics, University Park, PA 16802

Study of Aging Effects in a Ti-6AL-4V Alloy with Widmanstätten and Equiaxed Microstructures by Non-Destructive Means
---H. Carreon, A. Ruiz, and B. Santoveña, Universidad Michoacana, Instituto de Investigaciones Metalurgicas, Morelia, Michoacan, Mexico

Generation of Low-Frequency Components in Ultrasonic Waves Penetrating the Interface Between Contacting Solids
---Hirotaka Tanaka, Tatsuhiro Okamoto, Kenji Kurihara, and Toshihiko Sugiura, Keio University, Department of Mechanical Engineering, Yokohama, Kanagawa, Japan

Signal Processing Techniques for Recovering Input Waveforms in Dispersive Lamb Wave Propagation
---Hyunjo Jeong, Wonkwang University, Division of Mechanical and Automotive Engineering, Iksan, Jonbuk 570-749, Republic of Korea; Young-Sang Joo, Hoe Woong Kim, and Jong-Bum Kim, Korea Atomic Energy Research Institute, Fast Reactor Development, 150-1 Dukjin-Dong, Yuseong, Daejeon, Republic of Korea

Simulation and Analysis of the Corrugated Pipe Grouting Defects in Ultrasonic Testing
---Han Qingbang, Changzhou Key Laboratory of Sensor Networks and Environmental Sensing, Hohai University, Changzhou 213022, China; Sun Hong, Changzhou Green Bamboo Middle School, Changzhou 213022, China

Feasibility Study on Ultrasonic Lateral Displacement Measurement for Structural Health Monitoring
---Iwao Matsuya, Fumiya Matsumoto, and Ikuo Ihara, Nagaoka University of Technology, Department of Mechanical Engineering, Nagaoka, Niigata, Japan

Ultrasonic Method for Evaluating Residual Stress Distributed within a Welded Metal Plate
---S. H. Kim, D. R. Kwak, and I. K. Park, Seoul National University of Science and Technology, Department of Mechanical Engineering, Seoul, Korea; J. Todd and C. Miyasaka, The Pennsylvania State University, Department of Engineering Science and Mechanics, University Park, PA 16802; S. Yoshida, Southeastern Louisiana University, Department of Chemistry and Physics, Hammond, LA 70402; T. Sasaki, Niigata University, Department of Mechanical Engineering, Niigata, Japan; Y. H. Park, Sunchon University, Department of Polymer Engineering, Sunchon, Korea

The Measurement of Axial Stress in a Tightened Bolt by the Combination of Shear Wave and Longitudinal Wave
---Chunguang Xu, Xiao Li, Beijing Institute of Technology, Zhongguancun South Street #5, Haidian District, Peking 100081, China

Virtual Ultrasound Sources for Inspecting Nuclear Components of Coarse-Grained Structure
---Jose Brizuela, Consejo Nacional de Investigaciones Científicas y Técnicas, Ciudad Autónoma de Buenos Aires, Argentina; Pablo Katchadjian, Carlos Desimore, and Alejandro D. Garcia, Comisión Nacional de Energía Atómica, Departamento de Ensayos No Destructivos y Estructurales, San Martín, Pcia. de Buenos Aires, Argentina

A Comparison Between Beamforming and Super Resolution Ultrasonic Array Imaging Algorithms for NDE
---Chengguang Fan, National University of Defense Technology, College of Mechatronic Engineering and Automation, Changsha, 410073, Hunan, PR China; Chengguang Fan and Bruce W. Drinkwater, University of Bristol, Department of Mechanical Engineering, Bristol, BS8 1TR, United Kingdom
The Effect of Fatigue Cracking on Elastic Moduli and Coda Waves in Composites
---Richard Livings and Vinay Dayal, Iowa State University, Composite Design & Analysis Center, 2328 Howe Hall, Ames, IA 50011

Evaluation of Thermally Degraded 2205 Duplex Stainless Steel Using Guided Ultrasonic Waves
---Alberto Ruiz and Hector Carreon, Universidad Michoacana de San Nicolás de Hidalgo, Instituto de Investigaciones Metalúrgicas, Morelia, Michoacan, México

A Web-Based Tutorial for Ultrasonic Attenuation Measurements
---Frank J. Margetan, Dan Barnard, David Orman, Alex Feygin, and Brittney Pavel, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

Damage Evaluation for CFRP Components Using Acoustic Emission Monitoring
---Russell Austin and David Forsyth, Texas Research Institute, 9225 Bee Cave Road, Austin, TX 78733; Jianguo (Peter) Yu, Mohamed ElBatanouny, and Paul Ziehl, University of South Carolina
Progress in Quantitative GPR Development at CNDE
---David Eisenmann, Frank Margetan, Chien-Ping T. Chiou, Ron Roberts, and Scott Wendt, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

---Ground penetrating radar (GPR) is routinely used to locate and map buried objects. In the vast majority of GPR applications the emphasis is on producing images for simple visual interpretation. However, much information is available in GPR signals beyond the rescaled amplitudes that are typically used to make B-scan and C-scan images. At the Center for Nondestructive Evaluation (CNDE) efforts are underway to develop a more quantitative approach to GPR inspections. The eventual goal is to develop simulation tools that can be used to assess the usefulness of GPR for a given inspection scenario, to optimize inspection choices, and to determine inspection reliability. In doing this we are proceeding in analogy to ultrasonic inspection where measurement models and simulation tools are routinely used. There are three thrusts to the GPR research effort: (1) Familiarization with the operation of the specific commercial GPR instrument and antennas at hand, and the development of software tools to read and process raw data. (2) Developing and testing pulse/echo and pitch/catch methods to measure material properties which influence GPR inspections, such as electromagnetic wave speed and attenuation. (3) Developing forward models of the GPR inspection process capable of predicting time-domain responses from buried objects. This presentation reviews progress on each of these fronts.---This work was supported by the Institute for Physical Research and Technology at Iowa State University.

Complex Surface Ultrasonic Detection Technology Based on Joint Robot
---Juan Hao, Chunchuang Xu, and Lan Zhang, Beijing Institute of Technology, School of Mechanical Vehicle, No. 5 Zhongguancun South Street, Haidian District, Beijing, China

---Some components have complex surface such as an airplane wing and the shell of pressure vessel etc. The quality of these components determines the reliability and safety of related equipment. Ultrasonic nondestructive testing is one of the main methods used for the detection of material defects at present. In order to improve detection precision, the acoustic axis of the ultrasonic transducer should be consistent with the normal direction of the measured points. In the actual detecting process, with the help of joint robots, automatic ultrasonic scan along the component surface normal direction can be realized because the joint robots are composed by multiple (common for 6) joints which are connected in series, so the gripper can reach arbitrary pose in its Reachable workspace. But the motion coordinate of the robots may not be identical to the pose description of the detected components, if this is true, coordinate transformation is needed between them. In addition, in order to express the defects in the components effectively, accurately and truly, the motion trajectory of the robots should be planned beforehand. Meanwhile, the robot position and the signal of the ultrasonic transducer should be synchronized.
**NDE Sensors and Systems**

**Evaluation of Hydrogen Embrittlement of API X70 Pipeline Steel by Electrical Resistivity**  
---Young-Hyun Nam, Un-Bong Baek, Jeon-Hong Kang, and Seung-Hoon Nahm, Korea Research Institute of Standards and Science, Center for Material Measurement, 267 Gajeongro, Yuseong, Daejeon 305-340, Republic of Korea

---The objective of this study is to investigate the possibility of the application of electrical resistivity method to estimate the hydrogen embrittlement of API X70 pipeline steel for natural gas transportation pipelines, and to analyze the change in electrical resistivity with hydrogen exposure time and hydrogen pressure. The electrical resistivity measuring system was developed to evaluate material properties in high-pressure gaseous environments. The hydrogen gas of 99.999% purity was charged into the measuring system. The charging pressure was controlled from 0 to 16 MPa. Plane specimens of 35×10×6 mm (length × width × thickness) were machined from API X70 steel. The electrical resistivity of the specimens was measured by DC two-point probe method at 14 ℃. The home-made probe and Burster 2304 were utilized for the resistance measurement. When the hydrogen pressure was changed from 0 to 15 MPa, the mean values of electrical resistivity had a tendency to decrease with the increase of hydrogen pressure. In the case of hydrogen exposure time, no significant difference in electrical resistivity was observed in this material with varying time (0~168 hr.).

**NDE Sensors and Systems**

**Investigations Into the Negative Measurement Sensitivity Values of Planar Capacitive Imaging Probes**  
---Xiaokang Yin, Guoming Chen, and Wei Li, China University of Petroleum, Centre for Offshore Engineering and Safety Technology, Qingdao, Shandong, People’s Republic of China, 266580; David A. Hutchins, School of Engineering, University of Warwick, Coventry CV4 7AL, United Kingdom

---The measurement sensitivity distribution of planar capacitive imaging (CI) probes describes how effectively each region in the sensing area is contributing to the measured charge signal on the sensing electrode. It can be used to determine the imaging ability of a CI probe. It is found in previous work that, there are regions in the sensing area where the change of the charge output and the change of targeting physical parameter are of opposite trends. This opposite correlation implies that the measurement sensitivity values in such regions are negative. In this work, the cause of negative sensitivity is discussed. Experiments are also designed and performed so as to verify the existence of negative sensitivity and study the factors that may affect the negative sensitivity distributions.
Detecting the Defect in the Cold-Rolled Steel Strip Using Linear Hall Array Sensor Based on MFL
---Sang-Woo Choi, JuSeung Lee, and Ho-Moon Bae, POSCO, System Engineering Research Group, Pohang, Gyeongsangbuk-do, Korea; SeHo Choi, POSCO, Process Engineering Research Group, Pohang, Gyeongsangbuk-do, Korea

---Internal defects which were created during the steel manufacturing process could cause the failure of final products or parts. The ultrasonic testing and the magnetic flux leakage testing were used to applied for on-line inspection for detecting the internal defect in the steel strip. Prospective inspection technique was tested to detect the internal defect in the cold-rolled steel strip in the steel works. Linear Hall elements array sensors with high-speed signal processors were employed to show real-time magnetic flux leakage images like the optical line camera. Most of defects were elongated along the rolling direction during hot rolling and cold rolling process. Distortion of the magnetic field direction was invited to enhance the signal of major linear defects, aligned into the rolling direction. Defect images were obtained to detect the actual defects from the field test using pilot system which was installed in the re-coiling line where the final inspection is carried out before the shipment.

Synergistic Smart Fuel for Microstructure Mediated Measurements
---James A. Smith and Dale K. Kotter, Idaho National Laboratory, Fuel Performance & Design, Idaho Falls, ID 83415-6188; Steven L. Garrett, Penn State, Graduate Program in Acoustics and Applied Research Laboratory, State College, PA 16802

---Advancing the Nuclear Fuel Cycle and Next Generation Nuclear Power Plants requires enhancing our basic understanding of fuel and materials behavior under irradiation. The two most significant issues limiting the effectiveness and lifespan of the fuel are the loss of thermal conductivity of the fuel and the mechanical strength of both fuel and cladding. The core of a nuclear reactor presents an extremely harsh and challenging environment for both sensors and telemetry due to elevated temperatures and large fluxes of energetic and ionizing particles from radioactive decay processes. The majority of measurements are made in reactors using “radiation hardened” sensors and materials. A different approach has been pursued in this research that exploits high temperatures and materials that are robust with respect to ionizing radiation. This synergistically designed thermoacoustic sensor will be self-powered, wireless, and provide telemetry. The novel sensor will be able to provide reactor process information even if external electrical power and communication are unavailable. In addition, the form-factor for the sensor is identical to the existing fuel rods within reactors and contains no moving parts. Results from initial proof of concept experiments designed to characterize porosity, surface properties and monitor gas composition will be discussed.
THURSDAY, SESSION 36

NDE Sensors and Systems

THz Methods for Corrosion Detection in Steel-Reinforced Concrete
---Shin G. Chou, Paul E. Stutzman, Shuangzhen Wang, Edward J. Garboczi, David F. Plusquellic, Robert D. McMichael, Mark D. Stiles, Virgil Provenzano, Nicos S. Martys, and Ahmed Hassan, National Institute of Standards and Technology, Gaithersburg, MD 20899; Jack Surek, Michael D. Janezic, Sung Kim, and James Baker-Jarvis, National Institute of Standards and Technology, Boulder, CO 80301

---THz methods are used for the characterization and detection of corrosion products in steel-reinforced concrete. Results of our recent study of the antiferromagnetic resonance (AFMR) in \( \alpha \)-hematite and its strong temperature dependence will be reviewed. A new portable chirped pulse instrument has been designed to target the AFMR transition (line width < 2 GHz) over a temperature range from 0 °C to 8 °C, which corresponds in \( \alpha \)-hematite to a spectral region from 115 GHz to 128 GHz and was chosen to maximize the signals for penetration through concrete. The chirped pulse system is demonstrated to scan a range of 6 GHz at a repetition rate of 1 MHz. Using a prototype system that generates 5 mW, the absorption sensitivity for AFMR detection in a 1 sec integration time is demonstrated to exceed 100:1 through 1 cm of concrete. Preliminary results will be presented for a new 100 mW system, as well as improvements in the broadband THz system (0.02 THz to 3 THz) used for characterization of other AFMR components in steel corrosion products.

NDE Sensors and Systems

New Customizable Phased Array UT Instrument Opens Door for Forthering Research and Better Industrial Implementation
---Gavin Dao, Advanced OEM Solutions, 8044 Montgomery Road 700, Cincinnati, OH 45236

---Phased array UT as an inspection technique in itself continues to gain wide acceptance. However, there is much room for improvement in terms of implementation of phased array (PA) technology for every unique NDT application across several industries (e.g., oil and petroleum, nuclear and power generation, steel manufacturing, etc.). Having full control of the phased array instrument and customizing a software solution is needed for more seamless and efficient inspections, from setting the PA parameters, collecting data, reporting to the final analysis. NDT Researchers and Academics also need a flexible and open platform to be able to control various aspects of the phased array process. A high performance instrument with advanced PA features, faster data rates, a smaller form factor, and capability to adapt to specific applications will be discussed.
NDE Sensors and Systems

Modular Instrument for Eddy Current Testing with Magnetic Field Sensors
---Nikolaos Poulakis, Technological Educational Institute of Western Macedonia, Department of Electrical Engineering, Kozani, Greece; Charitini Voulgaraki and Theodoros Theodoulidis, University of Western Macedonia, Department of Mechanical Engineering, Kozani, Greece

---Standard and commercially available eddy current testing instruments are based on a Wheatstone Bridge for measuring the output voltage of induction coil probes. Although this technique is precise and capable of setting up portable instruments, it lacks in sensitivity at lower frequencies due to the weakening of the induction coils' voltage output. In this work, we present an alternative portable eddy current instrument, based on the lock-in amplifier technique, able to adapt to every common magnetic field sensor like Hall, GMR, Fluxgate and even SQUID. The main advantages of the proposed instrument, besides portability, are modularity, flexibility, rigidity, and user configurability thanks to its open code programming. In terms of hardware, the instrument is based on a configurable PXI platform (PCI eXtensions for Instrumentation) comprising of an ac current source module to drive the excitation coil, a DMM module and a data acquisition card. The functionality of the modular instrument is tested on aluminum samples with surface and subsurface notches using Hall and SQUID sensors and its performance is compared to a standard commercial eddy current instrument.

NDE Sensors and Systems

Fully Contactless Ultrasonic System to Characterize Concrete Structures with a Guided Wave Approach
---Suyun Ham and John S. Popovics, The University of Illinois at Urbana-Champaign, Civil and Environmental Engineering, Urbana, IL 61801-2352

---Ultrasonic techniques provide an effective non-destructive evaluation (NDE) method to monitor concrete structures, but the need to perform rapid and accurate interpretation assessment requires evaluation of hundreds, or even thousands, of measurement data. Use of a fully contactless ultrasonic system can save time and labor through rapid implementation, and can enable automated and controlled data acquisition, for example through robotic scanning. Here we present results using a fully contactless ultrasonic system. This paper describes our efforts to develop a contactless ultrasonic guided wave NDE approach to detect and characterize delamination defects in concrete structures. The developed contactless MEMS sensor, controlled scanning system and employed signal processing scheme are reviewed. Then the guided wave interpretation approach is described. The presence of delamination is interpreted by guided plate wave (Lamb wave) behavior, where change in specific Lamb mode phase velocity and attenuation, is monitored. Experimental data collected from a concrete sample with simulated delamination defects are presented, where detection of delamination is illustrated. Finally the vision for implementation in active bridge structures is discussed.
NDE Sensors and Systems

Alternating Current Potential Drop Crack Measurements Using Four Point Probes
---Y. Ji and Y.Lu, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

---An important application of alternating current potential drop (ACPD) four point probe measurements is to determine crack depths. This is usually done using direct current or alternating current field measurement. The latter measurements are taken at a single frequency and requires moderate or large crack. In this article, multi-frequency potential drop measurements are performed to adapt ACPD to deal with small cracks, of the order of 1 mm, in low conductivity alloys. A robust and accurate crack measurement requires that the pin separation needs to be small and inductive pick-up effect needs to be controlled. Lock-in amplifier and transconductance amplifier needs to be able to generate driving current up to several megahertz. Technical challenges and proposed solutions are discussed in this paper. Model that predicts the measured potential drop in terms of phasor are used to compare the measured data with theoretical prediction.---This work was supported by the NSF Industry/University Cooperative Research Program of the Center for Nondestructive Evaluation at Iowa State University.

Design of Encircling Send-Receive Type Pulsed Eddy Current Probe
---Young-Kil Shin, Kunsan National University, Department of EE, Kunsan, Chonbuk, South Korea

---In order to inspect tubes or rods that are difficult to access, an encircling send-receive type pulsed eddy current (PEC) probe, which will be fixed outside the tubes, is designed using a numerical analysis technique. At first, PEC signals are calculated and their signal characteristics are investigated while the distance between exciter coil and sensor coil is varied. The results showed that signal characteristics are not easy to understand with the distance change. To get easier signal characteristics, the probe design is improved by introducing a shielding material between the two coils. These results and a way to utilize them for the monitoring of tube degradation will be presented.
Developing and Testing of a Novel Portable ACFM Intelligent Instrument

--- W. Li, G. Chen, C. Zhang, X. Yin, and T. Liu, China University of Petroleum, Centre for Offshore Engineering and Safety Technology, Qingdao, Shandong, China

---Considering the industry demand for enhancing the mobility and portability the nondestructive testing instrument, a novel portable Alternating Current Field Measurement (ACFM) intelligent instrument is developed and tested in this paper based on the ACFM principle. The CPU and DAQ (data acquisition) module, core hardware of the portable ACFM intelligent instrument, are designed miniature and modular to make it possible to realize both high speed data acquisition and processing in function and portability in structure. The ACFM defect intelligent recognition software is developed to process data for crack sizing. Finally, the real crack detection experiments are designed and conducted to test the efficiency of the portable ACFM instrument. The results show that the portable instrument can recognize cracks intelligently and accurately and it is easy to use and convenient to carry.

