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Review of Progress in QNDE

Plenary Speakers Highlight Imaging and Enhancement

by Dale Chimenti

The opening Monday morning plenary sessions of this year's Review of Progress in QNDE promise imagery that's out of this world. Showing participants the big picture of the submicroscopic world will be Dr. Kumar Wickramasinghe of IBM's Watson Research Center in Yorktown Heights, New York. Dr. Wickramasinghe will begin the plenary session, which has a theme of Imaging and Image Enhancement, by speaking on "Scanning Probe Microscopy—From Birth to Adolescence." The presentation will trace the development of this fascinating new ultramicroscopic tool (invented 20 years ago by Nobel Prize-winning IBM scientists) from its origin to the spawning of atomic force microscopy for the imaging of insulator surfaces. From there, Dr. Wickramasinghe will show how these advances have led to major improvements in our ability to characterize surfaces nondestructively.

Moving from the nanoscopic world and into a virtual one, Professor Jim Oliver of the Iowa Center for Emerging Manufacturing Technology at Iowa State University will demonstrate how virtual reality can be used as an interface tool to explore the results of scientific simulations. Not content with a simple static display of precomputed data, Professor Oliver will demonstrate that integrated, scalable, high-performance computers, advanced virtual environments, and high-speed network communications can create a real-time distributed environment for visual interaction with computationally intense applications. His paper, "Interactive Visual Supercomputing: A New Tool for Science and Engineering," promises to describe a synthetic environment where scientists and engineers have at their fingertips both qualitative and quantitative information about the process under investigation, providing new insights and discoveries.



Dr. Kumar Wickramasinghe studied electrical engineering at the University of London, earning the B.S. and Ph.D. degrees, and did his postdoctoral research at University College, London. As a research associate in applied physics at Stanford University, Stanford, California, he conducted research in acoustic microscopy and photoacoustic microscopy. He is currently manager of physical measurements at IBM in Yorktown Heights, New York, and has received several prestigious awards for his research. He is a fellow of the American Physical Society, the International Institute of Electrical and Electronic Engineers (IEEE), and the Royal Microscopical Society.



Professor Jim Oliver is associate director of the Iowa Center for Emerging Manufacturing Technology and associate professor in the Mechanical Engineering Department at Iowa State University. He earned his Ph.D. in mechanical engineering at Michigan State University, East Lansing. His research interests include geometric modeling, computer visualization, and synthetic environments. Oliver has also held industrial positions at International TechneGroup, Cincinnati, Ohio, and at Fluor Engineers and Constructors, Irvine, California. In addition, he was an assistant professor in mechanical and aerospace engineering at SUNY-Buffalo, New York. Oliver is a National Science Foundation Presidential Young Investigator, and he received the 1992 Rockwell Excellence Award from ISU.



Bill Green is manager of the Science Data Processing Systems Section at Caltech's Jet Propulsion Laboratory, Pasadena. He has responsibility for design, development, implementation, and operation of ground-based systems used to process science instrument data returned by the National Aeronautics and Space Administration's planetary and earth

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The third plenary speaker, Bill Green of Caltech's Jet Propulsion Laboratory in Pasadena, literally propels us out of this world with his talk on "Digital Processing of Remotely Sensed Imagery." Starting in the 1960s, digital image processing was applied to enhance imagery returned from the lunar surface by Surveyor spacecraft. More recently, commercial equipment has reduced the cost of developing and operating image processing systems as the technology supported a wide range of applications, including nondestructive testing, motion picture special effects, biomedical applications, and high-definition television broadcasting. This talk will describe the basic methods of digital image processing and digital image enhancement for remotely sensed images. The talk will also include, as a special feature, recent updates from the Galileo to Jupiter and the Mars Pathfinder missions.

As a follow-up to last year's plenary session on biomedical applications of noninvasive sensing, Drs. Mark Holland and Scott Handley of Washington University in St. Louis, Missouri, assumed responsibility for organizing this year's biomedical session. Their efforts have really paid off. The invited speakers (giving double-length talks) for this special session are Samuel Wickline, M.D., from Washington University School of Medicine; Anthony DeMaria, M.D., from University of California, San Diego; and Howard Dittrich, M.D., from Molecular Biosystems, Inc., San Diego. The talks will highlight some of the most active research areas of biomedical sensing. Dr. Wickline will speak on cardiac magnetic resonance imaging (MRI), and Drs. DeMaria and Dittrich will discuss ultrasonic contrast agents. This promises to be a stimulating session with internationally recognized experts.

