IS-5058
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CENTER FOR NDE

Abstracts

Review of Progress in Quantitative NDE

Bowdoin College, Brunswick, Maine
July 28-August 2, 1991

Sponsored by:

Center for Nondestructive Evaluation and Ames Laboratory
Iowa State University

In cooperation with:

Air Force Materials Directorate, Wright Laboratory
Wright Patterson Air Force Base

American Society for Nondestructive Testing

Basic Energy Sciences, USDOE

Federal Aviation Administration

National Institute of Standards and Technology

National Science Foundation,
Industry/University Cooperative Research Centers

Office of Naval Research

AMES LABORATORY

Technical Session Locations:
MG-*Morrell Gymnasium*
SA-*Smith Auditorium*
KA-*Kresge Auditorium*
CH108-*Cleaveland Hall*
LL-*Lancaster Lounge/Moulton Union*

1991
REVIEW OF PROGRESS IN QUANTITATIVE NDE
PROGRAM SUMMARY

SUNDAY 7/28

Registration - Sills Hall, Rm. 117 (1 - 8 p.m.)

Hospitality Social
Wentworth Hall/Daggett Lounge
(7:15 - 9:30 p.m.)

MONDAY 7/29

I. DOE Environmental Restoration and Waste Management - MG

II. Environmental Monitoring and Sensors - MG

LUNCH

III. Sensors - SA

IV. NDE of Composites (mostly fiber matrix) - KA

V. UT Thin Plates and Tubes - I - CH108

VI. Imaging and Inversion Techniques LL

TUESDAY 7/30

VII. NMR for NDE - LL

VIII. X-Ray Instruments and Techniques - SA

IX. NDE of Composites - KA

X. UT Interfaces; UT Thin Plates and Tubes - II - CH108

LUNCH

XI. Posters -- UT Anisotropic Materials, Composites, Bonded Materials, Radiography, Eddy Current and Other EM Techniques, and NDE in Manufacturing

XII. Applications of Neural Networks - LL
XIII. Eddy Current Arrays - KA
XIV. Stress Measurements - SA
XV. Magnetic Materials - CH108

CONFERENCE DINNER
WENTWORTH HALL
(6:15 - 9:30 p.m.)

WEDNESDAY 7/31

XVI. Eddy Currents - KA

XVII. NDE for Adhesive Bonds - LL

XVIII. Signal Processing - UT - SA

XIX. NDE of Civil Structures and Materials - CH108

LUNCH

XX. Laser Ultrasonics - SA

XXI. Tomography and UT Scattering - I - LL

XXII. Defect Sizing - CH108

XXIII. NDE of Metal Bonds - KA

SPECIAL EVENING SESSION - KA

THURSDAY 8/1

XXIV. Image and Signal Processing - SA

XXV. Thermal Techniques and Applications - CH108

XXVI. Material Properties (Plastics, Ceramics, and Others) - KA

XXVII. UT Scattering - II - LL

LUNCH

XXVIII. Posters - Materials Properties, Acoustic and Ultrasonic Techniques and Systems, Optical and Laser Techniques, Thermal Techniques, Imaging, Signal Processing, Tomography

XXIX. NDE for Thick Composites - KA
XXX. New Techniques - SA
XXXI. Optical Techniques - LL
XXXII. Electromagnetic Techniques (mostly microwave) - CH108

5K FUN RUN
(5:45 - 6:30 p.m.)

FRIDAY 8/2

XXXIII. New Systems - KA

XXXIV. UT Transducers, Calibration, and Standards - LL

XXXV. Material Properties (Metals) - SA

XXXVI. Nonlinear Techniques in Material Characterization - CH108

LUNCH

Next Year's Meeting:

University of California, San Diego
La Jolla, California

July 19 - 24, 1992

8 9 10 11 12 1 2 3 4 5 6 7 8 9

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REVIEW OF PROGRESS IN QUANTITATIVE NDE
Bowdoin College
Brunswick, Maine

July 28 - August 2, 1991

PROGRAM

Monday, July 29, 1991

PLENARY SESSION I
DOE ENVIRONMENTAL RESTORATION and WASTE MANAGEMENT
J. Corones, Chairperson
Morrell Gymnasium
Page 1:

9:00 AM	**Opening Remarks** ---D. O. Thompson, Center for NDE and Ames Laboratory, Iowa State University
9:10 AM	**The Impact of Waste Characterization on Environmental Restoration and Waste Management Activities in the Department of Energy** ---C. W. FRANK, ASSOCIATE DIRECTOR, OFFICE OF TECHNOLOGY DEVELOPMENT, DEPT. OF ENERGY, ROOM 7A049, EM-50, 1000 INDEPENDENCE AVE., SW, WASHINGTON, D.C. 20585
10:00 AM	**DISCUSSION**
10:10 AM	**COFFEE BREAK**

PLENARY SESSION II
ENVIRONMENTAL MONITORING and SENSORS
B. Barna, Chairperson
Morrell Gymnasium
Page 2:

10:30 AM	**Issues in Global Environmental Monitoring** ---G. BRUCE WIERSMA, COLLEGE OF FOREST RESOURCES, UNIVERSITY OF MAINE, ORONO, MAINE 04469
11:15 AM	**Tiny Chips, Big Jobs: Microscale Services and Environmental Probing** ---R. M. WHITE, UNIVERSITY OF CALIFORNIA, 479 CORY HALL, BERKELEY, CA 94720
12:00 PM	**LUNCH**

Monday, July 29, 1991

SESSION III
SENSORS
R. O. Claus, Chairperson
Smith Auditorium
Pages 3-7:

1:30 PM **UHF Modulation and Fourier Transform Differential Time Domain Techniques for Measuring Strain Via Fiber Optics**
---J. S. SCHOENWALD, SCIENCE CENTER, R. H. MESSINGER, SPACE SYSTEMS DIVISION, ROCKWELL INTERNATIONAL CORPORATION, 1049 CAMINO DOS RIOS, THOUSAND OAKS, CA 91360

1:50 PM **Composite Embedded Optical Fiber Sensors for Strain, Damage and Cure Monitoring**
---R. M. MEASURES, K. KIU, M. LEBLANC, T. VALIS, D. HOGG, B. PARK, M. OHN AND A. DAVIS, UNIVERSITY OF TORONTO INSTITUTE FOR AEROSPACE STUDIES, 4925 DUFFERIN ST., DOWNSVIEW, ONTARIO, M3H-5T6, CANADA AND THE ONTARIO LASER AND LIGHTWAVE RESEARCH CENTRE

2:10PM **High Temperature Fabry-Perot Based Strain Sensor for Ceramic Cross Flow Filters**
---K. A. MURPHY, C. E. KOOB, A. J. PLANTE, A. M. VENGSARKAR AND R. O. CLAUS, FIBER & ELECTRO-OPTICS RESEARCH CENTER, BRADLEY DEPARTMENT OF ELECTRICAL ENGINEERING, VIRGINIA TECH, BLACKSBURG, VA 24061-0111

2:30 PM **Quantitative Evaluation of Steel Corrosion in Microenvironments Using the Corrosion Coulometer**
---RICHARD D. GRANATA, ZETTLEMOYER CENTER FOR SURFACE STUDIES; WILLIAM D. MICHALERYA, ATLSS RESEARCH CENTER, LEHIGH UNIVERSITY, BETHLEHEM, PA; ROGER H. WILDT, BETHLEHEM STEEL CORP., BETHLEHEM, PA; HENRY LEIDHEISER, JR., VENICE, FL; BRENDAN W. O'MALLEY, JR., NEW YORK, NY

2:50 PM **Investigations of Extensional and Torsional Acoustic Wave Thin Rod Sensors**
---M. VIENS*, Y. LIU*, Z. WANG**, C. K. JEN**, AND J. D. N. CHEEKE*,***, **IMI, NATIONAL RESEARCH COUNCIL, BOUCHERVILLE, QUEBEC, CANADA J4B 6Y4; *DEPT. OF PHYSICS, UNIVERSITY OF SHERBROOKE, SHERBROOKE, QUEBEC, CANADA J1K 241; ***SIRICON, MONTREAL, QUEBEC, CANADA H3G 1M8

3:10 PM COFFEE BREAK

3:30 PM **Active Corrosion Site Detection Scheme Using Optical Fibers**
---R. D. REMPT, BOEING DEFENSE & SPACE GROUP, MS/87-60, P. O. BOX 3999, SEATTLE, WA 98072

3:50 PM **Smart Materials Used in Frequency Selective Passive Pressure Sensors**
---J. R. LHOTA, P. M. SHEAFFER, AND G. F. HAWKINS, THE AEROSPACE CORPORATION, M2/248, P. O. BOX 92957, LOS ANGELES, CA 90009.