Integration of Microwave and Thermographic NDT Methods for Corrosion Detection

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---Modern infrared cameras allow rapid, non-contact measurement of the surface temperature of an Object Under Test (OUT). Infrared (IR) thermography is a powerful nondestructive testing (NDT) technology, with benefits including high accuracy, fast response times over large inspection areas, and intuitive results. NDT applications of thermography involve detecting and identifying discontinuities by observing their effect on the real-time surface temperature as heat diffuses through the OUT. Active thermography utilizes an external heat source such as a flash lamp, or through eddy current (induction) heating. These heating techniques have limitations; for example, eddy current heating is limited to conductive materials and flash lamp heating suffers from long thermal propagation times, in addition to risking heat damage. This work proposes utilizing microwave energy to locally heat corrosion on steel reinforcing bars in concrete structures. Subsequently, the heat profile will be mapped using an IR camera. Utilizing microwave energy is advantageous since microwave energy can penetrate concrete and locally heat the area of interest. Steel corrosion byproducts are electromagnetically lossy and can be easily heated using microwave energy. Initial results obtained using microwave heating for IR detection of corrosion will be presented, along with a discussion of future applications and system improvements.
**NDE Sensors and Systems**

**Review of Progress in MPI**

---Dave Eisenmann, Darrel Enyart, and Chester Lo, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

---Magnetic Particle Inspection (MPI) has seen considerable use in the aviation industry for decades, with up to 90% of steel parts being inspected with MPI at some point in its lifecycle. Despite its widespread use, there are many poorly understood or misinterpreted concepts that would benefit from an in-depth study of the method. For this study a priority list of topics was identified by the research team along with industry participants. The priority list includes items ranging from aspects of the bath concentration and type to the wave form used during the magnetizing process. Although the majority of the study concentrates on the use of a bench for the process, other means of magnetizing are also being investigated as time allows. The industry participants serve as a guidance panel for the project, a method that has worked well in past work with fluorescent penetrant studies. The final deliverables from the study will be in the public domain which can be used to improve industry specifications and OEM guidance for the method.---This material is based upon work supported by the Federal Aviation Administration under Grant No. 10-5-002.

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**Non-Destructive Evaluation of Adhesive in Composite Material Tube by 3D Microcomputed Tomography**

---I. Lima, D. de Oliveira, and R. T. Lopes, Nuclear Instrumentation Laboratory, PEN/COPPE/UFRJ, P. O. Box 68.509, Zip Code: 21941-972 – Rio de Janeiro, Brazil; D. de Oliveira, Physics Institute, UERJ – Rio de Janeiro – Brazil

---Adhesive bonded structure inspection and measurements in a non-destructive way is quite important in industrial area. Ultrasound and x-ray radiography can be used in order to check weld integrity. However they just can often provide visual inspection and low accuracy in quantitatively measurements. However, 3D x-ray microcomputed tomography allows quantitative investigation all over the entire volume of the material with a spatial resolution of few micrometers. The major factors determining the integrity of an adhesive bond are selection of the appropriate adhesive, joint design, preparation of the bonding surfaces, strict quality control in production and condition monitoring in service. In this context, the evaluation of porosity and identification of density material can be very important in mechanical performance. The goal of this work is to investigate adhesive bonded structures by 3D x-ray microcomputed tomography and digital radiography. The results show that both radiography and microcomputed tomography are powerful techniques used in order to inspect such kind of material. However, bond strength and the sealing ability are better evaluation by 3D volumetric dataset, which provide better non-destructive inspection.
NDE Sensors and Systems

Reinforced Concrete inspection
---I. Lima, A. Machado, and R. T. Lopes, Federal University of Rio de Janeiro, Nuclear Engineering Program, Rio de Janeiro, Brazil

---Unsaturated polyester resins as well as inclusion of steel fibers has been widely studied in order to investigate possible changes in mechanical properties of concretes. The three-dimensional computed microtomography is a technique used to characterize the internal structures of various materials based on the interaction of X-rays with the inspected object, being considered a non-destructive testing. Topological and morphological properties can be obtained directly in three dimensions by means of mathematical reconstruction of the radiographs, which allows analyzing, for example, porosity and distribution of objects. In this context, the aim of this work is to investigate morphological structures, such as, porosity distribution in several types of reinforced concretes samples. For this purpose, it was used a high energy microtomography system. The results showed different type of porosity, which were not uniformly distributed throughout the sample.

NDE Sensors and Systems

Handheld System for Non-Destructive Temperature Profiling of Hot Surfaces for Critical Components
---Christopher C. Pilgrim, Joerg P. Feist, Pierre Y. Sollazzo, Stephane Berthier, and Shilpi K. Biswas, Sensor Coating Systems, Imperial Incubator, Imperial College London, London, United Kingdom

---A new technique will be demonstrated to overcome the disadvantages in the measurement of surface temperatures in harsh environments. The technique is based on thermally induced permanent changes in ceramic phosphors. The permanent changes effectively store the temperature information which can be interpreted at a convenient time through the automated interpretation of the inherent phosphorescence of the material. A measurement system will be demonstrated comprising the sensor paint and the instrumentation required to interpret the phosphorescence. The sensor material can be used in a number of ways depending on the measurement requirement. A measurement device has been developed for the interrogation of the phosphorescence from sensor paints. The primary components in the measurement device are a pulsed laser, an optical fiber guide and a light detector. A pulse of excitation light, guided through the fiber guide to the sensor coating surface, excites the phosphorescence which decays exponentially with time. The phosphorescent light is captured and directed to the light detector through the same fiber guide. The duration of the decay can be related to temperature through a calibration table. The device will be demonstrated on paints heat treated at temperatures between 300 and 900°C.
**Ultrasonics**

**Welding for Testability: An Approach Aimed to Improve the Ultrasonic Testing of Thick-Walled Austenitic and Dissimilar Welds**
---Sabine Wagner and Sandra Dugan, Materialprüfungsanstalt, Universität Stuttgart, ZFP in Anlagen und Maschinenbau, Stuttgart, Germany; Martin Barth, Frank Schubert, and **Bernd Köhler**, Fraunhofer IZFP, Dresden Branch, Dresden, Germany

Austenitic and dissimilar welds in thick-walled components show a coarse grained, dendritic microstructure. Therefore, ultrasonic testing has to deal with beam refraction, scattering and mode conversion effects. As a result, the testing techniques typically applied to isotropic materials yield dissatisfying results. Most approaches for improvement of ultrasonic testing have been based on modeling and improved knowledge of the complex wave propagation phenomena. In this paper, we discuss an alternative approach: is it possible to use a modified welding technology which eliminates the cause of the UT complications, i.e., the large-grained structure of the weld seams? Various modification parameters were tested, including: TIG current pulsing, additional DC and AC magnetic fields, and also additional external vibrations during welding. For all welds produced under different conditions, the grain structure of the weld seam was characterized by optical and GIUM microstructure visualizations on cross sections, wave field propagation measurements, and ultrasonic tests of correct detectability of flaws. Moreover, the mechanical properties of the welds were also tested.

**Ultrasonics**

**A Coupled Finite Element Model for Meander Coil Electromagnetic Acoustic Transducer-Receiver Systems**
---Zhichao Li, Weiting Zhai, Pengzhan Li, Riliang Su, and Guofu Zhai, Harbin Institute of Technology, School of Electrical Engineering and Automation, Harbin, China

Electromagnetic acoustic transducers (EMATs) are used for nondestructive testing/evaluation of electric conductive materials. This paper presents a 2-D finite element model for meander coil EMAT transducer-receiver systems, working under the Lorentz force principle. The finite element model is a multi-field coupled model, which contains two sub physical fields: the electromagnetic field and the elasto-dynamic field. There are coupling areas under the EMAT transmitter and receiver respectively. In the elastic wave generation process, the Lorentz forces, output of the electromagnetic field, is set to be body loads of the elasto-dynamic field in the coupling area. While in the elastic wave reception process, the wave vibration velocities are used as input of the electromagnetic field in the coupling area. The EMAT transmitting and receiving processes can be described by this coupled finite element model. To increase the signal to noise ratio, our numerical work is extended to analyze the relationship between the induced voltage in the EMAT receiver and the coil parameters. The simulation results are validated against experiments.
Ultrasonics
Nonlinear Acoustics Experimental Characterization of Microstructure Evolution in Alloy 617
---Xiaochu Yao, Yang Liu, and Clifford J. Lissenden, The Pennsylvania State University, Department of Engineering Science and Mechanics, University Park, PA 16802

---Alloy 617 is a candidate material for the intermediate heat exchanger in a very high temperature reactor for the next generation nuclear power plant. This application will require the material to withstand creep-fatigue-ratcheting interaction at temperatures up to 950°C. Therefore nondestructive evaluation and structural health monitoring are important capabilities. Acoustic nonlinearity (which is quantified in terms of a material parameter, the acoustic nonlinearity parameter, $\beta$) has been proven to be sensitive to microstructural changes in material. This research develops a robust experimental procedure to track the evolution of damage precursors in laboratory tested Alloy 617 specimens using ultrasonic bulk waves. The results from the acoustic non-linear tests are compared with (destructive) microscopy results. Therefore, the relationship between acoustic nonlinearity and microstructural evaluation can be clearly demonstrated for the specimens tested.

Ultrasonics
Study of Aging Effects in a Ti-6AL-4V Alloy with Widmanstätten and Equiaxed Microstructures by Non-Destructive Means
---H. Carreon, A. Ruiz, and B. Santoveña, Universidad Michoacana, Instituto de Investigaciones Metalurgicas, Morelia, Michoacan, Mexico

---When the Ti-6Al-4V alloy is over-aged at 500–600°C, nanometer-sized $\alpha_2$ (Ti3Al) phases can be homogeneously precipitated inside $\alpha$ phases, thereby leading to the additional improvement of mechanical properties. The present study was concerned with the effects of over-aging on ultrasonic velocity and thermoelectric power (TEP) measurements in Ti-6Al-4V alloy. Widmanstätten and equiaxed microstructures containing fine $\alpha_2$ (Ti3Al) particles were obtaining by over-aging a Ti-6Al-4V alloy. Over-aging heat treatments were conducted at 515°C, 545°C and 575°C for different aging times. In order to find out the factors affecting the variation in the wave velocity and TEP, the over-aging samples were examined by X-ray diffraction (XRD) and (SEM) scanning electron microscopy. It was found that the ultrasonic velocity measurements changed considerably due to the different over-aging conditions. Shear wave velocities exhibited a stronger interaction with microstructural and sub-structural features as compared to that of longitudinal waves. On the other hand, TEP measurements reveal an increase in the absolute TEP value of the over-aged Widmanstätten and equiaxed microstructures with regards to the unaged condition for different aging times, with a somewhat higher value at 515°C.
**Ultrasonics**

**Generation of Low-Frequency Components in Ultrasonic Waves Penetrating the Interface Between Contacting Solids**
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Hirotaka Tanaka, Tatsuhiro Okamoto, Kenji Kurihara, and Toshihiko Sugiura, Keio University, Department of Mechanical Engineering, Yokohama, Kanagawa, Japan

---In internal inspection of nondestructive evaluation, one of subjects of ultrasonic testing is detection of a closed crack. Cracks in solids can be detected by ultrasonic testing if they are open. However, it is difficult to detect them if they are closed. It is said that nonlinear ultrasonics is useful for detection of closed cracks in structures. This study experimentally examined propagation of ultrasonic waves through the interface between contacting solids. Two aluminum specimens pressed by a compressor were used to make interface as modelling of a closed crack. The transmit frequency was changed in the range of 1.0-2.0MHz and several types of surface roughness of specimens were used. As a result, generation of low-frequency components of 600 kHz can be found regardless of the transmit frequency. Such a feature of low-frequency components is different from that of subharmonics. Additionally, this kind of phenomenon was not confirmed in specimens having smoother surface. Therefore, surface roughness may be one of its important factors. The results suggest that this low-frequency component can be useful for detecting a closed crack.

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**Signal Processing Techniques for Recovering Input Waveforms in Dispersive Lamb Wave Propagation**
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---Lamb waves are extensively used in plate-like structure inspection because of their guided nature. However, their dispersive properties often limit their use in flaw detection and other applications. Dispersion weakens and defocuses interrogating Lamb waves and makes it difficult to accurately interpret signals reflected from defects or boundaries. Time reversal (TR) processing can be applied to compensate for the effect of dispersive Lamb waves. Thus, the TR operation will enable the amplification of dispersive Lamb wave signals by signal compression in time. In this study, experiments are performed in order to examine the refocusing and recovering the initial input waveform in the long range propagation of dispersive Lamb waves in a plate. Three different time reversal processes (regular TR, 1 bit TR, and reciprocal TR or inverse filtering) are tested and the experimental results are compared.
Simulation and Analysis of the Corrugated Pipe Grouting Defects in Ultrasonic Testing
---Han Qingbang, Changzhou Key Laboratory of Sensor Networks and Environmental Sensing, Hohai University, Changzhou 213022, China; Sun Hong, Changzhou Green Bamboo Middle School, Changzhou 213022, China

---The cement grouting process of the prestressed corrugated pipes will generate various defects, which may seriously impair the safety of the whole bridge. This paper focuses on the propagation characteristics of the acoustic fields in corrugated pipes concrete structures with different defects. The finite element method is applied to simulate the multiple reflection, refraction and scattering of propagating waves; it shows that the scattering by the metal pipe play the dominate roles and the local backscattering by air defects is submerged in signals. The influence of defects are recognized by the deconvolution method, compared with small defects, the deconvolution signals of big defects at the same position will lead to a larger head wave amplitude and shorter arrive time and in the frequency domain, big defects will result in larger amplitude, lower center and cutoff frequencies.

Feasibility Study on Ultrasonic Lateral Displacement Measurement for Structural Health Monitoring
---Iwao Matsuya, Fumiya Matsumoto, and Ikuo Ihara, Nagaoka University of Technology, Department of Mechanical Engineering, Nagaoka, Niigata, Japan

---In structural health monitoring, measuring the relative lateral displacement of the structure is essential for direct damage detection. Although large numbers of studies have been made on the development of range finder utilizing optical sensor, ultrasound and mechanical method, little attention has been given to the measuring method for lateral displacement. We propose a novel measurement method for directly measuring the lateral displacement for the structures by means of the air-coupled ultrasound. The measurement system is composed of two flat-type air-coupled ultrasound detectors and a steel wire as a target. The ultrasound detectors are immobilized on the fixed point, whereas a steel wire is separately arranged on an opposite side. When the steel wire is displaced laterally to the ultrasound detectors, the lateral displacement is calculated by taking advantage of the intensity ratio of the reflected ultrasound waves. The accuracy of the lateral displacement measurement is experimentally assessed by conducting a shaking table test. Estimated displacement value agrees well with the theoretical value. The result shows that the developed displacement measurement method will be useful for the health diagnosis of structures in real-time.
**Ultrasonics**

**Ultrasonic Method for Evaluating Residual Stress Distributed within a Welded Metal Plate**

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---This paper presents the results from the set of experiments designed to measure the SAW (Surface Acoustic Wave) velocity distribution in accordance with the residual stress distribution within dissimilar metal weld joint. A mechanical scanning acoustic reflection microscope (SAM), with a V(z) curve method was used to measure the SAW distribution in the welded plate comprising the Cold-rolled carbon sheet (SPCC), and the Stainless steel (SUS 304). For quantitative data acquisition (i.e., surface acoustic wave (SAW) velocity measurement), a point focus acoustic lens of frequency 200 MHz was used, and the diameter of the ultrasonic beam spot on the surface of the specimen was substantially 5 µm. The SAW velocities within the specimen were precisely measured and the changes in SAW velocities were related to the distribution of residual stresses. Furthermore, a 400 MHz frequency acoustic lens was used to obtain the acoustic images of the SAM and compared to the optical images. The primary results indicate that SAM may be successfully applied to nondestructively measure the distribution of the residual stress of the dissimilar metal weld joint.

**Ultrasonics**

**The Measurement of Axial Stress in a Tightened Bolt by the Combination of Shear Wave and Longitudinal Wave**

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---This paper provides a non-destructive way to evaluate axial stress in a tightened bolt which is made of austenitic stainless steel #45 by the combination of shear wave and longitudinal wave. By using finite element analysis, a more precise model to deduce axial stress in a tightened bolt based on the contributions of former researchers has been established. This model has also been verified by strain gauge testing. According to the acoustoelasticity theory, ultrasonic wave propagation in the metal transit time associated with the stress state. Whether shear wave or longitudinal wave cannot detect axial stress of bolt which is tightened or fixed in the structure separately. Only through the division of transit time of shear wave and longitudinal wave, the influence of the length of bolt could be eliminated. Meanwhile, formulas also been provided. Two different series (1MHz, 2.25MHz) transducers have been used to reduce the influence of the frequency variation. Besides the formulas which have been issued, a comparison with field measurement to tensile testing also has been given and a more convincing result has been provided. At last, we establish a coupling model for bolt cap and make the formulas more accurately.
**Virtual Ultrasound Sources for Inspecting Nuclear Components of Coarse-Grained Structure**

---Jose Brizuela, Consejo Nacional de Investigaciones Científicas y Técnicas, Ciudad Autónoma de Buenos Aires, Argentina; Pablo Katchadjian, Carlos Desimone, and Alejandro D. Garcia, Comisión Nacional de Energía Atómica, Departamento de Ensayos No Destructivos y Estructurales, San Martín, Pcia. de Buenos Aires, Argentina

---This paper describes an ultrasonic inspection procedure designed for verifying coarse-grained structure materials which are commonly used on nuclear reactors. In this case, conventional phased array techniques cannot be used due to attenuating characteristics and backscattered noise from microstructures inside the material. Thus, synthetic aperture ultrasonic imaging (SAFT) is used for this approach under immersion conditions. In order to increase energy transferred to the medium, synthetic transmit aperture is formed by several elements which generate a diverging wave front equivalent to a virtual ultrasound source behind the transducer. On the other hand, the phase coherence technique has been applied to reduce more structural noise and improve the image quality. The beamforming process has been implemented over a GPU platform to reduce computing time.