The Wednesday evening problem session returns to its roots this year with a presentation by Tobey Cordell of the Air Force Materials Directorate. Cordell is chief of the Nondestructive Evaluation Branch at Wright-Patterson Air Force Base in Dayton, Ohio, and will set forth his vision of "NDE—A Full-Spectrum Technology." At the same time, he will discuss the Air Force's upcoming long-term contract to provide on-demand research and development in nondestructive evaluation (NDE). This setting out of a research agenda is very much in the spirit of the Wednesday evening session, which began in the mid-1970s as a vehicle for the funding agencies to communicate inspection problems of high priority.

The Review of Progress is organized by CNDE in cooperation with the American Society of Nondestructive Testing, the U.S. Department of Energy, the Federal Aviation Administration, the National Institute of Standards and Technology, and the National Science Foundation Industry/University Cooperative Research Centers. Cooperation with other technical societies interested in NDE is encouraged.

For more information about the Review, contact QNDE at 515-294-6770 or at <http://www.cnde.iastate.edu/qnde/qnde.html> on the Internet.



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observation spacecraft. His section produces a variety of digital, film, and video products, including CD-ROM and photo product archival databases, animations, and "fly-over" sequences of planets and other solar system objects. Green has also served as vice president of engineering at Terminal Data Corporation in Moorpark, California, and as general manager of the Image and Signal Processing Division of Unisys Defense Systems in Camarillo, California. He is the author of two textbooks and has taught image processing at Harvard University, Cambridge, Massachusetts; State University at Northridge, Northridge, California; and George Washington University, Washington, D.C. Green is a senior member of IEEE.

Dr. Samuel Wickline is professor of medicine and adjunct associate professor of physics and of biomedical engineering at Washington University in St. Louis, Missouri. He also is co-director of the Cardiovascular Division at the Washington University School of Medicine.

Dr. Anthony DeMaria is professor of medicine and chief of the cardiology division at the University of California, San Diego. He is board certified in cardiovascular disease and a past president of the American College of Cardiology. His field of specialization is cardiac imaging techniques, especially echocardiography.

Dr. Howard Dittrich is the vice president of research/medical and regulatory affairs at Molecular Biosystems, Inc., a biomedical company in San Diego that develops a range of contrast agents for use with diagnostic ultrasound. He also serves as clinical professor of medicine at the University of California, San Diego.





Fred Child, Lockheed Martin, presents a plaque from the CNDE sponsors to retiring CNDE director Don Thompson at the spring NSF Industry/University sponsors meeting in April.

Distinguished Professor Award to Deputy Director



R. Bruce Thompson was recognized at the Iowa State University Convocation Awards in April. The CNDE deputy director received ISU's Anson Marston Distinguished Professor of Engineering Award.

The title of Distinguished Professor is the highest academic honor bestowed by ISU. A \$2,500 increment in base salary is granted, and the awardees retain the title for the remainder of their careers at the university.

Thompson, a professor of aerospace engineering and engineering mechanics, as well as a professor of materials science and engineering, has served CNDE since 1985.

Thompson received a B.S. in physics from Rice University, Houston, Texas, and M.S. and Ph.D. degrees from Stanford University, Stanford, California. He joined ISU in 1980 as a senior scientist with the U.S. Department of Energy's Ames Laboratory and as an adjunct professor in the department of engineering science and mechanics.



Pioneering Effort Grows

Karl Mieke is a pioneer.

In 1994, he became the first student to receive a B.S. degree from Iowa State University in engineering science with an emphasis in nondestructive evaluation (NDE) after transferring from a community college nondestructive testing (NDT) program. ISU is the home of the only NDE program of this kind in the country.

But Mieke hopes he won't be alone for long. He encouraged others to follow his path when he spoke at the first NDE Engineering Information Day in February. Hosted by the College of Engineering and CNDE, the program's purpose was to increase the number of students transferring to ISU from community college NDT programs and encourage and motivate students to pursue NDE careers.

Thompson Retires

A university-wide reception and evening dinner marked the phased retirement of CNDE Director and Anson Marston Distinguished Professor of Engineering Donald Thompson.