4:10 PM **Calibration and Characterization of Eddy Current Probes by Photoinductive Field Mapping**
---J. C. MOULDER, M. W. KUBOVICH, M. S. HUGHES, S. MITRA, AND A. DEGERATU, CENTER FOR NDE, IOWA STATE UNIVERSITY, AMES, IA 50011

4:30 PM **Optimization of Sound Pulse Generation for Photoacoustic Sensing Applications**
---MARKKU OKSANEN, DEPARTMENT OF PHYSICS, UNIVERSITY OF HELSINKI, SILTAVUORENPENGER 20 D, SF00170 HELSINKI, FINLAND AND JUNRU WU, DEPARTMENT OF PHYSICS, UNIVERSITY OF VERMONT, BURLINGTON, VT 05405.

4:50 PM **Small Flaw Detection With a Magnetic Recording Head Probe**
---T. E. CAPOBIANCO, ELECTROMAGNETIC TECHNOLOGY DIVISION, NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY, 325 BROADWAY, BOULDER, CO.

Monday, July 29, 1991

SESSION IV
NDE OF COMPOSITES
(MOSTLY FIBER MATRIX)
D. Chimenti, Chairperson
Kresge Auditorium
Pages 8-12:

1:30 PM **Acoustic Emission from Internal Delamination of a Four-Ply Plate**
---E. RHIAN GREEN, DEPARTMENT OF ENGINEERING, UNIVERSITY OF LEICESTER, LEICESTER, LE1 7RH, UK

1:50 PM **Transient Response of a Laminated Composite Plate**
---T. H. JU, S. K. DATTA, AND R. L. BRATTON, DEPARTMENT OF MECHANICAL ENGINEERING, UNIVERSITY OF COLORADO, BOULDER, CO 80309-0427, AND A. H. SHAH, DEPARTMENT OF CIVIL ENGINEERING, UNIVERSITY OF MANITOBA, WINNIPEG, CANADA R3T 2N2

2:10 PM **Ultrasonic Evaluation of Damage Zones in Glass/PVC and Glass/Vinylester Composites**
---VINAY DAYAL, JAWAD MOKHTAR, AND DAVID K. HSU, CENTER FOR NDE, IOWA STATE UNIVERSITY, AMES, IA 50011

2:30PM **Ultrasonic Evaluation of Anisotropic Damage Induced in Glass/Epoxy Composites by Water Immersion.**
---BERNARD HOSTEN AND STEPHANE BASTE, UNIVERSITE DE BORDEAUX, LABORATOIRE DE MECANIQUE PHYSIQUE C.N.R.S. (URA N° 867), 351 COURS DE LA LIBERATION 33405 TALENCE CEDEX, FRANCE.

2:50 PM **Non Destructive Inspection for Carbon-Carbon with Adapted Coating for Oxidation.**
---P. PLOTARD, C. LE FLOC'H, AEROSPATIALE AQUITAINE, STRATEGIC AND SPACE DIVISION, 33165, SAINT MEDARD-EN-JALLES, FRANCE.

3:10 PM **COFFEE BREAK**

3:30 PM **Thermal and Ultrasonic Evaluation of Porosity in Composite Laminates**
---PATRICK H. JOHNSTON AND WILLIAM P. WINFREE, N. NATHAN*, NASA LANGLEY RESEARCH CENTER, HAMPTON, VIRGINIA, *ANALYTICAL SERVICES AND MATERIALS, HAMPTON, VIRGINIA

3:50 PM **Application of Acoustic Emission to Studying Fiber Fragmentation as a Process in Single Fiber Composites**
---ROGER B. CLOUGH, MATERIALS SCIENCE AND ENGINEERING LABORATORY, NATIONAL INSTITUTE OF SCIENCE AND TECHNOLOGY, GAITHERSBURG, MD 20899.

4:10 PM **Thermographic Characterization of Stress Induced Damage in Composites**
---D. MICHELE HEATH, WILLIAM P. WINFREE, T. KEVIN O'BRIEN*, MAIL STOP 231, NASA LANGLEY RESEARCH CENTER, HAMPTON, VA 23665, *U.S. ARMY AEROSTRUCTURES DIRECTORATE, MAIL STOP 188E, LANGLEY RESEARCH CENTER, HAMPTON, VA 23665

4:30 PM **Quantitative Measurement of Delamination Area in Low-Velocity Impacted Composites Using Acoustic Microscopy**
---A. C. WEY AND L. W. KESSLER, SONOSCAN, INC., 530 E. GREEN STREET, BENSENVILLE, IL