**A Comparison Between Beamforming and Super Resolution Ultrasonic Array Imaging Algorithms for NDE**

---Chengguang Fan, National University of Defense Technology, College of Mechatronic Engineering and Automation, Changsha, 410073, Hunan, PR China; Chengguang Fan and Bruce W. Drinkwater, University of Bristol, Department of Mechanical Engineering, Bristol, BS8 1TR, United Kingdom

---In this paper the performance of the total focusing method (TFM) is compared and contrasted with a time reversal based super resolution technique (SR). The former is selected as the best available ‘classical’ beamforming algorithm and the latter selected as being typical of a class of algorithms termed super-resolution. The algorithms are tested with both experimental data from a range of samples with differing levels of noise, as well as with simulated data. The simulated time domain signals allow the effects of array geometry, frequency, scatterer location, scatterer separation and random noise to be carefully controlled. The performance of the algorithms is evaluated in terms of resolution and its sensitivity to random noise. It is shown that for very low noise data SR provides significantly enhanced resolution when compared to the TFM, breaking the diffraction limit as expected. However, at higher noise levels the TFM is shown to be relatively robust, whilst the performance of the SR technique is degraded.
Ultrasonics

The Effect of Fatigue Cracking on Elastic Moduli and Coda Waves in Composites
---Richard Livings and Vinay Dayal, Iowa State University, Composite Design & Analysis Center, 2328 Howe Hall, Ames, IA 50011

---Many current ultrasonic techniques attempt to directly detect flaws. Their success is limited by the flaw size and the wavelength of the frequency used, which means that anything smaller than one wavelength is difficult to detect. This makes the very initial stages of fatigue cracking almost impossible to detect. This research uses the indirect means of considering an effective material to determine the initial stages of fatigue. Any flaws in a sample will change the effective elastic constants, and any change in the elastic constants will affect waves traveling in the media. These changes can be used as a damage metric for the sample.

Ultrasonics

Evaluation of Thermally Degraded 2205 Duplex Stainless Steel Using Guided Ultrasonic Waves
---Alberto Ruiz and Hector Carreon, Universidad Michoacana de San Nicolás de Hidalgo, Instituto de Investigaciones Metalúrgicas, Morelia, Michoacan, México

---Heat treatment and ageing affect the hardness, toughness and strength of duplex stainless steels by changing their balanced duplex microstructure. It has been already established that ultrasonic attenuation and dispersion are also affected by the material microstructure. It is investigated in this paper if the ultrasonic variables of ultrasonic guided waves can be correlated with the degree of thermal degradation or aging and material properties. To do this five identical 2205 duplex stainless steel plate specimens were isothermally aged for different holding times at 750 C. Lamb wave propagation was used to nondestructively evaluate the specimens. Rockwell hardness test and metallographic analysis were performed to corroborate the ultrasonic observations. From these results it is concluded that guided wave inspection method is a reliable and probably more desirable alternative for characterizing the degradation and microstructure of aged duplex stainless steels.
A Web-Based Tutorial for Ultrasonic Attenuation Measurements
---Frank J. Margetan, Dan Barnard, David Orman, Alex Feygin, and Brittney Pavel, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

---An ultrasonic attenuation-versus-frequency curve can serve as an “ultrasonic signature” which may be correlated with microstructural properties of interest such as grain size in metals or porosity level in composites. Attenuation also plays a role in ultrasonic inspections and is consequently a key input into many inspection simulation models. A web-based self-tutorial on practical attenuation measurements is under development. The focus is on pulse/echo immersion measurements made using a broadband transducer to deduce attenuation within the transducer’s useable bandwidth. Two approaches are considered: one using a calibration specimen having a known attenuation curve, and one without. In the first approach a back-wall (BW) echo in the calibration specimen is compared with a BW echo in the test specimen. In the second approach various BW reverberation echoes in the test specimen are compared with one another. The web-based course incorporates three classes of materials. The first includes written documentation and videos describing the measurement setups, the data-acquisition and analysis procedures, and the underlying models used to analyze the raw UT data. Secondly “stand-alone” data-analysis software is supplied, designed to be used with any UT inspection system that can output A-scan data as a text file. Thirdly, we supply “demonstration software” where the data acquisition and analysis procedures are integrated with a specific class of commercial UT instruments, namely those running UTEX Winspect control software. This presentation will provide an overview of the measurement methods and tutorial materials. We will also present early results from round-robin trials in which selected metal and composite specimens are being sent to participating partners for attenuation measurement.---This work was supported by the NSF Industry/University Cooperative Research Program of the Center for Nondestructive Evaluation at Iowa State University.

Damage Evaluation for CFRP Components Using Acoustic Emission Monitoring
---Russell Austin¹, David Forsyth¹, Jianguo (Peter) Yu², Mohamed ElBatanouny², Paul Ziehl². ¹Texas Research Institute, 9225 Bee Cave Road, Austin, TX 78733; ²University of South Carolina, 300 Main Street, Columbia SC 29208

---Acoustic emission (AE) monitoring can provide confidence in the reliability of a structure or component then reducing unnecessary maintenance and inspection. Due to the brittle nature of carbon fiber reinforced polymer (CFRP) failure and critical applications at which CFRP operates it is crucial to develop a real-time monitoring technique that is able to assess structural integrity. Comparable evaluation criteria for the evaluation of structural integrity are needed as a part of AE monitoring system. Based on Austin and Coughlin criteria, number of high amplitude AE hits/events, historic index, AE cumulative energy, and severity were utilized to evaluate structural damage by a numerical rating. AE signals associated with structural damage were collected through stepwise loading, impact, low-cycle and high-cycle fatigue tests. A combination of source location filtering, waveform feature analysis and pattern recognition was used to filter acquired AE signals. The effect of prescribed signal period on Austin and Coughlin criteria was studied. Due to the fact that the number of hits does not weigh the intensity of each hit, the Austin and Coughlin criteria was modified by excluding the number-of-hit score.
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Thursday, July 25, 2013

SESSION 37
ELECTROMAGNETIC MODELING
Jiming Song, Chairperson
Key Ballroom 9

3:30 PM Three Dimensional Boundary Element Solutions for Eddy Current Nondestructive Evaluation
---Ming Yang and Norio Nakagawa, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011; Ming Yang and Jiming Song, Electrical and Computer Engineering, Iowa State University, Ames, IA 50011

3:50 PM Modelling of Eddy-Current Inspection of Axi-Symmetrical Workpieces Using 3D Probes Based on a Mixed Numerical/Modal Formulation
---Anastassios Skarlatos and Christophe Reboud, CEA, LIST, Centre de Saclay, France

4:10 PM A Fast 3D Semi-Analytical Model for Simulating Flaw Responses Provided by a Magnetic Flux Leakage NDT System Inspecting Ferromagnetic Pipes
---Adrien Trillon and François Deneuville, VMF-VRA (Vallourec Research Aulnoye), NDT Department, F-59620 Aulnoye-Aymeries, France; Denis Prémel and Steve Djafa, CEA-LIST, Centre de Saclay, F-91191 Gif sur Yvette, France; Lionel Pichon, Laboratoire de génie électrique de Paris (LGEP), Supélec, Gif sur Yvette, France

4:30 PM Artifact Reduction in Industrial Computed Tomography via Data Fusion of 3-D Surface Data and Ultrasonic Imaging
---Michael Schrapp, Jürgen Stephan, and Matthias Goldammer, Siemens AG, Corporate Technology RTC SET INT-DE, Otto-Hahn-Ring 6, 81739 Munich, Germany; Michael Schrapp, Technical University of Munich, Physics Department, Munich, Germany
Three Dimensional Boundary Element Solutions for Eddy Current Nondestructive Evaluation
---Ming Yang and Norio Nakagawa, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011; Ming Yang and Jiming Song, Electrical and Computer Engineering, Iowa State University, Ames, IA 50011

---The boundary integral equations (BIE) method is a numerical computational method of solving linear partial differential equations which have been formulated as integral equations. It can be applied in many areas of engineering and science including fluid mechanics, acoustics, electromagnetics, and fracture mechanics. The eddy current problem is formulated by the BIE and discretized into matrix equations by the method of moments (MoM) or the boundary element method (BEM). The three dimensional arbitrarily shaped objects are described by a number of triangular patches. In our implementation of the Stratton-Chu formulation for the conductive medium, the equivalent electric and magnetic surface currents are expanded in terms of Rao-Wilton-Glisson (RWG) vector basis function while the normal component of magnetic field is expanded in terms of the pulse basis function. Also, a low frequency approximation is applied in the external medium. Computational tests are presented to demonstrate the accuracy and capability of the three-dimensional BIE method with a complex wave number. These numerical results include near field distribution and impedance change. Additionally, we introduce Auld’s impedance formulas to calculate impedance variation. The agreement between numerical results and those from theory and/or experiments is good in both cases of a single-turn coil above a sphere and a finite cross-section above a wedge or a rectangular slot in a thick plate, which also give us confidence that our numerical codes can successfully simulate impedance change for arbitrary shape conductive objects interacted with coils in NDE application.---This material is based upon work supported in part 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.

Modelling of Eddy-Current Inspection of Axisymmetrical Workpieces Using 3D Probes Based on a Mixed Numerical/Modal Formulation
---Anastassios Skarlatos and Christophe Reboud, CEA, LIST, Centre de Saclay, France

---In most eddy-current testing (ECT) applications, one observes that inspected pieces present some sort of symmetry (e.g., by extrusion of revolution). Whereas for canonical pieces, semi-analytical methods may be used for ECT simulation, for more complicated profiles the use of generic numerical tools, like Finite Element Method (FEM) Finite Integration Technique (FIT) or Surface Integral Equation (SIE), is required. Yet, general purpose numerical tools do not fully exploit the possible symmetry of the piece, if this symmetry is not verified for other configuration parts, like the sensor. The present contribution considers a mixed numerical/modal approach based on the FIT method, for the ECT modelling of axisymmetrical structures inspected with punctual coils. A 2D mesh in the r,z plane and a modal technique along the angular direction are jointly used to describe fields variations. Such decomposition is always possible for simple air-cored coils, which behave like permanent sources. According to this approach, the original 3D problem is decomposed in a number of angular modes, calculated numerically in 2D. The inspection, using pancake coils, of a beading located at the base of a steam generator tube will be simulated as case-study, in order to demonstrate the performance of the proposed approach.
A Fast 3D Semi-Analytical Model for Simulating Flaw Responses Provided by a Magnetic Flux Leakage NDT System Inspecting Ferromagnetic Pipes

---Adrien Trillon and François Deneuville, VMF-VRA (Vallourec Research Aulnoye), NDT Department, F-59620 Aulnoye-Aymeries, France; Denis Prémel and Steve Djafa, CEA-LIST, Centre de Saclay, F-91191 Gif sur Yvette, France; Lionel Pichon, Laboratoire de génie électrique de Paris (LGEP), Supélec, Gif sur Yvette, France

---In order to improve the capabilities of detection of longitudinal flaws in steel pipes, CEA LIST and Vallourec Research Aulnoye (VRA) are collaborating to develop fast 3D numerical models for simulating MFL NDT systems. This communication presents a semi-analytical model based on BEM formalism for computing MFL flaw responses. MFL 2D configurations have been already simulated in the linear case taking into account the complex shape of the magnetizing circuit surrounding the pipe to be inspected. In this paper, the 3D problem is considered, but, in a first step, we assume that each ferromagnetic part can be divided in a finite number of trapezoidal cells, assuming that the relative magnetic permeability is constant inside each cell. The kernels derived from integral equations can be analytically evaluated. This is the novelty of this work since the implemented semi-analytical model reveals itself to be very effective. The chosen approach will be analyzed in the full paper and some simulated data will be presented for a specific NDT MFL configuration. Then qualitative comparisons between simulated results and experimental data will be carried out.

Artifact Reduction in Industrial Computed Tomography via Data Fusion of 3-D Surface Data and Ultrasonic Imaging

---Michael Schrapp, Jürgen Stephan, and Matthias Goldammer, Siemens AG, Corporate Technology RTC SET INT-DE, Otto-Hahn-Ring 6, 81739 Munich, Germany; Michael Schrapp, Technical University of Munich, Physics Department, Munich, Germany

---As highly stressed parts, turbine blades are subject to a number of inspections before service. Unfortunately, computed tomography as one of the most interesting methods is very difficult for the materials involved. Full penetration of large sized turbine blades is often only possible for high X-ray voltages, causing disproportional high costs. A reduction of the X-ray voltage also reduces the costs but results in non-penetration artifacts in the reconstructed CT image. In most instances, these artifacts manifest themselves as blurred and smeared regions at concave edges due to a reduced signal to noise ratio. In order to complement the missing information and to increase the overall image quality of the reconstruction, we use further imaging modalities, such as a 3-D scanner and ultrasonic imaging. A 3-D scanner is easy and cheap to implement and is able to acquire all relevant data simultaneously with the CT projections. If, however, the interior structure is of supplemental interest, an ultrasonic imaging method is additionally used. We consider this data as a priori knowledge to employ them in an iterative reconstruction. To do so, standard iterative reconstruction methods are modified to incorporate the a priori data in a regularization approach in combination with minimizing the total variation of our image. Applying this procedure on turbine blades, we are able to reduce the apparent artifacts almost completely.
Session 38
SESSION 38
ROBOTIC AND AUTOMATION
Tom Batzinger and Don Palmer, Co-Chairpersons
Key Ballroom 10

3:30 PM Remotely Deployable Surface Inspection Using Tactile Sensors
---Charles N. MacLeod, S. Gareth Pierce, Gordon Dobie, and Rahul Summan, University of Strathclyde, Centre for Ultrasonic Engineering, EEE Department, Royal College Building, 204 George Street, Glasgow G1 1XW, United Kingdom; J. Charles Sullivan and Anthony Pipe, University of the West of England, Bristol Robotics Laboratory

3:50 PM An Automated Miniature Robotic Vehicle Inspection System
---Gordon Dobie, Charles MacLeod, Rahul Summan, Walter Galbraith, and S. Gareth Pierce, University of Strathclyde, Department of Electrical and Electronic Engineering, 204 George Street, Royal College Building, Glasgow, United Kingdom

4:10 PM Robotic Inspection of Fiber Reinforced Aerospace Composites Using Phased Array UT
---Jeffrey T. Stetson and Walter De Odorico, GE Measurement and Control Solutions, Ultrasonic Testing Machines, Lewistown, PA 17044
3:30 PM

Remotely Deployable Surface Inspection Using Tactile Sensors
---Charles N. MacLeod, S. Gareth Pierce, Gordon Dobie, and Rahul Summan, University of Strathclyde, Centre for Ultrasonic Engineering, EEE Department, Royal College Building, 204 George Street, Glasgow G1 1XW, United Kingdom; J. Charles Sullivan and Anthony Pipe, University of the West of England, Bristol Robotics Laboratory

---For structural monitoring applications, the use of remotely deployable Non-Destructive Evaluation (NDE) inspection platforms offer many advantages, including improved accessibility, greater safety and reduced cost, when compared to traditional manual inspection techniques. The use of such platforms, previously reported by researchers at the University Strathclyde facilitates the potential for rapid scanning of large areas and volumes in hazardous locations. A common problem for both manual and remote deployment approaches lies in the intrinsic stand-off and surface coupling issues of typical NDE probes. The associated complications of these requirements are obviously significantly exacerbated when considering remote inspection and deployment, resulting in simple visual techniques being the preferred sensor payload. Researchers at Bristol Robotics Laboratory have developed biomimetic tactile sensors modelled on the facial whiskers (vibrissae) of animals such as rats and mice, with the latest sensors actively sweeping their tips across the surface in a back and forth motion. The current work reports on collaborative studies to assess the feasibility of utilizing such sensors to perform surface profiling and inspection of representative industrial samples. Further work is presented on their performance and suitability when integrated into an automated remote NDE inspection platform, including their surface compliant nature.