Thompson, a pioneer of nondestructive evaluation, was joined by family, friends, and colleagues at the reception held in the Iowa State University Memorial Union. ISU President Martin Jischke and Institute for Physical Research and Technology Director Joel Snow were joined at the appreciation event by College of Engineering Dean James Melsa and Professor and Chair of Aerospace Engineering and Engineering Mechanics Thomas Rudolphi. A presentation of \$10,000 was made by the College of Engineering to the CNDE Founder's Prize program, a scholarship started by Thompson in 1995.

The dinner at the Holiday Inn Gateway in Ames included an open microphone for comments from guests, as well as the presentation of a mural representing Thompson's accomplishments.



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Support for the Information Day came from a \$96,000 grant from the National Science Foundation (NSF), which was provided to improve articulation and transfer between community college NDE programs and ISU engineering programs. The principal investigators on that grant are Interim CNDE Director Lester W. Schmerr, former CNDE Director Don Thompson, and Associate Dean of Engineering David Holger.

The Information Day is a follow-on to an NSF-funded community college/university cooperative collaboration that began in 1993. At that time, administrators at Northeast Iowa Community College (NICC) in Peosta, the College of Engineering, and CNDE began to discuss ways to facilitate student transfers. At the same time, a faculty enrichment component for community college instructors was put into place.

“Our original program seemed to work well, so the new NSF-funded efforts extend that idea to a broader area of the Midwest,” said Schmerr.

The Information Day was attended by more than 60 students, counselors, and instructors from five community colleges and two high schools.

An overview of the North Central Collaboration for Education in NDE/



Students view a simulation in a CNDE lab.

NDT, the NDE minor, and other engineering programs were topics for the event. Technical presentations from industry representatives and ISU researchers, as well as tours and demonstrations of NDE methods at CNDE, were included. Transfer issues were the focus for several presenters, including Mieke.

His story began almost 15 years ago when he was an ISU student in engineering science. Mieke left without completing his degree, and after working in construction and quality control for a time, he began taking classes at NICC in 1988. As he completed his work, he heard about the NSF program from his instructor, Arnold Prosh, who had received his masters at ISU as part of the community college/university program.

Now a quality assurance engineer at PMX Industries in Cedar Rapids, Iowa, Mieke said he feels “really lucky to have gone through a program like the one at NICC and ISU. The first company I interviewed with offered me a job. The hands-on practical experience provided by my community college was a real plus.”

Larson said the group is planning another Information Day this fall. In conjunction with the other related components—six renewable scholarships of \$2,500 per year and eight summer enrichment assistantships for potential community college transfer students—the collaborative effort should increase the number of students following Mieke’s footsteps.

“With industry’s increasing reliance on NDE and the rapid changes occurring in technology, this collaboration will allow

us to keep NDE technician education programs technically up to date as well as help us implement new teaching methods and tools,” Larson said.



Announcing the ETC Open Forum

The third Engine Titanium Consortium (ETC) Open Forum will be held November 18–20, 1997, at the Wyndham Greenspoint Hotel, Houston, Texas. This meeting is organized by the ETC on behalf of the Federal Aviation Administration (FAA) Technical Center and the FAA New England Propeller Directorate. The event will be co-hosted by Wyman-Gordon.

The Forum’s invitation list includes representatives from all segments of the titanium industry, from billet producers to engine manufacturers to airlines. Technical presentations on inspection, lifting, and materials issues important to the flight safety of engines will be on the agenda. A tour of the Wyman-Gordon facilities will take place as part of the meeting.

To receive further information about the Forum, contact Lisa Brasche at 515-294-5227 or at lbrasche@cnde.iastate.edu.



Technology to Increase Nuclear Power Plant Safety

A signal and imaging process system may soon improve the safety of nuclear power plants. CNDE scientists John Basart and John Moulder, with graduate student Sheng-Fa Chuang, are developing a way to detect flaws in nuclear plant steam generator tubes. By providing impartial, accurate information, the system could serve as a second line of defense to ensure nuclear power plant safety.

Water-filled tubes stand vertically within a nuclear plant's steam generator, ready to transfer heat from the pressurized radioactive fluid to the fluid that powers the electric generators. However, the radioactive fluid is highly corrosive, so it is possible for a tube to become damaged and carry the radioactive fluid, thus putting workers or others at risk.

To avoid this scenario, commercial inspections of the tubes are conducted periodically. The plant is shut down while an eddy current probe is pulled through each tube in the generator—1000 or more—in an attempt to locate damage. The inspectors work 24 hours a day until the evaluation is complete. CNDE's signal and imaging technology will be an aid to these inspectors, increasing the efficiency, consistency, and reliability of nondestructive evaluation (NDE) in nuclear power plants.

By analyzing the information from 183 data sets collected from 100 tubes, the CNDE team has developed a computer program to automatically study data sets and identify changes in a tube's condition over time. They are addressing three tasks

as they develop their signal processing system: signal preprocessing, flaw detection, and evaluation.

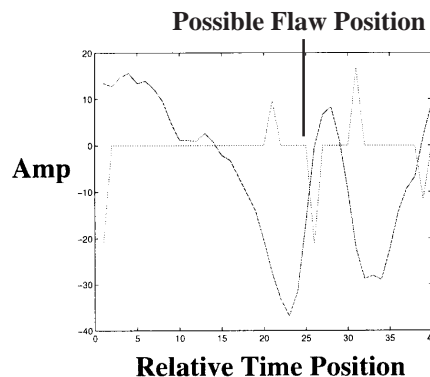
Within the signal preprocessing segment, the team developed a computer program that aligns two data sets in time, reduces noise, and calibrates the data. Reducing noise is a major challenge since a number of the changes recorded during inspection are due to variations in the speed with which the probe is drawn through a tube, variations in the tube wall, or deposits from the radioactive fluid on the outside of the tube. Accuracy of detection is also affected by the horizontal support plates that hold the tube, which make the signal more complex. This is a particular concern since the support area is also extremely susceptible to corrosion, making the identification of flaws in this area of critical importance.

In the flaw detection segment, a wavelet transform is used to define features in the data that are similar to the signal

noise and identify "bipolar signals." These signals, characterized by a positive peak in close proximity to a negative peak, are symptomatic of a defect. Three frequencies of eddy current signal are used to help ensure detection.

In the evaluation segment, the team employs a fuzzy logic system that analyzes the correlation of a signal with a template. The result is a quantifiable number that can be compared against a threshold value to identify the presence of a flaw. The system can also estimate the depth of the flaw.

Now in its third year of development, the team's system has proven its ability in a number of tests. "We can automatically detect flaws in almost all of the cases where a human can detect flaws," said Basart. The team expects that as the system becomes faster and more accurate, it will eventually minimize the human effort needed to conduct inspections.



A defect is identified when a bipolar signal is located, which is a positive peak followed by a negative peak.

variations caused by flaws. Further processing of the wavelet signal is completed to detect the largest excursions of the data in an attempt to reduce the

Ultrasonic Welding Inspection Technology Nears Prototype Stage

X-ray is the most common inspection method for determining the quality of a weldment. Its sharp images expose the presence of cracks, porosity, inclusions, and slag, all of which might weaken the weld. However, x-ray inspection has limitations: the generators are bulky and expensive, and safety issues are a concern.

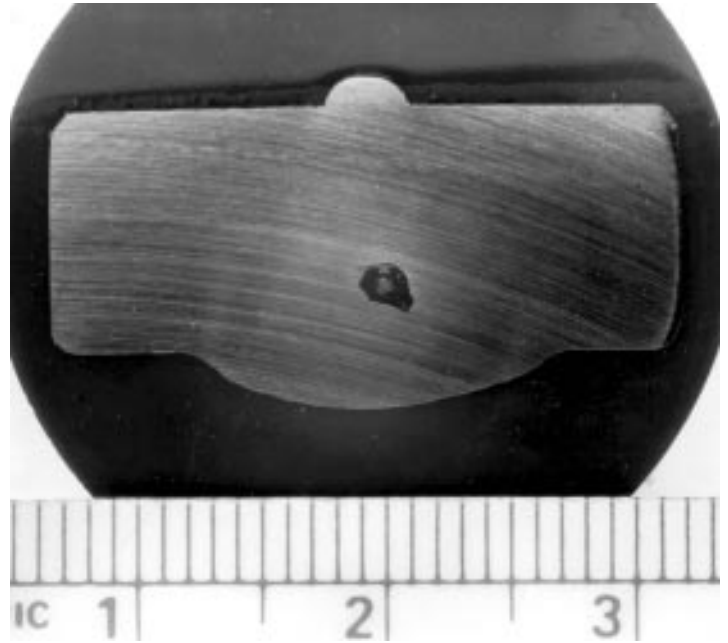
Work at CNDE on an industry/university-funded project may make ultrasonics the weldment inspection method of choice. CNDE scientists Tim Gray, Les Schmerr, and Dave Rehbein are developing an ultrasonic inspection method that can classify the information obtained from an ultrasonic inspection and ultimately provide accurate defect information.