3:50 PM

An Automated Miniature Robotic Vehicle Inspection System
---Gordon Dobie, Charles MacLeod, Rahul Summan, Walter Galbraith, and S. Gareth Pierce, University of Strathclyde, Department of Electrical and Electronic Engineering, 204 George Street, Royal College Building, Glasgow, United Kingdom

---A novel, autonomous reconfigurable robotic inspection system for quantitative NDE mapping is presented. The system consists of a fleet of wireless (802.11g) miniature robotic vehicles, each approximately 175 x 125 x 85 mm with magnetic wheels that enable them to inspect industrial structures such as storage tanks, chimneys and large diameter pipe work. The robots carry one of a number of payloads including a two channel MFL sensor, a 5 MHz dry coupled UT thickness wheel probe, a machine vision camera that images the surfaces and biologically inspired profiling sensors. The system creates an NDE map of the structure overlaying results onto a 3D model in real time. Data fusion techniques were used to improve the probability of detection, combining complementary sensing techniques from the different payloads. Robot positional estimation was achieved to within 1 mm in using a Bayesian filter processing measurements from wheel encoders, a 6 axis IMU and an optical global positioning system. The authors provide an overview of the system design, data fusion algorithms (positioning and NDE) and visualization software. The results section focuses on the characterization of inspection performance on a representative 2000 x 1000 x 10 mm carbon steel sample.
Robotic Inspection of Fiber Reinforced Aerospace Composites Using Phased Array UT
---Jeffrey T. Stetson and Walter De Odorico, GE Measurement and Control Solutions, Ultrasonic Testing Machines, Lewistown, PA 17044

---Ultrasound is the current NDE method of choice to inspect large fiber reinforced airframe structures. Over the last 15 years Cartesian based scanning machines using conventional ultrasound techniques have been employed by all airframe OEMs and their top tier suppliers to perform these inspections. Technical advances in both computing power and commercially available, multi-axis robots now facilitate a new generation of scanning machines. These machines use multiple end effector tools taking full advantage of phased array ultrasound technologies yielding substantial improvements in inspection quality and productivity. This paper outlines the general architecture for these new robotic scanning systems as well as details the variety of ultrasonic techniques available for use with them including advances such as wide angle phased array scanning and sound field adaptation for non-flat, non-parallel surfaces.
Session 39
SESSION 39  
TOMOGRAPHY, IMAGING, AND INVERSION  
Peter B. Nagy and Reinhold Ludwig, Co-Chairpersons  
Key Ballroom 3

3:30 PM  
A General Approach to High-Resolution Guided Wave Tomography of Tubular Structures  
---Francesco Simonetti, Alexander Brath, Carson L. Willey, and Peter B. Nagy, University of  
Cincinnati, School of Aerospace Systems, Cincinnati, OH 45221; Francesco Simonetti, Peter B.  
Nagy, and Geir Insatnes, Cincinnati NDE, Cincinnati, OH 45244; Geir Insatnes, ClampOn AS, 5162  
Laksevaag, Bergen, Norway

3:50 PM  
Ultrasonic Multi-Skip Tomography for Pipe Inspection  
---Tim van Zon and Arno Volker, TNO, Stieltjesweg 1, P.O. box 155, 2600 AD Delft, The  
Netherlands

4:10 PM  
Damage Detection in Composite Structures Using Time-Reversal Migration Technique  
---Dan Xiang, X-wave Innovations, Inc., Gaithersburg, MD 20878; Fuh-Gwo Yuan and Jason He,  
North Carolina State University, Raleigh, NC 27695

4:30 PM  
Constrained TV-Minimization Image Reconstruction for Industrial CT System  
---Buxin Chen, Zheng Zhang, Junguo, Bian, Xiao Han, and Emil Sidky, The University of Chicago,  
Department of Radiology, Chicago, IL 60637; Min Yang, Beijing University of Aeronautics and  
Astronautics, School of Engineering and Automation, Beijing, China; Xiaochuan Pan, The  
University of Chicago, Departments of Radiology & Radiation and Cellular Oncology, Chicago, IL  
60637

4:50 PM  
Software Optimization for Electrical Conductivity Imaging in Polycrystalline Diamond  
Cutters  
---Gene Bogdanov and Reinhold Ludwig, Worcester Polytechnic Institute, Department of Electrical  
Synthetic, Orem, UT 84058

5:10 PM  
Regularization Methods to Assess the Eddy Current Density Inside Conductive  
Non-Ferromagnetic Media  
---Artur L. Ribeiro, Dário J. Pasadas, Helena G. Ramos, and Tiago J. Rocha, Instituto de  
Telecomunicações, Instituto Superior Técnico, U.T.L., Lisboa, Portugal
3:30 PM

A General Approach to High-Resolution Guided Wave Tomography of Tubular Structures

--- Francesco Simonetti, Alexander Brath, Carson L. Willey, and Peter B. Nagy, University of Cincinnati, School of Aerospace Systems, Cincinnati, OH 45221; Francesco Simonetti, Peter B. Nagy, and Geir Insatnes, Cincinnati NDE, Cincinnati, OH 45244; Geir Insatnes, ClampOn AS, 5162 Laksevaag, Bergen, Norway

--- The transmission of guided ultrasonic waves across corrosion or erosion damage encodes information about the defect depth. Tomography maps the depth profile from multiple transmission experiments performed under different insonification angles by solving the so-called inverse problem; the accuracy of the depth estimation being dependent on the range of angles available for the inversion. Practical application of tomography to tubular structures, such as pipes and bends, requires the use of two ring arrays of ultrasonic transducers at the two ends of the section to be inspected. However, such a configuration leads to an insufficient angular coverage when considering the signals that travel along the shortest path between a source and a receiver transducer. This paper introduces a general approach that extends the range of insonification angles by exploiting the information carried by the signals that wrap around the structure multiple times before reaching the receive array, thus resulting in superior image resolution. It is shown that considering modes that have performed up to n full turns around the structure is equivalent to extending the linear aperture of each array by a factor n+1. This leads to the concept of ‘virtual’ transmit and receive arrays, each containing n times more transducers than the physical arrays. The effectiveness of the proposed approach is demonstrated experimentally using a schedule 40, 8” diameter pipe tested with EMAT ring arrays. It is shown that the maximum depth of an irregular corrosion defect is estimated with accuracy better than 1% of the wall thickness. Performance dependence on array separation distance is also presented.

3:50 PM

Ultrasonic Multi-Skip Tomography for Pipe Inspection

--- Tim van Zon and Arno Volker, TNO, Stieltjesweg 1, P.O. box 155, 2600 AD Delft, The Netherlands

--- The inspection of wall loss corrosion is difficult at pipe supports due to limited accessibility. The recently developed ultrasonic Multi-Skip screening technique is suitable for this problem. The method employs ultrasonic transducers in a pitch-catch geometry positioned on opposite sides of the pipe support. Shear waves are transmitted in the axial direction within the pipe wall, reflecting multiple times between the inner and outer surfaces before reaching the receivers. Along this path, the signals accumulate information on the integral wall thickness (e.g., via variations in travel time). The method is very sensitive in detecting the presence of wall loss, but it is difficult to quantify both the extent and depth of the loss. Multi-skip tomography has been developed to reconstruct the wall thickness profile along the axial direction of the pipe. The method uses model-based full wave field inversion; this consists of a forward model for predicting the measured wave field and an iterative process that compares the predicted and measured wave fields and minimizes the differences with respect to the model parameters (i.e., the wall thickness profile). Experimental results are very encouraging. Various defects (slot and flat bottom hole) are reconstructed using the tomographic inversion. The general shape and width are well recovered. The current sizing accuracy is in the order of 1 mm.
4:10 PM

**Damage Detection in Composite Structures Using Time-Reversal Migration Technique**

--- Dan Xiang, X-wave Innovations, Inc., Gaithersburg, MD 20878; Fuh-Gwo Yuan and Jason He, North Carolina State University, Raleigh, NC 27695

---The use of composites in aircraft manufacturing is growing dramatically. Ultrasonic guided waves (UGW) can propagate a long distance, and thus have been used in structural health monitoring (SHM) for large area composite structures like wings and fuselages. UGW can detect not only the damages on the surface of the structures, but also the flaws inside the structures. In this paper, a time-reversal migration (TRM) technique, which originates from the geophysical migration technique, is used to reconstruct the image of damage in composites. The TRM technique uses a linear-array transducer. Each time, one element is used as actuator and the rest of elements in the linear-array transducer are used as receiver. With the TRM scheme, a damage (or the secondary sources) in the composite specimen can be reconstructed. By sequentially switching the element in the linear-array transducer as the actuator, a set of images of the same damage in the composite are reconstructed. Through stacking all images together, a final image of the damage with higher accuracy and lower noise than each individual image is obtained. Experiment results confirm the promising of the TRM technique for damage detection in composite structures.

4:30 PM

**Constrained TV-Minimization Image Reconstruction for Industrial CT System**

--- Buxin Chen, Zheng Zhang, Junqiao, Bian, Xiao Han, and Emil Sidky, The University of Chicago, Department of Radiology, Chicago, IL 60637; Min Yang, Beijing University of Aeronautics and Astronautics, School of Engineering and Automation, Beijing, China; Xiaochuan Pan, The University of Chicago, Departments of Radiology & Radiation and Cellular Oncology, Chicago, IL 60637

---In this work, we investigate the applicability of the constrained total-variation (TV)-minimization reconstruction method to industrial CT system under sparse-view data condition. In general, industrial CT systems have the same principles of imaging process with clinical CT systems, but different imaging objectives and evaluation metrics. Optimization-based image reconstruction methods have been actively developed to meet practical challenges and extensively tested for both diagnostic and dedicated clinical CT systems. However, the utility of optimization-based reconstruction methods is task-specific and not necessarily transferrable among different tasks. In this work, we adopt constrained TV-minimization programs together with adaptive-steepest-descent-projection-onto-convex-sets (ASD-POCS) algorithm for reconstructing images from data of concrete and coal sample collected using a laboratory industrial CT system developed for nondestructive evaluation. Resulting images are compared with those reconstructed from the FBP-based algorithm currently used in the nondestructive testing industry. Specific imaging objectives are incorporated in the evaluation. Our results suggest that the constrained TV-minimization program combined with ASD-POCS algorithm is much less sensitive to angular data undersampling and can yield images with equivalent or improved visual quality and achieving equivalent or better imaging objectives over the currently used algorithm, using full- or sparse-view data.
4:50 PM
Software Optimization for Electrical Conductivity Imaging in Polycrystalline Diamond Cutters
---Gene Bogdanov and Reinhold Ludwig, Worcester Polytechnic Institute, Department of Electrical and Computer Engineering, Worcester, MA 01609; Jason Wiggins and Ken Bertagnolli, US Synthetic, Orem, UT 84058

---We have previously reported on an electrical conductivity imaging instrument developed for measurements on polycrystalline diamond cutters. These cutters are used in oil and gas drilling, and feature an approximately 0.1" thick polycrystalline diamond layer placed on a tungsten carbide substrate. The instrument uses electrical impedance tomography to profile the conductivity in the diamond table. Although the information collected in the conductivity images proved relevant to the cutter manufacturer, the method becomes less useful if images cannot be acquired quickly. This paper reports on efforts made to optimize the conductivity reconstruction routine, porting major portions of it to NVIDIA GPUs using custom kernels for Jacobian computation. As a result, computation time has been reduced to less than 3 sec on the coarsest discretization meshes. Data acquisition time has also been significantly optimized, requiring on average 2-3 sec. Due to this optimization effort, combined with increased power of PC hardware, the conductivity imaging method has become an important on-line process monitoring tool.

5:10 PM
Regularization Methods to Assess the Eddy Current Density Inside Conductive Non-Ferromagnetic Media

---This presentation describes two regularization methods that were applied to preview the current density induced in an aluminum plate. The images that resulted from the measurement of one magnetic field component by scanning the plate were used to determine the current density. The maps of the measured magnetic field were disturbed by the presence of some defects that had been previously machined. The scanning was performed using a constant field eddy current probe and a rectangular area including the defect was covered. With the constant field probe a sinusoidal excitation was imposed to the plate, being the amplitude and phase invariant under a limited space translation. The secondary magnetic field created by the eddy currents was measured using a giant magneto-resistance sensor that increased the sensitivity. The inversion problem was solved using discrete Fourier transform methods with Tikhonov regularization and the total-variation method. Both methods produced equivalent results, but the Tikhonov regularization algorithm is very fast while the total-variation iterative method is quite slow. We conclude that Tikhonov method is appropriate to be programmed either using software or using hardware directly.
Session 40
SESSION 40
TERAHERTZ NDE
Yuri Plotnikov and Premjeet (“Prem”) Chahal, Co-Chairpersons
Key Ballroom 11

3:30 PM  Applications of Terahertz Waves on the Penetration in Thick FRP Composites
---Kwang-Hee Im, Woosuk University, Department of Automotive Engineering, Chonbuk, 565-701, Korea; David K. Hsu, Chien-Ping Chiou, and Daniel J. Barnard, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, Iowa, 50011; Je-Woong Park, Chosun University, Department of Naval Architecture and Ocean Engineering, Gwangju 501-759, Korea; In-Young Yang, Department of Mechanical Design Engineering, Chosun University, Gwangju 501-759, Korea

3:50 PM  THz and FTIR Spectroscopic Imaging for NDE Applications
---Chien-Ping T. Chiou, Matthew Meyer, and Jonathan Runchey, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

4:10 PM  High Power THz Sources for Nonlinear Imaging
---Patrick F. Tekavec and Vladimir G. Kozlov, Microtech Instruments, 858 W Park Street, Eugene, OR 97401

4:30 PM  Non-Destructive Imaging with Compact, Portable Terahertz Systems
---Albert Redo-Sanchez, Norman Laman, Brian Schulkin, and Thomas Tongue, 15 Tech Valley Dr., Suite 102, East Greenbush, NY 12061

4:50 PM  Design Study of Millimeter Wave and THz Spoof Plasmon Near Field Probes for NDE Applications
---K. Y. Park and Premjeet (“Prem”) Chahal, Michigan State University, Department of Electrical and Computer Engineering, 428 S. Shaw Lane, East Lansing, MI 48824-1226

5:10 PM  Nondestructive Millimeter Wave Imaging and Spectroscopy Using Dielectric Focusing Probes
---Jose A. Hejase, IBM Corporation, Power Series Hardware Development, Austin, TX 78758; K. Y. Park, Steven S. Shane, and Premjeet (“Prem”) Chahal, Michigan State University, Terahertz Systems Laboratory (TeSLa) -- Electrical and Computer Engineering, East Lansing, MI 48824
Applications of Terahertz Waves on the Penetration in Thick FRP Composites

---Kwang-Hee Im, Woosuk University, Department of Automotive Engineering, Chonbuk, 565-701, Korea; David K. Hsu, Chien-Ping Chiou, and Daniel J. Barnard, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, Iowa, 50011; Je-Woong Park, Chosun University, Department of Naval Architecture and Ocean Engineering, Gwangju 501-759, Korea; In-Young Yang, Department of Mechanical Design Engineering, Chosun University, Gwangju 501-759, Korea

---Fiber reinforced plastics (FRP) are increasingly utilized in engineering structures because of their performance and fabrication advantages. With this increased utilization, a technique to gage quality and further characterize the materials would be beneficial. The nondestructive applications for Terahertz (T-ray) methods have also experienced increased utilization for evaluating engineering materials and will be reported on here in applications for the inspection and characterization of FRP materials used in wind energy components. First, reflection and transmission T-ray modes are used to determine the refractive index (n) of a glass fiber reinforced plastic (GFRP) reference sample, and extended for calculating the refractive indices for a sample of GFRP, balsa and epoxy. Additionally, carbon fiber reinforced plastic (CFRP) samples were evaluated with respect to fiber directions versus T-ray electric field polarization direction to evaluate the level of penetration of T-ray energy due to the fiber orientation dependent conductivity of this composite material. Finally, an evaluation of T-ray data was made to evaluate resonance effects, where the resonance frequency was found to agree with that expected from reflections from individual plies in thick GFRP laminates.

THz and FTIR Spectroscopic Imaging for NDE Applications

---Chien-Ping T. Chiou, Matthew Meyer, and Jonathan Runche, Iowa State University, Center for NDE, Applied Sciences Complex II, 1915 Scholl Road, Ames, IA 50011

---Terahertz radiation (THz), as an emerging electromagnetic modality for material characterization and inspection, has attracted much attention in NDE community in recent years. It not only complements existing infrared technology at the lower end of infrared spectrum, but also possesses exceptional penetrability and spatial resolution for inspecting many dielectric materials. Similar to conventional infrared techniques, THz is also capable of identifying material composition via spectral fingerprints. Better yet, it often performs well even under obscured condition. Utilizing this unique ability in a robotic scan system allows us to simultaneously obtain temporal, spatial and spectral information about a part, leading to the powerful approach of “spectroscopic imaging”. In this work, we demonstrate THz spectroscopic imaging by several application examples, including the assessment of low impact damage in glass fiber composites and the detection of concealed explosive surrogates. On the other hand, mobilizing the established infrared technology for NDE application is slower in development. Fieldable Fourier transform infrared (FTIR) equipment only became available recently and is still lack of imaging capability. For this shortcoming, we prototyped a scan frame to work with a commercial hand-held FTIR spectrometer and conducted a proof-of-principle study in FTIR imaging. A number of benchmark tests were carried out to determine the system’s performance limits such as scan resolution and detection sensitivity. Preliminary results successfully illustrate FTIR imaging and identification of various chemical contaminations on composites.---This material is based on work supported by the Army Research Laboratory as part of cooperative agreement number W911NF0820036 at the Center for Nondestructive Evaluation at Iowa State University.
**High Power THz Sources for Nonlinear Imaging**  
---Patrick F. Tekavec and Vladimir G. Kozlov, Microtech Instruments, 858 W Park Street, Eugene, OR 97401

---The Terahertz (THz) region of the electromagnetic spectrum (0.1 – 10 THz) is very attractive for non-destructive evaluation applications in defense, security, biomedical imaging, and monitoring of industrial processes. However, performance of THz imaging systems is limited by the lack of high power sources and sensitive detectors in this spectral range. Here we present a novel, high power THz source and propose an imaging method based on up-conversion of THz waves to infrared (IR) light which offers orders of magnitude increase in contrast over existing systems. The source is a terahertz parametric oscillator, which generates THz radiation through frequency down-conversion optical cavity. The output delivers 6 ps pulses at 1.5 THz, with an average power of >300 μW and peak power >450 mW. The proposed imaging method mixes the THz signal with IR light to create an up-converted image that can be detected with commercially available IR cameras. The high peak THz power provides high efficiency, while the narrow spectrum of THz and IR pulses produces an up-converted signal that can be spectrally filtered from the IR light. This has the potential for a dramatic increase in contrast compared to THz up-conversion images produced by broadband THz pulses.

**Non-Destructive Imaging with Compact, Portable Terahertz Systems**  
---Albert Redo-Sanchez, Norman Laman, Brian Schulkin, and Thomas Tongue, 15 Tech Valley Dr., Suite 102, East Greenbush, NY 12061

---Time of flight data provided by terahertz time-domain systems can be used to study the structural characteristics of materials that show certain transparency to terahertz waves such as plastics, ceramics, paper, canvas, textiles, foam, and certain composites. Similar to ultrasound, the position, amplitude and polarity of pulses contained in a terahertz waveform can be used to analyze the different layers of a sample and measure their thickness. In this paper, we show examples of using a compact THz time-domain system to analyze the layered structure of plastic slabs bonded with adhesive and inspection of artwork in search of defects and structural information not accessible by other methods, including optical and X-ray. The structural information capabilities that a time domain THz systems provide can be extended to other type of samples and applications. For example, a similar inspection could be done to measure coating thicknesses and check the integrity of a seal. Furthermore, the compact size, high speed, and high integration of systems such as the Mini-Z and Micro-Z enables the deployment of THz technology as a quality control tool at a production facility.
**Design Study of Millimeter Wave and THz Spoof Plasmon Near Field Probes for NDE Applications**

---Kyoung Youl Park and Premjeet (“Prem”) Chahal, Michigan State University, Department of Electrical and Computer Engineering, 428 S. Shaw Lane, East Lansing, MI 48824-1226

---This paper presents the design and test of spoof surface plasmon (SPs) enhanced THz near field probes in the millimeter wave and terahertz (THz) frequency range. Surface plasmon phenomenon has been utilized in the optical spectral range to enhance waveguiding and to achieve sub-wavelength focusing. Here this phenomenon is used to interrogate surface of an object under test to determine surface and sub-surface detects. The spoof surface plasmon structures are built using corrugated metal structure in a bulls-eye like pattern to confine the fields to a local spot in order to improve resolution and contrast. The electromagnetic propagation characteristics were simulated and analyzed using both FDTD and commercial FEM software tools. For the experimental setup, a free space setup that couples radiation from transmit and receive antennas to these probes is utilized. Details of probe design and experimental setup will be presented.