Ultrasonic inspection, although safe, portable, and inexpensive, does not produce the clear images associated with x-ray analysis. An interdisciplinary research team led by Gray is developing computer models to transform ultrasonic measurement data into information that is as understandable as that obtained from an x-ray.

To produce good models, the team first needed to develop technology that can separate defect-related ultrasonic signals from the background noise produced as part of the ultrasonic inspection. The system also had to discriminate between the signals caused by various defects. For instance, a crack must be discernible from slag.

To accomplish this task, Rehbein, the metallurgist in the group, is cutting apart actual welding samples and analyzing the response of ultrasound to known flaws. Information regarding features characteristic of a given flaw and the signal it produces will be used to differentiate between various signals. “We can then predict the signal we would obtain from similar flaws,” said Rehbein.

To complement the sample analysis, Gray is using Rehbein’s information to construct an accurate software model. The model



This photomicrograph shows the type of weld inclusion a CNDE team hopes to model.

will predict the signals produced by defects in a variety of situations without having completed an actual measurement. “It can tell us what kind of features we can expect from signals produced by defects when we do not have experimental data,” said Gray. The model should be able to produce a visual image that accurately portrays the weld and any defects. A substantial body of software models have now been developed that are “able to predict signals from many different types of weld flaws,” said Gray.

The data obtained from the model is being used to develop a flaw classification system under the guidance of Schmerr. This tool will be able to extract information from the signals and draw conclusions about the weld. To do this, the system must be trained to make correct decisions about the data, according to Gray. Rehbein’s data, along with Gray’s models, will be used to train the classification system to be accurate for any measurement. The technology is of interest to the power and oil industries, as well as the U.S. Navy.



Standards and Modeling Workshop Held at CNDE

Approximately 45 participants attended a two-day workshop on Standards and Modeling held at CNDE on April 23–25. The workshop explored the ways that nondestructive evaluation (NDE) models can be used to develop new calibration methods, improve qualification procedures, and formulate more effective training methods. A number of CNDE principal investigators gave reviews of the status of modeling work at the Center in the areas of ultrasonics, x-rays, and eddy currents. Demonstrations of model-based simulations were included.

George Alers (National Institute of Standards and Technology, Boulder, Colorado), Gerald Posakony (J-Tech, Richland, Washington), Donald Thompson (CNDE), Tom Jones (Industrial Quality, Inc., Gaithersburg, Maryland), Dick Trantow (General Electric, Evendale, Ohio), and Bob Shannon (Westinghouse, Pittsburgh, Pennsylvania) were among the invited speakers. The range of topics included the past history of standards activities, how standards are generated, past industrial uses of models that could suggest future roles for models in standards, and some recent work to adopt a medical imaging data standard to NDE. A panel consisting of Jones, Alers, and Jack Spanner, Jr., (Electric Power Research Institute, Charlotte, North Carolina), led a discussion on where standards are going in the U.S. and how models might fit into those efforts.

More details on the workshop discussions and results will be presented at the European-American Workshop on

Reliability and Validation of NDE Methods, June 18–20, 1997, in Berlin, Germany.



Lerch Receives NIST Appointment



Terry Lerch, CNDE postdoctoral research associate, recently received a National Institute of

Standards and Technology (NIST) postdoctoral appointment. Lerch will join NIST scientists Chris Fortunko and George Alers at the Materials Characterization Group in Boulder, Colorado, to study acoustic microscopy.

The two-year appointment is an opportunity “for a young researcher like myself to work with wiser and more experienced researchers,” said Lerch. Developing and applying analytic models to simulate acoustic microscope inspections of computer integrated circuit (IC) chips will be the focus of the work. Since the IC chips found in a typical personal computer are mass produced in huge quantities, chips of poor quality are occasionally produced. The NIST team hopes to develop a reliable nondestructive inspection technique that can identify bad IC chips, which would mean significant monetary savings for the IC manufacturing industry.

The development of ultrasonic transducer beam models was the focus of Lerch’s research with Interim CNDE Director Les Schmerr, who served as the major

professor. In his postdoctoral work at CNDE, Lerch has also been developing crack scattering models with Associate Director Bruce Thompson. Lerch expects to begin the NIST appointment this fall.

Lerch received his Ph.D. in Engineering Mechanics from Iowa State University in May of 1996. He also holds a B.S./M.S. degree from the Rochester Institute of Technology, Rochester, New York.



Founder’s Prize Winners Announced

Greg Hughes and Tim Mull are the 1996–97 CNDE Founder’s Prize winners. The two received \$1,500 scholarships to help complete their undergraduate degrees at Iowa State University.

Hughes is a senior in ceramic engineering with a minor in nondestructive evaluation (NDE). A native of Papillion, Nebraska, he has devoted a portion of his time to developing multimedia animation courseware that will make hard-to-visualize ceramic engineering processes easier to understand. An ISU student since 1993, Hughes plans to work in the general engineering area specializing in communications.

Mull is a senior in mechanical engineering with a minor in NDE. A native of Torrance, California, Mull worked for Boeing’s Operations Technology group in Seattle, Washington, as an intern last year. While there, he categorized parts used to

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Seniors Greg Hughes (left) and Tim Mull receive scholarship.

create inspection procedures and developed a searchable web database of the parts. He will return to Boeing this summer to work for the Commercial division as a liaison engineer. Mull plans to accept a job with the company after graduating in December 1998.

The CNDE Founder's Prize was created in April 1995 and is supported by CNDE alumni, friends, and industrial partners. Winners are chosen from ISU juniors with a declared minor in NDE who have demonstrated exceptional academic performance. Community college students transferring to ISU are included in the award pool.



Program Graduates

The year 2000 is fast approaching. CNDE, in cooperation with several academic colleges at Iowa State University, is helping educate and train future scientists in NDE and related disciplines so that they are prepared for the next century.

Each year, we at CNDE have the privilege of working with outstanding students. As they graduate, we are pleased to honor their dedication by showcasing their research on this and the following pages.



Sriram Chavali

M.S., Aerospace Engineering and Engineering Mechanics

“Adoptive Learning Methods and Their Use in Flaw Classification”

An important goal of nondestructive evaluation is the detection and classification of flaws in materials. This process of flaw classification involves the transformation of the raw data into other domains, the extraction of features in those domains, and the use of those features in a classification algorithm that determines the class to which the flaw belongs.

In this work, we describe a flaw classification software system, CLASS, and the updates made to it. Both a hierarchical clustering algorithm and a backpropagation neural network algorithm were implemented and integrated with CLASS. A fast Fourier transform routine was also added to CLASS in order to enable the use of frequency domain and cepstral domain features.

This extended version of CLASS is a very user friendly software, which requires the user to have little knowledge of the actual learning algorithms. CLASS can be extended if needed, in the future.



Sheng-Fa Chuang

Ph.D., Electrical and Computer Engineering

“Eddy Current Automatic Flaw Detection System for Heat Exchanger Tubes in Steam Generators”

We have developed an automatic flaw detection system for heat exchanger tubes in steam generators. The system utilizes two well-known techniques, wavelets and fuzzy logic, to automatically detect the flaws in tubing data. The analysis of eddy current inspection data is a difficult task that requires intensive labor by

GRADUATES/continued from page 8
experienced human analysts. To aid the analysts, an accurate and consistent automatic data analysis package was developed. The software development is divided into three parts: data preprocessing, wavelet analysis, and a fuzzy inference system.

The data preprocessing procedure is used to set up a signal analysis standard for different data and also to remove the variations due to lift-off and other geometrical effects. The wavelet technique is used to reduce noise and identify possible flaw indications. Due to multiresolution and the unique time-frequency localization properties of the wavelet transform, the flaw signals have specific characteristics in the wavelet domain. We fully utilize those characteristics to distinguish flaw indications from noise. To further evaluate the flaw candidates and reduce false calls, we invoked fuzzy logic to discriminate between true positives and false positives. A template matching technique and fuzzy inference system were also developed. The template matching technique uses signals from artificial flaws as templates to match with possible flaw signals and execute a normalized complex cross correlation. Through this process, we obtain both phase and shape information, which are placed into a fuzzy inference system for final decision making.