**Nondestructive Millimeter Wave Imaging and Spectroscopy Using Dielectric Focusing Probes**

---Jose A. Hejase, IBM Corporation, Power Series Hardware Development, Austin, TX 78758; Kyoung Y. Park, Steven S. Shane, and Premjeet (“Prem”) Chahal, Michigan State University, Terahertz Systems Laboratory (TeSLa) -- Electrical and Computer Engineering, East Lansing, MI 48824

---A tool for testing composite materials at small stand-off distances (near field region) in the transmission mode using a single source and detector millimeter wave measurement setup is presented. The structure can be used to interrogate small areas of structures at a wide band of frequencies. The design utilizes optical like principles for guiding electromagnetic millimeter waves from large cross-sectional areas to considerably smaller sub-wavelength areas. While plano-convex lenses can be used to focus waves to a fine resolution, they usually require a large stand-off distance thus resulting in alignment and spacing issues. The design procedure and simulation analysis of the focusing probes are presented in this study along with experimental verification of performance and imaging and spectroscopy examples. Many nondestructive evaluation applications can find benefit from such an apparatus including biological tissue imaging, electronic packaging integrity testing (including lamination and moisture ingression), composite dielectric structure evaluation for defects and microfluidic spectroscopy.
Session 41
Thursday, July 25, 2013

SESSION 41
THERMOGRAPHY AND THERMOSONICS II
Xiaoyan Han and Stephen D. Holland, Co-Chairpersons
Key Ballroom 12

3:30 PM  Estimation of Material Parameters from PPT-Data
---Bernhard Stotter, Karl-Heinz Gresslehner, Guenther Mayr, and Guenther Hendorfer, FH OOE Forschungs & Entwicklungsl GmbH, Wels, Austria; Jakov Sekelja, FACC AG, NDT Engineering, Ried, Austria

3:50 PM  Li-ion Batteries: Production NDE, Property Evaluation and Service Life Monitoring
---Leonid C. Lev, General Motors R&D, Mail Code 480-106-224, 30500 Mound Road, Warren, MI 48090; Nikolay Kondratyev, Meda Engineering, Warren, MI 48090

4:10 PM  Sonic IR Crack Detection of Aircraft Turbine Blades with Multi-Frequency Ultrasound Excitations
---Ding Zhang and Xiaoyan Han, Wayne State University, Department of Electrical and Computer Engineering, Detroit, MI 48202; Golam Newaz, Wayne State University, Department of Mechanical Engineering, Detroit, MI 48202; Lawrence Favro and Robert Thomas, Wayne State University, Department of Physics and Astronomy, Detroit, MI 48202

4:30 PM  A Quantitative NDE Method Suitable for the Investigation of Carbon Bicycles and Classic Automobiles by Using Active Thermography
---Volker Carl, Carl Messtechnik und Prüfsysteme, Thyssenstrasse 183, 46535 Dinslaken, Germany

4:50 PM  Eddy Current Pulsed Thermography for Evaluation of Gear Fatigue
---Gui Yun Tian1, 3, Aijun Yin2, 3*, Bin Gao1, 3, Jishan Zhang4, and Brian Shaw4, 1School of Automation Engineering, University of Electronic Science and Technology of China, Chengdu, Sichuan, 611731 P. R. China; 2State Key Laboratory of Mechanical Transmission College of Mechanical Engineering, Chongqing University, P. R. China; 3 School of Electrical and Electronic Engineering, Newcastle University, Newcastle upon Tyne, NE1 7RU, UK; 4 Design unit, School of Mechanical Engineering and System, Newcastle University, Newcastle upon Tyne, NE1 7RU, United Kingdom
Estimation of Material Parameters from PPT-Data

---Bernhard Stotter, Karl-Heinz Gresslehner, Guenthier Mayr, and Guenthier Hendorfer, FH OOE Forschungs & Entwicklung GmbH, Wels, Austria; Jakov Sekelja, FACC AG, NDT Engineering, Ried, Austria

---Previous studies of our research group have shown that the pulse-phase thermography (PPT) in reflection mode is a fast and effective method to detect flaws in CFRP (Carbon Fiber Reinforced Plastic) parts. We also have shown that PPT provides additional information about the inner structure of the specimen, such as staggered or concentrations of resin. This is a great advantage of PPT, because these defects are not detectable by the use of ultrasonic with an industrial setup. In this paper we present a method to extract material parameters of the examined specimens. A semi analytical solution for describing the theoretically phase curve was developed by using a Green’s Function for a Medium of thickness L. We adapted an algorithm to fit the measured data to the Green’s Function to obtain important material parameters in a fast and robust way. Furthermore studies on parts of the aviation industry validated the suitability of the PPT to extract material parameters from measurements.

Li-ion Batteries: Production NDE, Property Evaluation and Service Life Monitoring

---Leonid C. Lev, General Motors R&D, Mail Code 480-106-224, 30500 Mound Road, Warren, MI 48090; Nikolay Kondratyev, Meda Engineering, Warren, MI 48090

---Automotive Li-ion batteries are manufactured from Li-ion cells in a multi-step assembly process. To achieve the highest battery quality, NDE operations are used after each step of the assembly process. We will present some of the tests developed to evaluate the quality of the battery. Thermography is used to evaluate internal cell quality and the quality of the external welds. High-precision temperature measurements are used to evaluate the thermal properties of the cell. Changes in the cell properties throughout the battery service life provide the basis for evaluation of the battery State of Health (SOH).
4:10 PM

Sonic IR Crack Detection of Aircraft Turbine Blades with Multi-Frequency Ultrasound Excitations
---Ding Zhang and Xiaoyan Han, Wayne State University, Department of Electrical and Computer Engineering, Detroit, MI 48202; Golam. Newaz, Wayne State University, Department of Mechanical Engineering, Detroit, MI 48202; Lawrence Favro and Robert Thomas, Wayne State University, Department of Physics and Astronomy, Detroit, MI 48202

---Effectively and accurately detecting cracks or defects in critical engine components, such as turbine blades, is very important in aircrafts. Sonic Infrared (IR) Imaging is such a technology with great potential for these applications. This technology combines ultrasound excitation and IR imaging to identify cracks and flaws in targets. In general, failure of turbine blades begins with tiny cracks. Since the attenuation of the ultrasound wave propagation in turbine blades is small, the efficiency of crack detection in turbine blades can be quite high. The authors at Wayne State University have been developing the technology as a reliable tool for the future field use in aircraft engines and engine parts. One part of the development is to use finite element modeling to assist our understanding of effects of different parameters on crack heating while experimentally hard to achieve. The development has been focused with single frequency ultrasound excitation and some results have been presented in a previous conference. We are currently working on multi-frequency excitation models. The study will provide results and insights of the efficiency of different frequency excitation sources to foster the development of the technology for crack detection in aircraft engine components.
Eddy Current Pulsed Thermography for Evaluation of Gear Fatigue

---Gui Yun Tian1, 3, Aijun Yin2, 3*, Bin Gao1, 3, Jishan Zhang4, and Brian Shaw4, 1School of Automation Engineering, University of Electronic Science and Technology of China, Chengdu, Sichuan, 611731 P. R. China; 2State Key Laboratory of Mechanical Transmission College of Mechanical Engineering, Chongqing University, P. R. China; 3 School of Electrical and Electronic Engineering, Newcastle University, Newcastle upon Tyne, NE1 7RU, UK; 4 Design unit, School of Mechanical Engineering and System, Newcastle University, Newcastle upon Tyne, NE1 7RU, United Kingdom

---The pulsed eddy current (PEC) technique generates responses over a wide range of frequencies, containing more spectral coverage than traditional eddy current inspection. Eddy current pulsed thermography (ECPT), a newly developed non-destructive testing (NDT) technique, has advantages such as rapid inspection of a large area within a short time, high spatial resolution, high sensitivity and stand-off measurement distance. This paper investigates ECPT for the evaluation of gear fatigue tests. The paper proposes a statistical method based on single channel blind source separation to extract details of gear fatigue. The discussion of transient thermal distribution and patterns of fatigue contact surfaces as well as the non-contact surfaces have been reported. In addition, the measurement for gears with different cycles of fatigue tests by ECPT and the comparison results between ECPT with magnetic Barkhausen noise (MBN) have been evaluated. The comparison shows the competitive capability of ECPT in fatigue evaluation.
FRIDAY

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Session 42
SESSION 42
NEW QNDE TECHNIQUES AND APPLICATIONS
Igor Solodov, Chairperson
Holiday Ballroom 3

8:30 AM  Simulation of Computed Radiography with Imaging Plate Detectors
---D. Tisseur1, M. Costin1, F. Mathy2, and A. Schumm3, 1CEA LIST, CEA Saclay 91191 Gif sur Yvette Cedex, France; 2 CEA LETI, CEA Grenoble 38054 Grenoble Cedex, France; 3EDF R&D, 1 avenue du général de gaulle 92141 Clamart, France

8:50 AM  Split D Differential Probe Model Validation Using an Impedance Analyzer
---Jeremy S. Knopp, Air Force Research Labs (AFRL/RXCA) Wright Patterson AFB, OH, 45433; Ryan D. Mooers and Shamachary Sathish, University of Dayton Research Institute, Structural Integrity Division, NDE Branch, Dayton, OH, 45433; John C. Aldrin, Computational Tools, Gurnee IL, 60031

9:10 AM  Reverse Engineering of ECT Probes for Non-Destructive Evaluation of Moving Conductors
---Konstantin F. Porzig, Matthias Carlstedt, Hartmut Brauer, and Hannes Toepfer, Ilmenau University of Technology, Department of Advanced Electromagnetics, Ilmenau, Germany

9:30 AM  Using Phase Information to Enhance Speckle Noise Reduction in the Ultrasonic NDE of Coarse Grain Materials
---Timothy Lardner, Minghui Li, and Anthony Gachagan, University of Strathclyde, Centre for Ultrasonic Engineering, Glasgow, United Kingdom

9:50 AM  Local Defect Resonance (LDR): A Route to High-Performance Thermosonic and Nonlinear Ultrasonic NDT
---Igor Solodov, University of Stuttgart, Institute of Polymer Technology, Department of Non-Destructive Testing (IKT-ZfP), 70569 Stuttgart, Germany

10:10 AM  Break

10:30 AM  An Improved Piezoelectric Detection Method for Accurate Ultrasonic Nonlinearity Parameter Measurements
---To Kang, Taek Gyu Lee, Sung-Jin Song, and Hak-Joon Kim, Sungkyunkwan University; Jeong-Kwan Na, Edison Welding Institute, 1250 Arthur E. Adams Drive, Columbus, OH 43221

10:50 AM  Analysis on Closed Crack in Nonlinear Ultrasonic Images Using Amplitude Difference by Damped Double Node Model
---Kentaro Jinno, Masako Ikeuchi, Azusa Sugawara, Yoshikazu Ohara, and Kazushi Yamanaka, Tohoku University, Department of Materials Processing, Sendai, Miyagi, Japan

11:10 AM  Parallel Implementation of the Genetic Algorithm on NVIDIA GPU Architecture for Synthesis and Inversion
---Victor U. Karthik, Sivamayam Sivasuthan, and Samuel Ratnajeevan H. Hoole, Michigan State University, Department of Electrical and Computer Engineering, East Lansing, MI 48824

11:30 AM  Adjourn
Simulation of Computed Radiography with Imaging Plate Detectors

---D. Tisseur\(^1\), M. Costin\(^1\), F. Mathy\(^2\), and A. Schumm\(^3\), \(^1\)CEA LIST, CEA Saclay 91191 Gif sur Yvette Cedex, France; \(^2\) CEA LETI, CEA Grenoble 38054 Grenoble Cedex, France; \(^3\)EDF R&D, 1 avenue du général de gaulle 92141 Clamart, France

---Computed radiography (CR) using phosphor imaging plate detectors is taking an increasing place in Radiography Testing. CR uses similar equipment as conventional radiography except that the classical X-ray film is replaced by a numerical detector, called image plate (IP), which is made of photostimulable layer and which is read by a scanning device through photostimulated luminescence. Such digital radiography has already demonstrated important benefits in terms of exposure time, decrease of source energies and thus reduction of radioprotection area besides being a solution without effluents. This paper presents a model for the simulation of radiography with image plate detectors in CIVA together with examples of validation of the model. The study consists in a cross comparison between experimental and simulation results obtained on a step wedge with a classical X-ray tube. Results are proposed in particular with wire Image Quality Indicator (IQI) and duplex IQI.

Split D Differential Probe Model Validation Using an Impedance Analyzer

---Jeremy S. Knopp, Air Force Research Labs (AFRL/RXCA) Wright Patterson AFB, OH, 45433; Ryan D. Mooers and Shamachary Sathish, University of Dayton Research Institute, Structural Integrity Division, NDE Branch, Dayton, OH, 45433; John C. Aldrin, Computational Tools, Gurnee IL, 60031

---Impedance analyzers provide the highest standard for validating computational eddy current NDE models. By directly comparing the measured impedance response with the simulation output, the model can be validated for a known case of test conditions. Validation becomes more complex when differential probes are employed. Previous attempts at validating split D differential probe models have used commercial eddy current meters. These meters only produce a voltage representation of the differential response and thus are limited to either a qualitative comparison or relative quantitative comparisons with a 'calibration' case. To properly validate differential models, a new test cable configuration was employed to enable the impedance analyzer to collect data from the differential probe. In this system, each coil in the probe was read separately and the differential signal was created through post-processing. Experimental scans were run along two scan directions over two EDM notches of different surface lengths. Models were created using VIC 3D(c) for each case. Complete details about the experimental scans and model construction will be presented. A comparison of the simulated and experimental data sets showing good agreement will be presented along with conclusions about the validation of the models.
Reverse Engineering of ECT Probes for Non-Destructive Evaluation of Moving Conductors
---Konstantin F. Porzig, Matthias Carlstedt, Hartmut Brauer, and Hannes Toepfer, Ilmenau University of Technology, Department of Advanced Electromagnetics, Ilmenau, Germany

---Nowadays numerical simulations, its experimental validation and the comparison to common methods are essential key points in the development process of new NDE methods. This work is motivated by the comparison between the new technique “Lorentz force eddy current testing” (LET) and classical eddy current testing (ECT). Therefore, numerical modeling of available ECT devices requires preparatory work in reverse engineering. The reconstruction of given ECT probes was performed in terms of (i) geometry, (ii) material properties and source parameters, and (iii) normalized impedance calculation. Limited available information about commercial hardware makes the reconstruction process more difficult and increases time consumption. High-resolution X-ray images were taken in order to build appropriate CAD models of given ECT probes. An optimization strategy was applied in order to estimate the permeability of the magnetic shield as well as the supply current by means of measurement data of the magnetic flux density. Subsequently, normalized impedance calculations were performed and compared to measurements to validate receiver coil configurations. As a result, these models were used and compared in generic benchmark models with moving conductors containing artificial defects.

Using Phase Information to Enhance Speckle Noise Reduction in the Ultrasonic NDE of Coarse Grain Materials
---Timothy Lardner, Minghui Li, and Anthony Gachagan, University of Strathclyde, Centre for Ultrasonic Engineering, Glasgow, United Kingdom

---Materials with a coarse grain structure are becoming increasingly prevalent in industry due to their resilience to stress and corrosion. These materials are difficult to inspect with ultrasound because reflections from the grains lead to high noise levels which hinder the echoes of interest. Spatially Averaged Sub-Aperture Correlation Imaging (SASACI) is an advanced array beamforming technique that uses the cross-correlation between images from array sub-apertures to generate an image weighting matrix, in order to reduce noise levels. This paper presents a method to further improve SASACI using phase information to improve focusing and reduce reflections from sidelobes. A-scans from adjacent array elements are cross-correlated to refine initial delay laws and minimize phase aberration. The differences between correctly focused, instantaneous phases are used to create the phase coherence factor which is a weighting matrix that is combined with SASACI’s output via data fusion. Each processing stage is within a domain orthogonal to the others, therefore they are potentially synergistic. This approach was validated experimentally using a 5 MHz array on both stainless steel and Inconel welds, and compared to traditional SASACI. Initial results have seen SNR improvements of 15 dB compared to SASACI, and the resolution is 40% higher.
9:50 AM

Local Defect Resonance (LDR): A Route to High-Performance Thermosonic and Nonlinear Ultrasonic NDT
---Igor Solodov, University of Stuttgart, Institute of Polymer Technology, Department of Non-Destructive Testing (IKT-ZfP), 70569 Stuttgart, Germany

---The concept of LDR is based on the fact that inclusion of a defect leads to a local drop of rigidity for a certain mass of the material and therefore manifests in a particular characteristic frequency of the defect. A frequency match between the driving ultrasonic wave and this characteristic frequency provides an efficient energy pumping from the wave directly into the defect. For simulated and realistic defects in various materials, the LDR-induced local increase in the vibration amplitude averages up to ~ (20-40 dB). Due to a strong resonance amplification of the local vibrations, the LDR-driven defects exhibit a profound nonlinearity even at moderate ultrasonic excitation level. The nonlinearity combined with resonance results not only in an efficient generation of the higher harmonics but is also used as a filter/amplifier in the frequency mixing mode of nonlinear NDT. The LDR produces a high-Q thermal response and enables to implement frequency-selective thermosonic imaging with an opportunity to distinguish between different defects by changing the driving frequency. The LDR-thermosonics requires much lower acoustic power to activate defects that makes it possible to avoid high-power ultrasonic instrumentation and even proceed to a remote ultrasonic thermography by using air-coupled ultrasonic excitation.