Results from a rigorous test of the system using actual inspection data indicate that the new techniques show a great deal of promise for automatic flaw detection.



Mike Garton

M.S., Aerospace Engineering and Engineering Mechanics

“Refining Automated Ultrasonic Inspections Using Simulation Models”

Methods were presented to quantitatively access the coverage of an automated ultrasonic immersion scan on a complex geometry with software simulations. The simulations can solve for a map of sensitivity as a function of position throughout the volume of the part. The sensitivity levels are output in volts expected from a reference reflector as a function of position in the volume or in dB relative to the calibration experiment as a function of position in the volume. The methods work for focused and unfocused probes on flat and curved interfaces. Several examples were shown where the maximum allowable scan step size that guarantees a specified level of detection sensitivity throughout the volume was calculated.

Clay Maranville

M.S., Materials Science and Engineering

“A Radiographic Imaging of Microstructural Defects in Ceramic Tapes”

A prototype method was developed utilizing recent advances in x-ray microfocus radiography and image processing to study the effects of ceramic tape casting variables on microstructure development. The system was designed to incorporate several advantages over traditional ceramic characterization routes: (i) the system functions as an area detector (rather than a conventional point- or line-detector), providing rapid statistical information on inhomogeneities in tape microstructures; (ii) it is capable of detecting small pores and surface pits on the order of 10 microns in size; (iii) it can detect tape thickness variations on the order of 10 microns; (iv) it is capable of tracking these heterogeneities as a function of time and position throughout casting, debinding, and sintering; and (v) using standard equipment, it is amenable to scale up for quantitative process control and monitoring in an industrial setting.

The prototype involved magnification radiography using a microfocus x-ray generator, digitization of the radiographs using a 14-bit CCD camera, and image processing of the digitized radiographs. Key parameters affecting image resolution were analyzed including: magnification, the presence or absence of film cassettes, variations in film type, and the x-ray energy. The system was benchmarked in a study of the effects of particle size, tape

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thickness, and sintering temperature of alumina tapes. Optical and scanning electron microscopy were also performed to confirm the results of the radiography data.

Ananth Sethuraman

Ph.D., Electrical and Computer Engineering

“Depth of Small Cracks (circa 100 microns) From Photoinductive Data”

The reconstruction of small, tight, surface-breaking cracks is one of the key problems of nondestructive evaluation (NDE). Many of the established methods of NDE have been defeated by the smallness and the tightness of such cracks. The photoinductive method, which combines a laser with the eddy current method, is known to have a particularly fine spatial resolution. Consequently, we have investigated whether it would be well-suited for determining the size and the shape of small, tight, surface-breaking cracks.

The development of a method for investigating the size (especially the depth) and shape of such cracks is the central problem of this dissertation. A fundamental feature of the photoinductive method is that it uses a coil to induce an eddy current in the test specimen and, associated with it, an electric field. A photoinductive measurement is essentially the square of this electric field, evaluated at points on the surface of the test specimen. We therefore derived a formula for the square of the electric field, using a formalism of Bowler’s. In this approach, the electric

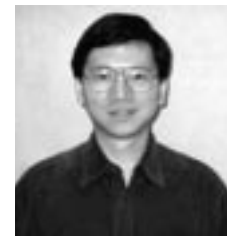
field interaction of the crack is described with a concept known as the current dipole density. It is shown that the square of the electric field is connected to the current dipole density through a nonlinear integral equation (nonlinear because of the need to take the square).

Another integral equation is also set up that reflects that each point on the cross-section is (i) either in a crack, and hence blocks the flow of electric current, or (ii) is intact, and hence has a zero current dipole density. This second integral equation is also nonlinear. Solving this pair of integral equations, the current dipole density is determined from the photoinductive data. The result is that we can determine the shape of the crack since the current dipole density has the property that the set of points where the current dipole density is nonzero can be identified as the crack. Therefore, everything depends on solving the pair of nonlinear integral equations mentioned above.

The dissertation uses standard numerical techniques to solve the pair of nonlinear integral equations. The problem is reduced to an optimization problem simply by taking the modulus squared of the difference between the left-hand and the right-hand sides as an objective function for minimization.