10:30 AM

An Improved Piezoelectric Detection Method for Accurate Ultrasonic Nonlinearity Parameter Measurements
---To Kang, Taek Gyu Lee, Sung-Jin Song, and Hak-Joon Kim, Sungkyunkwan University; Jeong-Kwan Na, Edison Welding Institute, 1250 Arthur E. Adams Drive, Columbus, OH 43221

---An improved piezoelectric detection measurement of nonlinearity parameter is presented in Cu [100] and Ti-6Al-4V. Piezoelectric detection measurement has been interested to measure nonlinearity parameter during two decades years due to experimental simplicity (its industrial adoptable approach) compare to capacitive detector and Michelson interferometer. Despite of the simplicity with the piezoelectric method, it has been found that the level of experimental uncertainties is close to ±10%, which is considered to be too high. The primary source of this high uncertainty level was found to be caused by the FFT or IFFT signal processing performed with highly noisy second harmonic signals. So, in this study, we describe improved piezoelectric detection measurement to improve linearity of vs. and determine accurate nonlinearity parameter with simple addition of a high Q-valued band-pass filter and a low-noise preamplifier in the current piezoelectric detection process.---This work was supported by the Power Generation & Electricity Delivery Program of the Korea Institute of Energy Technology Evaluation and Planning (KETEP) grant funded by the Korea government Ministry of Knowledge Economy (No. 20111020400020), and in part by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MEST) (No. 2011-0020024).
10:50 AM

Analysis on Closed Crack in Nonlinear Ultrasonic Images Using Amplitude Difference by Damped Double Node Model

---Kentaro Jinno, Masako Ikeuchi, Azusa Sugawara, Yosikazu Ohara, and Kazushi Yamanaka, Tohoku University, Department of Materials Processing, Sendai, Miyagi, Japan

---For applying nonlinear ultrasound techniques to closed cracks, simulation model of closed crack is required. So, we have reported 2D analysis of subharmonic generation at closed cracks using damped double nodes (DDN) by FDTD method. However, this model was not detailed enough for real condition sufficiently. Here, we improved this model by enlarging its calculating area, adding a wider array and a notch to simulate a fatigue crack specimen and extending the lateral crack model to vertical one. In snapshots of incident wave, scattered waves from the notch were always observed. While at the closed crack, small amplitude incident wave was completely transmitted, but scattered waves were observed only with large amplitude incident wave. By making similar simulation condition to real fatigue crack specimen, simulated images with respective amplitudes were agreed well with the experimental results in features of crack tip and the notch responses. So, this model can be used as simulation model of nonlinear ultrasound images for fatigue crack specimen. Furthermore, we simulated the application of the subharmonic amplitude difference (SAD) and fundamental amplitude difference (FAD) methods. These results were also agreed well with the experimental results.

11:10 AM

Parallel Implementation of the Genetic Algorithm on NVIDIA GPU Architecture for Synthesis and Inversion

---Victor U. Karthik, Sivasuthan, and Samuel Ratnajeevan H. Hoole, Michigan State University, Department of Electrical and Computer Engineering, East Lansing, MI 48824

---The computational algorithms for device synthesis and NDE are often the same. In both we have a goal – a particular field configuration yielding the design performance in synthesis or to match exterior measurements in NDE. The geometry of the design or the postulated interior defect is then computed. Several optimization methods are available for this. The most efficient like conjugate gradients are very complex to program for the required derivative information. The least efficient zeroth order algorithms like the genetic algorithm take much computational time but little programming effort. This paper reports launching a Genetic Algorithm kernel on thousands of CUDA threads exploiting the NVIDIA GPU architecture. The efficiency of parallelization, although below that on shared memory supercomputer architectures, is quite effective in cutting down solution time into the realm of the practicable. We carry this further into multiphysics electroheat problems where the parameters of description are in the electrical problem and the object function in the thermal problem. Indeed, this is where the derivative of the object function in the heat problem with respect to the parameters in the electrical problem is the most difficult to compute for gradient methods, and where the genetic algorithm is most easily implemented.
Session 43
SESSION 43
ULTRASONICS – NEW TECHNIQUES AND SENSORS
Vinay Dayal, Chairperson
Key Ballroom 9

8:30 AM A Fast Ultrasonic Simulation Tool Based on GPU Implementation
---Jason Lambert, Gilles Rougeron, and Sylvain Chatillon, CEA, LIST, F-91191 Gif-sur-Yvette, France; Lionel Lacassagne, Université Paris-Sud, LRI, F-91405 Orsay cedex, France

8:50 AM Stress Wave Simulations Using a GPU
---Peter Huthwaite and Michael J. S. Lowe, Imperial College, 682 Mechanical Engineering, Exhibition Road, London SW7 2AZ, United Kingdom

9:10 AM Development of an Ultrasonic Pulse-Echo (UPE) Technique for Aircraft Icing Studies
---Yang Liu, Wenli Chen, Leonard J. Bond, and Hui Hu, Iowa State University, Department of Aerospace Engineering, 2271 Howe Hall, Room 1200, Ames, IA 50011

9:30 AM Precise Wall Thinning Measurement in Inaccessible Regions of Pipes Using Ultrasonic Multiple Reflection Method Using a Collimated Beam
---Yoshikazu Ohara, Hironori Yoshida, Kentaro Jinno, Akihiro Ohuchi, and Kazushi Yamanaka, Tohoku University, Department of Materials Processing, Sendai, Miyagi, Japan

9:50 AM Topological Imaging of Defects by Inspection of Lamb Waves
---S. Rodriguez, M. Deschamps, and M. Castaings, University of Bordeaux, I2M, UMR-CNRS 5295, F-33400 Talence, France; E. Ducasse, Arts Et M_etiers Paristech, I2M, UMR-CNRS 5295, F-33400 Talence, France

10:10 AM Break

10:30 AM Study on EMAT Configuration for Generating SH Waves
---Tatsuya Hiramoto, Kodai Okazaki, and Toshihiko Sugiura, Keio University, Department of Mechanical Engineering, Yokohama, Kanagawa, Japan

10:50 AM How to Generate Omni-Directional Shear-Horizontal Waves in Plates?
---Hong Min Seung and Yoon Young Kim, Seoul National University, School of Mechanical and Aerospace Engineering, Seoul, Republic of Korea; Hoe Woong Kim, Korea Atomic Energy Research Institute, Fast Reactor Technology Demonstration Division, Daejeon, Republic of Korea

11:10 AM Passive Wireless Ultrasonic Transducer Systems
---Cheng H. Zhong, Paul D. Wilcox, and Anthony J. Croxford, University of Bristol, Mechanical Engineering, Faculty of Engineering, Queen's Building, University Walk, Bristol, BS8 1TR, United Kingdom

11:30 AM Calculation of Ultrasonic Fields Radiated in a Ferromagnetic Medium by an EMAT of Arbitrary Bias Field Driven by a Current of Arbitrary Intensity
---Clémence Rouge and Alain Lhémery, CEA, LIST, Gif-sur-Yvette, France; Christophe Aritégui, Université de Bordeaux, UMR CNRS 5295, I2M/Acoustique Physique, Talence, France; Henri Walaszek, CETIM, Senlis, France

11:50 AM Air-Coupled Ultrasonic Testing of Metal Adhesively Bonded Joints Using Cellular Polypropylene Transducers
---Mate Gaal, Jürgen Bartusch, Elmar Dohse, and Marc Kreutzbruck, BAM - Federal Institute for Materials Research and Testing, Berlin, Germany; Jay M. Amos, Cessna Aircraft, Wichita, KS 67277

12:10 PM Adjourn
A Fast Ultrasonic Simulation Tool Based on GPU Implementation
---
Jason Lambert, Gilles Rougeron, and Sylvain Chatillon, 1CEA, LIST, F-91191 Gif-sur-Yvette, France; Lionel Lacassagne, Université Paris-Sud, LRI, F-91405 Orsay cedex, France

---This paper presents a CIVA optimized ultrasonic inspection simulation tool, which takes benefit of the power of massively parallel graphical processing units (GPU). This tool is based on the classical approach used in CIVA: the interaction model is based on Kirchhoff, and the ultrasonic field around the defect is computed by the pencil method. The model has been adapted and parallelized for GPU with the CUDA language. At this stage, the configurations addressed by the tool are: multi and mono-element probes, simple isotropic materials, planar rectangular defects or side drilled holes of small diameter. Validations on the model accuracy and performances measurements are presented.

Stress Wave Simulations Using a GPU
---
Peter Huthwaite and Michael J. S. Lowe, Imperial College, 682 Mechanical Engineering, Exhibition Road, London SW7 2AZ, United Kingdom

---The fast generation of accurate numerical wave propagation data is important for research in the field of non-destructive testing, allowing predictions to be made prior to lab tests, and also forms a key component of inversion imaging methods. The majority of numerical wave calculation methods are highly parallelizable, with the same calculation being performed many times with different input values. Graphics cards are widely recognized to possess an architecture well suited to such calculations, by allowing many small, lightweight threads to be run in parallel. In this presentation we introduce Pogo, a solver written to calculate the propagation of stress waves using a graphics card. The finite element method was used, since it is well suited to modelling the complex structures common in a number of fields. Pogo is available as an open source package, and has been found to allow a speed improvement of approximately two orders of magnitude over typical commercial finite element packages run on the CPU. This talk will discuss various aspects of the implementation and some examples of the performance compared to commercial alternatives will be presented.
Development of an Ultrasonic Pulse-Echo (UPE) Technique for Aircraft Icing Studies
--- Yang Liu, Wenli Chen, Leonard J. Bond, and Hui Hu, Iowa State University, Department of Aerospace Engineering, 2271 Howe Hall, Room 1200, Ames, IA 50011

--- Aircraft operating in some cold weather conditions face the risk of icing. Icing poses both a safety threat to flight safety and its management is expensive. Removing light frost on a clear day from a medium-size business jet can cost $300, heavy wet snow removal can cost $3,000 and removal of freezing rain can cost close to $10,000. Understanding conditions that lead to severe icing events is important and challenging. When an aircraft or rotorcraft flies in a cold climate, some of the super cooled droplets impinging on exposed aircraft surfaces may flow along the surface prior to freezing to form ice shapes. The runback behavior of water film on aircraft wings would affect the ice formation and accretion on aircraft wings greatly. In this study, we report the recent progress made in our effort to develop an Ultrasonic Pulse-Echo (UPE) technique to achieve time-resolved thickness distribution measurements of surface water flows driven by boundary layer airflows for aircraft icing studies. A series of experimental investigations are conducted in an open circuit wind tunnel employing an array of ultrasonic transducers flush mounted with the surface of a flat plate for the UPE measurements. The water runback behavior on the plate is evaluated by measuring the thickness profile variation of the surface water film along surface by using UPE technique under various wind speed and flow rate conditions.

Precise Wall Thinning Measurement in Inaccessible Regions of Pipes Using Ultrasonic Multiple Reflection Method Using a Collimated Beam
--- Yoshikazu Ohara, Hironori Yoshida, Kentaro Jinno, Akihiro Ohuchi, and Kazushi Yamanaka, Tohoku University, Department of Materials Processing, Sendai, Miyagi, Japan

--- Wall thinning of pipe is inspected by ultrasonic thickness meter. However, the inspection becomes difficult in transducer-inaccessible regions such as branched pipe with a reinforcing plate. To solve this problem, the M-skip has been proposed. It uses multiple reflections of shear waves in pipe with a transmission configuration, where transducers are positioned on both sides of the inaccessible region. Note that the algorithm for measuring wall thinning depths is based on the propagation of diffusive waves. However, an exact algorithm considering the curvature is difficult to formulate because the reflection of the diffusive wave on curved surfaces is complicated. Moreover, a part of the diffusive wave with wide angular components should inevitably hit the fillet welds between reinforcing plate and main pipe. They are drawbacks for achieving very precise wall thinning measurements. In this study, we propose a multiple reflection of a collimated beam (CB) before diffusing due to diffraction. Because of the simplicity of CB, we successfully formulated an algorithm considering the curvature. Furthermore, the effect of weld can be avoided by using a CB generated by a variable angle transducer (VAT), which enables us to select an appropriate incidence angle. In the verification, we first applied the method to a pipe without wall thinning and welded a reinforcing plate. By selecting an appropriate incidence angle with VATs, we succeeded in observing the transmitted waves without the disturbance of fillet weld. Then we applied it to the specimens with various wall thinning depths (1, 3, 5, 7 mm) for circumferential propagation. As a result, the measurement error was less than 0.1 mm, smaller than that obtained by the M-skip.
Topological Imaging of Defects by Inspection of Lamb Waves
---S. Rodriguez, M. Deschamps, and M. Castaings, University of Bordeaux, I2M, UMR-CNRS 5295, F-33400 Talence, France; E. Ducasse, Arts Et M etiers Paristech, I2M, UMR-CNRS 5295, F-33400 Talence, France

---Topological imaging is a recent method. So far, it has been applied to bulk waves, and high resolution has been demonstrated for imaging scatterers even with a single ultrasonic insonification of the inspected medium. This method consists in (i) emitting waves and measuring the response of the medium; (ii) solving two propagation problems: the direct problem, where the source is the one used for the insonification, and the adjoint problem, where the source is the time-reversed difference between the wave field measured and that obtained in the direct problem; (iii) computing the image from the two wave fields simply by multiplying both fields in the frequency domain, and integrating over the frequency. The quickness of the method only depends on the cost of the field computations that are performed in the defect-less medium. The present work deals with the application of the topological imaging to guided waves. Combining modal theory and Fourier analysis, the computations are performed in a very short time. The two-dimensional in-plane imaging is based on the propagation of the single S0 Lamb mode. Despite very high dispersion, scatterers are accurately localized and the spatial resolution is equal about one wavelength.

Study on EMAT Configuration for Generating SH Waves
---Tatsuya Hiramoto, Kodai Okazaki, and Toshihiko Sugiura, Keio University, Department of Mechanical Engineering, Yokohama, Kanagawa, Japan

---Guided wave is ideal for rapid non-destructive testing of thin plates. Among several modes of guided wave, shear horizontal (SH) wave is useful because of its simple dispersion characteristics. To generate SH wave, ElectroMagnetic Acoustic Transducers (EMATs) are more suitable than traditional transducers. Instead of known EMAT configurations such as PPM (Periodic Permanent Magnet), we propose an another configuration, which arrays several coils whose windings reverse alternately; Four sets of coils are placed next to each other, and two magnets are set to apply a magnetic field. We calculated dispersion curves to know the group velocities and to decide the optimal input frequency. Further, we did experiments to excite the zeroth-order symmetric mode, the lowest mode of SH wave, on an aluminum plate. In experiments, we input burst signals to a transmitter EMAT and observed the electric signal picked up by a receiver EMAT. As a result, the arrival times of the signal well correspond to theoretical ones lead from the dispersion curves. That means elastic wave is surely generated. We also confirmed that we can obtain the strongest signal when the frequency is at optimal point. In conclusion, we successfully generated the zeroth-order SH waves with these EMATs.
10:50 AM

How to Generate Omni-Directional Shear-Horizontal Waves in Plates?
---Hong Min Seung and Yoon Young Kim, Seoul National University, School of Mechanical and Aerospace Engineering, Seoul, Republic of Korea; Hoe Woong Kim, Korea Atomic Energy Research Institute, Fast Reactor Technology Demonstration Division, Daejeon, Republic of Korea

---Omni-directional transducers are important elements in forming ultrasonic phased-array systems. In this direction, we aim to develop transducers that can generate omni-directional ultrasonic Shear-Horizontal (SH) waves in a thin plate. While several transducers to generate bulk waves or guided Lamb waves are reported, there appears no transducer that transmits truly omni-directional SH waves. Here, we present a new transducer configuration operating by the magnetostrictive principle, the coupling phenomenon between strain and magnetic field. A typical SH wave magnetostrictive patch transducer applicable to plates consists of a thin magnetostrictive patch, coil and permanent magnets where the patch bonded onto a test plate generates SH waves. Because SH waves can be generated when the static bias magnetic field and the dynamic magnetic field to the patch are orthogonal to each other, static field should be radial in the patch while dynamic field, circumferential in the patch. To fulfill this requirement, we developed a new transducer consisting of an annular magnetostrictive patch, a cylindrical permanent magnet, and a specially-wound coil over the patch. Simulations as well as experiments were conducted to verify the omni-directivity of the developed transducer.

11:10 AM

Passive Wireless Ultrasonic Transducer Systems
---Cheng H. Zhong, Paul D. Wilcox, and Anthony J. Croxford, University of Bristol, Mechanical Engineering, Faculty of Engineering, Queen’s Building, University Walk, Bristol, BS8 1TR, United Kingdom

---Inductive coupling and capacitive coupling both offer simple solutions to wirelessly probe ultrasonic transducers. This paper investigates the theory and feasibility of such systems in the context of non-destructive evaluation (NDE) applications. Firstly, the physical principles and construction of an inductively coupled transducer system (ICTS) and a capacitively coupled transducer system (CCTS) are introduced. Then the development of a transmission line model with the measured impedance of a bonded piezoelectric ceramic disc representing a sensor attached to an arbitrary solid substrate for both systems is described. The models are validated experimentally. Several applications of ICTS and CCTS are presented, such as using ICTS for 300 mm coil separation wireless inspection, and using CCTS for the underwater inspection.
Calculation of Ultrasonic Fields Radiated in a Ferromagnetic Medium by an EMAT of Arbitrary Bias Field Driven by a Current of Arbitrary Intensity

---Clémence Rouge and Alain Lhémery, CEA, LIST, Gif-sur-Yvette, France; Christophe Aristégui, Université de Bordeaux, UMR CNRS 5295, I2M/Acoustique Physique, Talence, France; Henri Walaszek, CETIM, Senlis, France

---EMATs (ElectroMagnetic Acoustic Transducers) are contactless transducers generating ultrasonic waves in conductive media, notably shear horizontal and torsional waves (in plates and pipes), possibly in hostile environments. In a ferromagnetic part, the elastic strain and the magnetic field couple through magnetostriction phenomena, so that a magnetostriction force adds up to the Lorentz force created in any conductive media. Here, a model is proposed to predict these forces for an arbitrary bias field due to the EMAT permanent magnet and whatever the current intensity in its electric circuit, whereas the usual assumption of high bias field and low intensity current leads to important model simplifications. To handle the nonlinear behavior of both the Lorentz and the magnetostriction forces when the usual assumption cannot be made, both forces are expressed in the time domain. In particular, magnetostriction force generates waves at several harmonic frequencies of the driving current frequency. Both forces are transformed into equivalent surface stresses readily usable as source terms in existing models of ultrasonic radiation, under the assumption that ultrasonic wavelengths are much longer than force penetration depths, which is generally true in NDT applications of EMATs. Force spectra computed in various EMAT configurations are compared for illustration.