The reconstruction method was carried out for a variety of cracks using photoinductive data. Good results were obtained for the length and depth of the crack. The reconstruction of the crack shape was somewhat more ambiguous because of an ill-posedness inherent in this pair of nonlinear integral equations. The dissertation traces the ill-posedness to the behavior of a Green’s function that appears as a kernel in one of the integral

equations. This ill-posedness is essentially that which usually arises in Fredholm equations of the first kind. Subject to the issue of ill-posedness, cracks on the order of hundreds of microns to a few millimeters in size have been reconstructed in nonmagnetic materials. The depths of the example cracks were recovered in all of the cases attempted. The shapes of the examples were also recovered, after an additional condition—that of seeking the crack with the least perimeter—was adjoined to the problem to eliminate the ill-posedness.



Cheng-Chi Tai

Ph.D., Electrical and Computer Engineering

“Advanced Eddy Current Methods for Quantitative NDE”

The objective of this dissertation was to devise and develop advanced eddy current methods for quantitative NDE. The techniques used include time-domain methods (pulsed eddy current), frequency-domain methods (swept-frequency eddy current), and the photoinductive imaging method (eddy current and laser-based thermal-wave techniques combined).

We first developed theoretical models to predict the pulsed eddy current signal and

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showed that this technique can be used to characterize metallic coatings on metal substrates. A feature-based rapid inversion method was developed to determine the conductivity and thickness of the coating simultaneously.

In the second work, we studied the fundamentals of eddy current interactions with magnetic metals using the swept-frequency eddy current method. We found that the eddy current response of well-annealed, demagnetized commercially-pure nickel is dominated by a thin region at the sample's surface that has a very significantly reduced permeability—i.e., a surface dead-layer. This dead layer may be due to the presence of surface damage. We calculated the impedance of the coil based on the hypothesized single layer structure and found excellent quantitative agreement between the model and experiment. These results may have important consequences for many aspects of the interaction of low frequency electromagnetic fields with magnetically soft metals.

In the third work, we developed theoretical calculations and practical measurement methods using both swept-frequency eddy current and pulsed eddy current methods for determining the thickness, conductivity, and permeability of metallic coatings on metal substrates for the case when either coating, metal, or both are ferromagnetic. This work paves the way for development of new, quantitative methods to characterize surface layers on ferrous materials, such as depth of case hardening.

In the fourth work, we applied the photoinductive imaging technique to

characterize corner cracks on the surface around a bolt hole. The photoinductive signals reflect the geometrical shape of triangular and rectangular electrical-discharge-machined (EDM) notches as well as real fatigue cracks. The results show promise for using this technique to characterize the shape, depth, and length of corner cracks. The capability of the photoinductive imaging technique is demonstrated in this work.



Bing Wang

Ph.D., Electrical and Computer Engineering

“Signal Processing and Image Restoration Techniques for Two-dimensional Eddy Current Nondestructive Evaluation”

This dissertation presents a comprehensive study on the forward modeling methods, signal processing techniques, and image restoration techniques for two-dimensional eddy current nondestructive evaluation. The basic physical forward method adopted in this study is the volume integral method. We applied this model to the eddy current modeling problem for half space geometry and thin plate geometry. To reduce the computational complexity of the volume integral method, we developed a wavelet expansion method that utilizes

the multiresolution compression capability of the wavelet basis to significantly reduce the number of computations with little loss in accuracy. To further improve the speed of forward modeling, we developed a fast eddy current model based on a radial basis function neural network.

This dissertation also contains investigations on signal processing techniques to enhance flaw signals in two-dimensional eddy current inspection data. The processing procedures developed in this study include a set of preprocessing techniques, a background removal technique based on principal component analysis, and grayscale morphological operations to detect flaw signals. Another important part of the dissertation concerns image restoration techniques that can remove the blurring in impedance change images due to the diffusive nature of eddy current testing. We have developed two approximate linear image restoration methods—the Wiener filtering method and the maximum entropy method. Both linear restoration methods are based on an approximate linear forward model formulated by using the Born approximation.

To improve the quality of restoration, we also developed nonlinear image restoration methods based on simulated annealing and a genetic algorithm. Those nonlinear methods are based on the fast neural network forward model, which is more accurate than the approximate linear forward model.



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