Air-Coupled Ultrasonic Testing of Metal Adhesively Bonded Joints Using Cellular Polypropylene Transducers

---Mate Gaal, Jürgen Bartusch, Elmar Dohse, and Marc Kreutzbruck, BAM - Federal Institute for Materials Research and Testing, Berlin, Germany; Jay M. Amos, Cessna Aircraft, Wichita, KS

---Adhesively bonded aluminum components have been widely used in the aerospace industry for weight-efficient and damage-tolerant structures. Automated squirter jet immersion ultrasonic testing is a common inspection technique to assure the bond integrity of large, contoured assemblies. However, squirter jet inspection presents several limitations in scanning speed, related to water splash noise over protruding stiffeners and splash interference crosstalk in multi-channel inspection systems. Air-coupled ultrasonic testing has been employed as an alternative, offering the benefits of increased throughput by enabling higher speeds, and eliminating the maintenance issues of water couplant systems. Adhesive joints of multi-layer aluminum plates with artificial disbonds were inspected with novel air-coupled ultrasonic probes based on cellular polypropylene. Disbonds 13 x 13 mm (0.5”x0.5”) in size were engineered in several multi-layer configurations and at various depths. Results will be compared with squirter jet immersion and conventional piezoelectric transducer designs in terms of scan contrast, resolution and inspection time.
Session 44
8:30 AM Graphics Processing Unit (GPU) for Fast Inversion of Material Data from Ultrasonic Measurements
---Chetan Bademi, Nahas C.A., Krishnan Balasubramaniam and Prabhu Rajagopal, Center for NDE, Indian Institute of Technology Madras, Chennai 600036, T.N., India

8:50 AM Model-Based Inverse Methods for Bolt-Hole Eddy Current (BHEC) Inspections
---John C. Aldrin, Computational Tools, Gurnee, IL 60031; Harold A. Sabbagh, Elias Sabbagh and R. Kim Murphy, Victor Technologies LLC, Bloomington, IN 47401; Mark Keiser and David S. Forsyth, TRI/Austin, Austin, TX 78746

9:10 AM Depth Sizing of Intergranular Attack with Multi-Frequency Analysis of Eddy Current Data
---Jia Lei and Dag Horn, Atomic Energy of Canada Limited - Chalk River Laboratories, Inspection Monitoring and Dynamics, Chalk River, Ontario K0J 1J0, Canada

9:30 AM Determination of Linear Defect Depths from Eddy Currents Disturbances
---Helena G. Ramos, Tiago J. Rocha, Artur L. Ribeiro, and Dário J. Pasadas, Instituto Telecomunicações, Instituto Superior Técnico, Universidade de Lisboa, Portugal

---John C. Aldrin, Computational Tools, 7275 Chatham Avenue, Gurnee, IL 60031; Ryan D. Mooers, University of Dayton Research Institute, Dayton, OH 45469; Gary Steffes, Jeremy S. Knopp, Mark P. Blodgett and Eric A. Lindgren, Air Force Research Laboratory (AFRL/RXCA), Wright-Patterson AFB, OH 48533-7816

10:10 AM Adjourn
FRIDAY, SESSION 44

8:30 AM

Graphics Processing Unit (GPU) for Fast Inversion of Material Data from Ultrasonic Measurements
---Chetan Bademi, Nahas C.A., Krishnan Balasubramaniam and Prabhu Rajagopal, Center for NDE, Indian Institute of Technology Madras, Chennai 600036, T.N., India

---Many researchers have proposed the inversion of material properties of composite materials based on measurements of ultrasonic velocity. Such inverse problems are multi-parameter optimization problems and solution procedures often require the use of methods such as evolutionary algorithms. Codes based on evolutionary algorithms however can take very long to run when written and computed serially. Recent advances in Graphics Processing Unit (GPU) technologies offer the attraction of affordable advanced parallel programming. Here we study the application of GPU-based parallel processing for inversion of composite material properties from ultrasonic velocity data using Differential Evolution (DE). To parallelize the DE process, at every iteration of the loop a set of candidates and the fitness function are passed to the GPU. The GPU evaluates the fitness function and returns the fitness values of each candidate. The CPU then performs mutations and crossovers and passes the new set of candidates to the GPU. The algorithm was implemented using the CUDA compiler. Benchmarking tests were run for various problem sizes on a Nvidia GTX260 (compute capability 1.3) on an Intel E8400 3.0 GHz Core2 Duo processor. Results show that the speed-up achieved by the GPU version of the code depends on the NP, the population size. For values of NP less than 2000, the CPU version is faster, since the time required for computation is less than the time required to copy the data to the GPU. As the population size increases, the GPU version is much faster, and achieves a speed up of 20-30 for larger population sizes. However, at very large values (NP > 10000) of population sizes, the speed up achieved decreases slightly as the copying of data between the CPU and the GPU through the PCIe bus is a bottleneck.

8:50 AM

Model-Based Inverse Methods for Bolt-Hole Eddy Current (BHEC) Inspections
---John C. Aldrin, Computational Tools, Gurnee, IL 60031; Harold A. Sabbagh, Elias Sabbagh and R. Kim Murphy, Victor Technologies LLC, Bloomington, IN 47401; Mark Keiser and David S. Forsyth, TRI/Austin, Austin, TX 78746

---As maintenance of structural components of aircraft moves from time-based maintenance to condition-based maintenance, there is a need for innovative methods to not simply detect damage but to completely characterize their state. This paper presents progress on enhancing flaw characterization capability for bolt hole eddy current (BHEC) techniques. First, this work presents a comprehensive approach to perform model-based inversion of crack characteristics using eddy current techniques. This process includes a complete assessment of key factors, fast and accurate forward models, a robust noise removal process, the use of feature extraction to minimize inversion problem complexity, a model calibration and verification process, robust inverse method parameter estimation techniques, and a software environment to facilitate inversion applications. Second, progress has been made on a demonstration of using inverse methods of crack characterization using a BHEC nondestructive evaluation technique. Data were acquired using standard eddy current hardware for cases of through cracks in thin specimens, semi-elliptical mid-bore cracks in thick specimens and EDM notches in a calibration standard. Signal processing algorithms were developed to process and extract features from the 2D data sets, and inversion algorithms using VIC-3D® simulations were implemented. The results were found to be accurate within 10% for depth for through cracks and able to accurately bin mid-bore cracks by size.
9:10 AM

**Depth Sizing of Intergranular Attack with Multi-Frequency Analysis of Eddy Current Data**

---Jia Lei and Dag Horn, Atomic Energy of Canada Limited - Chalk River Laboratories, Inspection Monitoring and Dynamics, Chalk River, Ontario K0J 1J0, Canada

---Depth sizing of intergranular attack (IGA) with conventional eddy-current analysis is difficult, and typically gives results of poor accuracy. This paper presents a sizing technique using multi-frequency analysis for bobbin probe and X-Probe eddy-current data, along with a case study of outer-surface IGA in a 0.51” (12.95 mm) diameter, 0.044” (1.12 mm) wall Alloy 600 tubing. A mathematical framework for the expected eddy-current phase and amplitude response is provided. Using this formulation, eddy-current amplitude and phase responses at four inspection frequencies are calculated, and compared to the corresponding measured responses. IGA flaw geometry is approximated through the optimization of flaw parameters via a least-squares minimization of the residual from the comparison. Results from comparing IGA depth estimates from destructively examined depths showed root-mean-squared errors of 12% and 6% through-wall for the bobbin probe and X-Probe sizing techniques, respectively. This was a substantial improvement over traditional bobbin probe phase sizing and X-Probe amplitude sizing methods, with root-mean-squared errors of 29% and 28% through-wall, respectively.

9:30 AM

**Determination of Linear Defect Depths from Eddy Currents Disturbances**

---Helena G. Ramos, Tiago J. Rocha, Artur L. Ribeiro, and Dário J. Pasadas, Instituto Telecomunicações, Instituto Superior Técnico, Universidade de Lisboa, Portugal

---One of the still open problems in the inspection research concerns the determination of the maximum depth to which a surface defect goes. Eddy current testing being one of the most sensitive well established inspection methods, able to detect and characterize different types of defects in conductive materials, is an adequate technique to solve this problem. This paper reports a study concerning the disturbances in the magnetic field and in the lines of current due to a machined linear defect having different depths in order to extract relevant information that allows the determination of the defect characteristics. The image of the eddy currents (EC) is paramount to understand the physical phenomena involved. The EC images for this study are generated using a commercial finite element model (FLUX). The used excitation produces spatially a uniform magnetic field on the plate under test in the absence of defects and the disturbances due to the defects are compared with those obtained from experimental measurements. In order to increase the limited measuring range obtained with detection coils, giant magnetoresistors (GMR) are used which also allow to lower the working frequency. The geometry of the excitation planar coil produces a uniform magnetic field on an area around the GMR sensor, inducing a uniform eddy current distribution on the plate. In the presence of defects in the material surface, the line of currents inside the material are forced to flow around or underneath the defect and the magnetic field produced by these current disturbances is sensed by the GMR sensor. The paper describes the theoretical study of the electromagnetic system, the experiments that have been carried out to support the theory and conclusions are drawn for cracks having different depths.
Model-based Approach to Multi-parameter Crack, Part and Measurement System State Estimation for the Inspection of Fastener Sites Using Eddy Current NDE
---John C. Aldrin, Computational Tools, 7275 Chatham Aveune, Gurnee, IL 60031; Ryan D. Mooers, University of Dayton Research Institute, Dayton, OH 45469; Gary Steffes, Jeremy S. Knopp, Mark P. Blodgett and Eric A. Lindgren, Air Force Research Laboratory (AFRL/RXCA), Wright-Patterson AFB, OH 45433-7816

---To improve the ability of eddy current techniques to characterize fatigue cracks in multilayer structures, a model-based data processing approach is introduced that systematically fits models based on first-principles to image data at multiple frequencies. To accurately quantify the fatigue crack condition around a fastener site for complex structures under varying conditions, a number of parameters must be simultaneously estimated including crack dimensions, part characteristics, and the measurement system state. A 12-hole test specimen was designed with 11 sub-surface corner EDM notches of varying levels of depth and length and scanned using a low frequency eddy current probe from 100 Hz to 3.2 kHz with both an impedance analyzer and standard eddy current instrumentation. A data pre-processing approach was implemented that maximizes the fastener response through phase adjustment resulting in improved crack sensitivity with the secondary component for characterization purposes. Results demonstrate the feasibility of using multi-frequency data from both systems to classify discontinuities of similar cross-sectional area but different aspect ratios. A second case study is presented highlighting the importance of compensating for variation in the alignment of the eddy current scanner with part edges and the fastener site pattern. By estimating and compensating for slight orientation differences, it is feasible to significantly improve the edge removal process and thus improve signal-to-noise for crack indications between fastener sites.
Session 45
SESSION 45
MATERIALS CHARACTERIZATION
Key Ballroom 11

8:30 AM  
Thermal Characterization of Viscoelastic Materials Using Sonothermography
---Thierry Kouadio, Anissa Meziane, Christophe Pradere, Christophe Bacon, Jean-C. Batsale, and
Christine Biateau, University of Bordeaux, I2M, UMR 5295, F-33400 Talence, France; CNRS, I2M,
UMR 5295, F-33400 Talence, France; Arts et Metiers ParisTech, I2M, UMR 5295, F-33400 Talence,
France

8:50 AM  
Theoretical and Experimental Research on Solid-Solid Interface Waves with Laser
Ultrasonics
---Han Qingbang, Changzhou Key Laboratory of Sensor Networks and Environmental Sensing,
Hohai University, Changzhou 213022, Jiangsu, China; Sun Hong, Changzhou Green Bamboo
Middle School, Changzhou 213022, Jiangsu, China; Wang Hao, Institute of Acoustics, Tongji
University, Shanghai 200092, China

9:10 AM  
Detection of In-Plane Fiber Waviness in Composite Laminates Using Guided Lamb
Modes
---Sunil Kishore Chakrapani1,2, Vinay Dayal1,2, and Daniel Barnard2, 1Department of Aerospace
Engineering, Iowa State University, Ames IA 50011; 2Center for NDE, Iowa State University,
Ames IA 50011

9:30 AM  
Real-Time Ultrasonic Monitoring of Internal Temperature Profiles of Heated Materials
---Ikuo Ihara, Yugo Ifuku, Akira Kosugi, and Iwao Matsuya, Nagaoka University of Technology,
Department of Mechanical Engineering, Nagaoka, Niigata, Japan

9:50 AM  
Power Laws Behavior in Multiscale Multistate Models for Hysteretic Nonlinear Materials
---S. Idjimarene1,2, M. Scalerandi2, M. Bentahar1, and R. El Guerjouma1, 1Laboratoire
d'Acoustique de l'université du maine LAUM, Avenue Olivier Messiaen, 72085 Le mans, France;
2Politecnico di Torino, department of Applied Science and Technology, Institute of Condensed Matter
and Complex Systems Physics, Corso Duca degli Abruzzi, 24 10129 Torino, Italy

10:10 AM  
Break

10:30 AM  
Ultrasonic Scattering Measurements of Dispersed Oil Droplets in the Presence of Gas
VA 23062; Grace Cartwright and Carl Friedrichs, Virginia Institute of Marine Science of the
College of William & Mary, Gloucester Point, VA 23062

10:50 AM  
Characterization of Microstructure with Low Frequency Electromagnetic Techniques
---Matthew R. Cherry2, Shamachary Sathish2, Adam L. Pilchak1, and Mark P. Blodgett1, 1Air
Force Research Labs, Materials and Manufacturing Directorate, WPAFB, OH 45433-7817;
2University of Dayton Research Institute, Dayton, OH 45469

11:10 AM  
Ultrasonic Assessment of In-Plane Modulus of Materials Using a Contact Approach
---R. T. Ko2, M. Y. Chen1, and J. L. Blackshire1, 1Air Force Research Laboratory, Wright-
Patterson Air Force Base, OH 45433; 2University of Dayton Research Institute, 300 College
Park, Dayton, OH 45469

11:30 AM  
Ultrasonic Contact Surface Imaging of Bond Integrity in Foam-Based Hybrid Composite
Materials
---R. T. Ko2, M. Y. Chen1, and J. L. Blackshire1, 1Air Force Research Laboratory, Wright-
Patterson Air Force Base, OH 45433; 2University of Dayton Research Institute, 300 College
Park, Dayton, OH 45469

11:50 AM  
Adjourn
8:30 AM
Thermal Characterization of Viscoelastic Materials Using Sonothermography
---Thierry Kouadio, Anissa Meziane, Christophe Pradere, Christophe Bacon, Jean-C. Batsale, and Christine Biateau, University of Bordeaux, I2M, UMR 5295, F-33400, Talence, France; CNRS, I2M, UMR 5295, F-33400 Talence, France; Arts et Metiers ParisTech, I2M, UMR 5295, F-33400 Talence, France

---The “Sonothermography” technique consists in measuring temperature field during vibrations or ultrasonic wave propagation in viscolelastic material. If the level of energy is sufficient, the temperature field can be acquired with an infrared camera and exploited for nondestructive evaluation and testing. This paper proposed to use sonothermography as volumic heat source in order to characterize the thermal properties (i.e., thermal diffusivity) of a homogeneous viscoelastic sample. A new method based on a Low Order Weak Formulation (LOWF) of the heat equation is used. In this formulation, the spatial derivatives of temperature are substituted by an analytical expression using virtual test function. By this way, LOWF leads to a more robust estimation of the thermal diffusivity. LOWF method is numerically and experimentally applied to the temperature field generated by acoustic wave propagation in a thin viscoelastic sample.

8:50 AM
Theoretical and Experimental Research on Solid-Solid Interface Waves with Laser Ultrasonics
---Han Qingbang, Changzhou Key Laboratory of Sensor Networks and Environmental Sensing, Hohai University, Changzhou 213022, Jiangsu, China; Sun Hong, Changzhou Green Bamboo Middle School, Changzhou 213022, Jiangsu, China; Wang Hao, Institute of Acoustics, Tongji University, Shanghai 200092, China

---The theoretical and experimental investigation on transparent solid/solid (Aluminum and Plexiglas) interface waves generated by a pulse laser and detected with a photo elastic effect technique is reported in this paper. Three waves, i.e., longitudinal head wave, Leaky Rayleigh wave and Leaky Interface wave are solved and discussed based on Riemann analysis, and the transient respond are simulate. In the experiment three interface waves are detected successfully; The Leaky waves propagating along the ‘weak bonding’ interface are also measured, it was found with the continue Epoxy solidifying, the wave amplitude gradually decrease and the two Leaky waves are more difficult to distinguish. The velocities and the transient respond of the detected interface wave are in good agreement with theoretical prediction.
9:10 AM

Detection of In-Plane Fiber Waviness in Composite Laminates Using Guided Lamb Modes
---Sunil Kishore Chakrapani\textsuperscript{1, 2}, Vinay Dayal\textsuperscript{1, 2}, and Daniel Barnard\textsuperscript{2}, \textsuperscript{1}Department of Aerospace Engineering, Iowa State University, Ames IA 50011; \textsuperscript{2}Center for NDE, Iowa State University, Ames IA 50011

---This paper presents the study of Lamb wave interaction with in-plane fiber waviness in thin composite laminates. Previous studies show that a reduction in stiffness of the laminate occurs due to in-plane waviness. Aspect ratio and shear angles were used to define severity of waviness. Air coupled ultrasonic transducers were used to generate the fundamental anti-symmetric mode (A\textsubscript{0}), which was used in this study. A reduction in velocity of the A\textsubscript{0} mode was observed when it interacts with in-plane waviness. To confirm the findings, dispersion curves were plotted for straight fiber zone and waviness zone. Experimental B-Scans of wavy laminate were used to evaluate the velocity change. Conclusions were made based on the correlation between experimentally and analytically observed velocities.

9:30 AM

Real-Time Ultrasonic Monitoring of Internal Temperature Profiles of Heated Materials
---Ikuo Ihara, Yugo Ifuku, Akira Kosugi, and Iwao Matsuya, Nagaoka University of Technology, Department of Mechanical Engineering, Nagaoka, Niigata, Japan

---In various fields of science and engineering, there are increasing demands for temperature profiling of heated materials. Ultrasound, because of its capability to probe the interior of materials and high sensitivity to temperature, is a promising tool for internal temperature measurements. In this work, a PC-based ultrasonic measurement and analysis system has been developed for real-time monitoring of temperature profiles of heated materials. The temperature profiles are quantitatively determined by a hybrid method consisting of ultrasonic pulse-echo measurements and a finite difference calculation for estimating one-dimensional temperature distributions along the direction of ultrasound propagation. Advantage of the method is that no boundary condition at the heating surface is needed. To demonstrate the practical feasibility of the method, a single side of a steel plate of 30 mm thickness is heated up to around 500 K by gas burner flame and subsequently cooled down by contacting with water, and ultrasonic pulse-echo measurements at 2 MHz are then performed for the steel plate to monitor the temperature gradient and its transient variation in the plate. In addition, non-contact temperature monitoring of a rotating steel cylinder is demonstrated using a laser-ultrasonic technique. Furthermore, accuracy, time and spatial resolutions in the monitoring are discussed.
Power Laws Behavior in Multiscale Multistate Models for Hysteretic Nonlinear Materials
---S. Idjimarene\textsuperscript{1,2}, M. Scalerandi\textsuperscript{2}, M. Bentahar\textsuperscript{1}, and R. El Guerjouma \textsuperscript{1},
\textsuperscript{1}Laboratoire d'Acoustique de l'université du maine LAUM, Avenue Olivier Messiaen, 72085 Le mans, France; \textsuperscript{2}Politecnico di Torino, Department of Applied Science and Technology, Institute of Condensed Matter and Complex Systems Physics, Corso Duca degli Abruzzi, 24 10129 Torino, Italy

---Acoustic nonlinear Non Destructif Testing (NDT) is based on the elastic response of micro-inhomogeneous / micro-cracked media to an acoustic propagating wave. Nonlinear contribution of inhomogenities to the response is extracted using either the temporal signal or its frequency components. The nonlinear indicator could be calculated by quantifying the resonance frequency shift, harmonics generation or the loss in proportionality between input and output signals. Experiments show the different nonlinear indicators to be governed by a power law where 'a' is the nonlinearity strength and 'b' indicates the kind of nonlinearity involved. Here, we link the power law to the damage by studying the evolution of the exponent as a function of the damage evolution. To explain the experimental observations, we suggest to model these nonlinear acoustic phenomena. For this purpose, we define a class of models characterized by being multistate and multiscale mechanisms. Belonging to this class, clapping, adhesion and hysteresis are used to understand the behavior of micro-cracks and their evolution.

Ultrasonic Scattering Measurements of Dispersed Oil Droplets in the Presence of Gas

---To help minimize the effects of oil spills on marine environments, chemical dispersants are used to disperse the oil in the water column so the oil can be consumed by naturally occurring bacteria. During the Deepwater Horizon incident, 1.1 million gallons of chemical dispersant were injected directly into the flowing plume of oil and natural gas over 1500 meters deep. Dispersants main effect is to decrease the surface tension at the oil-water interface causing the oil to form droplets smaller than \~70 microns so they can remain in the water column. Currently the efficacy of aerial applied dispersants to treat surface slicks is determined by measuring the droplet size decrease using a Laser In-Situ Scattering Transmissometer (LISST) or by detecting the oil in the water column using fluorometers. LISST instruments are limited to dilute mixtures, below \~500 ppm, because the signal is saturated for concentrated mixtures, and their windows can become occluded by oil and biofilms. Fluorometers only measure oil concentration; thus they cannot distinguish between naturally dispersed oil droplets, which will float back to the surface, from chemically dispersed oil droplets, which will remain in the water column to be naturally biodegraded. When gas is present as was the case in the Deepwater Horizon incident where it was estimated that the plume consisted of \~22\% natural gas, the LISST cannot distinguish between oil droplets and gas bubbles and thus is not able to track the effectiveness of dispersants on oil in the presence of gas. We have developed methods to determine the oil droplet size using acoustic measurements. We are using the resonance behavior of the gas bubbles to separate their contribution to the measured scattering as a function of dispersant applications. We will report on results using acoustic scattering and resonance to track the size of oil droplets in the presence of gas during subsurface releases in our lab as well as in a large wave tank.
Characterization of Microstructure with Low Frequency Electromagnetic Techniques

---Matthew R. Cherry\(^2\), Shamachary Sathish\(^2\), Adam L. Pilchak\(^1\), and Mark P. Blodgett\(^1\), \(^1\)Air Force Research Labs, Materials and Manufacturing Directorate, WPAFB, OH 45433-7817; \(^2\)University of Dayton Research Institute, Dayton, OH 45469

---A new computational method for characterizing the relationship between surface crystallography and electrical conductivity in hexagonally symmetric microstructures with low frequency electromagnetic techniques is presented. The method is discussed from the standpoint of characterizing the orientation of a single grain, as well as characterizing statistical information about grain ensembles in the microstructure. A computed approximation for eddy current scans of randomly inhomogeneous, anisotropic media, based on segmented orientation imaging microscopy (OIM) results and simulated random conductivity fields is discussed for its role in microstructure characterization. Experimental eddy current results are compared to the computed eddy current approximations based on electron backscatter data and eddy current modeling results, demonstrating surprising agreement given that only surface features were considered from the OIM and simulated conductivity fields, without dimensional depth. The detectability of notches in the presence of noise from microstructure is analyzed with the described simulation methods and advantages and limitations of this method are discussed relative to other NDE techniques for such analysis.

Ultrasonic Assessment of In-Plane Modulus of Materials Using a Contact Approach

---R. T. Ko\(^2\), M. Y. Chen\(^1\), and J. L. Blackshire\(^1\), \(^1\)Air Force Research Laboratory, Wright-Patterson Air Force Base, OH 45433; \(^2\)University of Dayton Research Institute, 300 College Park, Dayton, OH 45469

---An ultrasonic contact technique was developed to assess the in-plane modulus of materials in the absence of multiple, distinct ultrasonic echoes within a specimen. This technique employs a dry-couplant for materials in which liquid couplant is not desirable and uses only the first received ultrasonic signal to estimate the ultrasonic velocity in the specimen. An ultrasonic guided wave of the lowest symmetrical mode was generated and received in the materials in a through-transmission mode. Prior to each measurement, a set of reference plates was used to estimate the extra travel time occurring within the wear plates in transducers and the dry-couplant. The ultrasonic velocity is estimated from the arrival time after subtracting the extra travel time in the experimental setup. The modulus is then evaluated based on the low frequency asymptotic velocity of the lowest symmetrical mode for an isotropic material. Preliminary estimates of modulus were encouraging. Further validation of this technique is still in progress.
Ultrasonic Contact Surface Imaging of Bond Integrity in Foam-Based Hybrid Composite Materials
---R. T. Ko², M. Y. Chen¹, and J. L. Blackshire¹, ¹Air Force Research Laboratory, Wright-Patterson Air Force Base, OH 45433; ²University of Dayton Research Institute, 300 College Park, Dayton, OH 45469

---Based on a prior ultrasonic study to assess bond integrity between a composite layer and a foam substrate in foam-based hybrid composite, a unique contact surface imaging technique was developed. The technique integrates a novel wedge, developed earlier, into a traditional C-scan system. Unlike a conventional ultrasonic C-scan, the sample was not immersed in water but a thin layer of water was still needed to couple ultrasound into the material. Using this approach, an ultrasonic contact surface C-scan inspection was performed. Both the amplitude and time-of-flight data of the ultrasonic waves were collected. Three categories of features in the contact surface C-scan image can be identified: (1) thermocouple holes (2) edge effects and (3) potential delamination areas. Using this approach, the bond integrity in the foam-based hybrid composite was evaluated.
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SESSION 46
STRUCTURAL HEALTH MONITORING
Cara Leckey, Chairperson
Key Ballroom 12

8:30 AM  Design, Manufacture and Testing of an FBG-Instrumented Composite Wing
---E. Abouzeida, V. Quinones, and Y. Gowayed, Auburn University, Department of Polymer and Fiber Engineering, AL 36849; P. Soobramaney and G. Flowers, Auburn University, Department of Mechanical Engineering, AL 36849; R. J. Black, J. M. Costa, F. Faridian, and B. Moslehi, Intelligent Fiber Optic Systems Corporation (IFOS), Santa Clara, CA 95054

8:50 AM  Monitoring of Surface Strain Fields of Structural Members Using Carbon Nanotube-Based Sensor Networks
---Erik T. Thostenson, University of Delaware, Department of Mechanical Engineering, Newark, DE 19716; Hongbo Dai, Thomas Schumacher, and Erik T. Thostenson, University of Delaware, Center for Composite Materials, Newark, DE 19716

9:10 AM  Applications of Inductively Coupled Transducer System for Structural Health Monitoring
---Cheng H. Zhong, Anthony J. Croxford, and Paul D. Wilcox, University of Bristol, Mechanical Engineering, Faculty of Engineering, Queen's Building, University Walk, Bristol, BS8 1TR, United Kingdom

9:30 AM  Application of Optical NDE Methods for the Investigation of Rotor Blades of a Wind Power Plant During Operation
---Volker Carl, Carl Messtechnik und Prüfsysteme, Thyssenstrasse 183, 46535 Dinslaken, Germany

9:50 AM  Damage Detection in Composites Using Optical Fiber Sensors
---Sepandarmaz Momeni, Jaya P. Koduru, and Valery F. Godinez-Azcuaga, Mistras Group Inc., Princeton Junction, NJ 08550; Dien Nguyen, VeraPhotonics Inc. Fremont, CA 94539

10:10 AM  Break

10:30 AM  3D Guided Wave Motion Analysis on Laminated Composites
---Zhenhua Tian1, Cara Leckey2, and Lingyu Yu1, 1University of South Carolina, Department of Mechanical Engineering, Columbia SC 29208; 2Nondestructive Evaluation Sciences Branch, NASA Langley Research Center, Hampton VA 23681

10:50 AM  A Method for Compensation of the Temperature Effect Disturbing Lamb Wave Propagation
---Lukasz Ambrozinski, Przemyslaw Magda, Tadeusz Stepinski, and Tadeusz Uhl, AGH University of Science and Technology, Krakow, Poland

11:10 AM  Adjourn
Design, Manufacture and Testing of an FBG-Instrumented Composite Wing
---E. Abouzeida, V. Quinones, and Y. Gowayed, Auburn University, Department of Polymer and Fiber Engineering, AL 36849; P. Soobramaney and G. Flowers, Auburn University, Department of Mechanical Engineering, AL 36849; R. J. Black, J. M. Costa, F. Faridian, and B. Moslehi, Intelligent Fiber Optic Systems Corporation (IFOS), Santa Clara, CA 95054

--- In this work, our research team investigated the efficacy of using optical static and dynamic strain sensing with embedded Fiber Bragg Gratings (FBGs) in structural health monitoring (SHM) of a model composite airplane wing. A one-fourth scale model of a T38 airplane wing was designed and manufactured using fabric reinforced polymer matrix composites with FBG sensors embedded under the top layer of the composite. The accuracy and durability of the sensors were evaluated at the coupon and structural levels utilizing static and dynamic testing. Strain measurements using embedded FBGs with an optical interrogator were found to be in agreement with values measured using other strain measuring devices and with results obtained using finite element analysis (ANSYS®). Preferred locations for the FBG sensors were identified in accordance with contour maps of internal strain distributions resulting from critical load cases. Manufacturing techniques used to address handling, survivability and durability of the embedded sensors during and post manufacturing of the composites were evaluated and optimized.

Monitoring of Surface Strain Fields of Structural Members Using Carbon Nanotube-Based Sensor Networks
---Erik T. Thostenson, University of Delaware, Department of Mechanical Engineering, Newark, DE 19716; Hongbo Dai, Thomas Schumacher, and Erik T. Thostenson, University of Delaware, Center for Composite Materials, Newark, DE 19716

---Structural health monitoring (SHM) is becoming a viable tool to collect real-time quantitative data from in-service structures concerning condition and performance. The present research focuses on the development of an innovative non-destructive evaluation tool for civil infrastructure components such as bridges. This tool consists of a carbon nanotube-based composite sensing layer capable of monitoring, detecting, and locating the initiation and evolution of surface strain fields in structural members. The central concept is that carbon nanotubes are integrated into a sensing layer to form an electrically conductive network that offers distributed sensing capabilities. By measuring the overall resistance change between two electrodes, surface strain can be quantified. By employing and multiplexing several individual electrodes on a sensing layer, local strain peaks and damage locations can be located over an area. An advantage of this approach is the capability of real-time strain monitoring for a member. In this paper we present and discuss the basic principles of our carbon nanotube-based sensing approach. Finally, we discuss experimental results from a set of laboratory specimens where we were able to quantify strain over a range of loading scenarios and also locate the failure regions.
9:10 AM

Applications of Inductively Coupled Transducer System for Structural Health Monitoring
---Cheng H. Zhong, Anthony J. Croxford, and Paul D. Wilcox, University of Bristol, Mechanical Engineering, Faculty of Engineering, Queen’s Building, University Walk, Bristol, BS8 1TR, United Kingdom

---An inductive coupled transducer system (ICTS) has been developed as a passive wireless transducer for non-destructive evaluation (NDE) applications. This paper investigates the construction and optimization of such a system for structural health monitoring (SHM). First of all, the physical principle and construction of a glass fiber panel with an embedded ICTS is introduced, and signal variation due to the relative positions of coils is examined. Then, signal processing techniques such as normalization, phase correction, and Wiener filtering are investigated in order to compensate for the signal variation due to lateral and vertical misalignment between coils. A practical example of using ICTS as structural health monitoring system for 12 inch steel pipe is presented.

9:30 AM

Application of Optical NDE Methods for the Investigation of Rotor Blades of a Wind Power Plant During Operation
---Volker Carl, Carl Messetechnik und Prüfsysteme, Thyssenstrasse 183, 46535 Dinslaken, Germany

---Wind mills are constantly exposed to extreme environmental conditions, leading to valuable stress upon material components and eventually even to material failures - visible as well as invisible – which has a considerable effect on the system’s productivity and service life. In particular, the rotor blades are at risk of heavy damage upon impact of storm, ice, UV radiation, lightning strikes, hail and heavy rain. Nowadays, the rotor blades are periodically inspected by rope access technicians. Thus, in particular, the increasing number of off-shore wind mills calls for new inspection approaches of wind mills in the next future. In our presentation, some optical methods using infrared as well as visible light are introduced, aimed at quantitative NDE possibilities suitable for a sophisticated investigation of surface failures and inner structure defects of the glass fiber reinforced plastics. We will present our first results on infrared blade structure analysis and infrared vibration analysis, both obtained upon moving blades, as well as a stereoscopic high-resolution analysis of the blade surface for the purpose of documentation. The impact of both different weather conditions as well as the influence of “flying equipment” on the results of our analysis were investigated.
9:50 AM

**Damage Detection in Composites Using Optical Fiber Sensors**

---Sepandarmaz Momeni, Jaya P. Koduru, and Valery F. Godinez-Azcua, Mistras Group Inc., Princeton Junction, NJ 08550; Dien Nguyen, VeraPhotonics Inc. Fremont, CA

---Composite materials are being increasingly used in many manufacturing sectors such as automotive, military, wind power and aerospace industries. Features such as high specific strength and stiffness made composites an excellent candidate to replace metallic structures where weight and long durability are issues. Structural health monitoring of composite structures is of particular interest for reasons of safety and maintenance. Acoustic emission (AE) is one of the NDE methods widely used to detect damages processes in composites. However, Monitoring AE in large structures at several locations over a long period of time is challenging as current AE sensor technology is susceptible to EMI, shock, vibration, temperature, and signal attenuation over a long distances. Over the past few years, Fiber Bragg Grating (FBG) sensors have become reasonably practical in detection of AE for large structure. FBG sensors are small, light, immune to EMI and capable to be multiplexed. These FBGs’ characteristics enable them to overcome many limitations for continuous monitoring of large structures. In this paper we discuss the results obtained in AE monitoring composite samples with arrays of FBG sensors during static and fatigue testing. Different loading conditions such as tensile and bending are applied to the composite samples.

10:30 AM

**3D Guided Wave Motion Analysis on Laminated Composites**

---Zhenhua Tian¹, Cara Leckey², and Lingyu Yu¹, ¹University of South Carolina, Department of Mechanical Engineering, Columbia SC 29208; ²Nondestructive Evaluation Sciences Branch, NASA Langley Research Center, Hampton VA 23681

---Ultrasonic guided waves have proved useful for structural health monitoring (SHM) and nondestructive evaluation (NDE) due to their ability to propagate long distances with less energy loss compared to bulk waves and due to their sensitivity to small defects in the structure. Analysis of actively transmitted ultrasonic signals has long been used to detect and assess damage. However, there remain many challenging tasks for guided wave based SHM due to the complexity involved with propagating guided waves, especially in the case of composite materials. The multimodal nature of the ultrasonic guided waves complicates the related damage analysis. This paper presents results from parallel 3D elastodynamic finite integration technique (EFIT) simulations used to acquire 3D wave motion in the subject laminated carbon fiber reinforced polymer composites. The acquired 3D wave motion is then analyzed by frequency-wavenumber analysis to study the wave propagation and interaction in the structure. The frequency-wavenumber analysis allows for the study of individual modes and visualization of occurrence of mode conversion. Delamination damage has been incorporated into the EFIT model to generate “damaged” data. The possibility of mode isolation is also explored and potential for damage detection in laminated composites is discussed in this paper.
A Method for Compensation of the Temperature Effect Disturbing Lamb Wave Propagation
---Lukasz Ambrozinski, Przemyslaw Magda, Tadeusz Stepinski, and Tadeusz Uhl, AGH University of Science and Technology, Krakow, Poland

Variations of environmental conditions, such as temperature, affect propagation of Lamb waves, which can severely limit their use for damage detection in SHM systems. Two approaches can be used to handle this effect in order to improve robustness of SHM systems, optimal baseline selection (OBS) and baseline signal stretch (BSS). The OBS techniques require collection of signals and considerable amount of memory for data storage. Here, we present a novel technique which can be classified as a BSS approach. The proposed technique requires a single baseline only for compensation of temperature influence on Lamb waves’ snapshots. The proposed scheme consists of two steps: first, the instantaneous phase of the snapshot is estimated and it is aligned with that of the baseline in the second step. Since the snapshots are generally nonstationary due to medium dispersion, wavelet transform is used for the estimation of their instantaneous phase. After phase alignment the snapshot is stretched and the temperature influence is compensated. The phase-compensated snapshots can be subsequently analyzed using classical damage indices which results in damage indices insensitive to temperature variation.
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Are you interested in chairing a session next year? If so, please provide your name, topic, and e-mail address: ___________________________________________________________

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