4:50 PM **The Effect of Exposure to Hot, Wet Conditions on the Dynamic Properties of Fibre Reinforced Plastics**
---R. D. ADAMS AND M. M. SINGH, DEPARTMENT OF MECHANICAL ENGINEERING, UNIVERSITY OF BRISTOL, QUEENS BUILDING, UNIVERSITY WALK, BRISTOL, BS8 1TR

Monday, July 29, 1991

SESSION V
UT THIN PLATES and TUBES - I
P. Nagy, Chairperson
Cleaveland Hall, Room 108
Pages 13-17:

1:30 PM **Complex Ray Analysis of Non-Specular Reflection of Bounded Beams from Multilayer Fluid-Immersed Elastic Structures**
---SMAINE ZEROUG AND LEOPOLD B. FELSEN, DEPT. OF ELECTRICAL ENGINEERING/WEBER RESEARCH INSTITUTE, POLYTECHNIC UNIVERSITY, FARMINGDALE, NY 11735

1:50 PM **Surface Wave Propagation in Fiber Composite Laminates**
---W. ANTHONY GREEN, DEPT. OF THEORETICAL MECHANICS, THE UNIVERSITY, NOTTINGHAM NG7 24D, U.K.

2:10 PM **Elastic Wave Propagation in Homogeneous and Layered Transversely-Isotropic Media: Gaussian Wave Packets and Green's Function.**
---M. SPIES, FRAUNHOFER-INSTITUT FUR ZERSTORUNGSFREIE PRUFVERFAHREN (IZFP), D-6600 SAARBRUCKEN, FRG, P. FELLINGER, K. J. LANGENBERG, DEPT. ELECTRICAL ENGINEERING, UNIVERSITY OF KASSEL, D-3500 KASSEL, FRG.

2:30 PM **Lamb Waves for the NDE of Composite Laminates**
---NINGQUN GUO AND PETER CAWLEY, DEPARTMENT OF MECHANICAL ENGINEERING, IMPERIAL COLLEGE, LONDON SW7 2BX, U.K.

2:50 PM **Guided Waves in Composite and Homogeneous Tubes: Effect of Material Properties**
---T. KOHL AND S. K. DATTA, DEPARTMENT OF MECHANICAL ENGINEERING AND CENTER FOR SPACE CONSTRUCTION, UNIVERSITY OF COLORADO, BOULDER, CO 80309-0427, AND A. H. SHAH AND N. RATTANAWANGCHAROEN, DEPARTMENT OF CIVIL ENGINEERING, UNIVERSITY OF MANITOBA, WINNIPEG, CANADA R3T 2N2

3:10 PM **COFFEE BREAK**

3:30 PM **Viscoelasticity Influence on Frequency Dependence of the Ultrasonic Transmission Through Plates of Composite Materials**
---MARC DESCHAMPS AND BERNARD HOSTEN, UNIVERSITE DE BORDEAUX i, LABORATOIRE DE ME CANIQUE PHYSIQUE C.N.R.S. (URA N° 867, 351, COURS DE LA LIBERATION 33405, TALENCE CEDEX, FRANCE.

3:50 PM **Effect of a Damping Layer on the Transient Response of a Laminated Plate**
---DANIEL NKEMZI AND W. ANTHONY GREEN, DEPT. OF THEORETICAL MECHANICS, NOTTINGHAM NG7 2RD, ENGLAND

4:10 PM **Wavefield Produced in a Composite Laminate by a Concentrated Surface Force**
---AJIT K. MAL, AND SHYH-S. LIH, MECHANICAL, AEROSPACE AND NUCLEAR ENGINEERING DEPARTMENT, UNIVERSITY OF CALIFORNIA, LOS ANGELES, CA 90024

4:30 PM **Finite Element Study of Lamb Wave Interactions with Hole and Through-Thickness Defects in Thin Metal Plate**
---G. S. VERDICT, P. H. GIEN AND C. P. BURGER, TEXAS A&M UNIVERSITY, DEPT. OF MECHANICAL ENGINEERING, COLLEGE STATION, TX 77843

4:50 PM **Acousto-Ultrasonic Wave Propagation in Fiber-Reinforced Composite Materials.**
---JAIHAK LEE, COMPOSITES MANUFACTURING TECHNOLOGY CENTER, THE PENNSYLVANIA STATE UNIVERSITY, UNIVERSITY PARK, PA 16802.

Monday, July 29, 1991

SESSION VI
IMAGING and INVERSION TECHNIQUES
R. Gilmore, Chairperson
Lancaster Lounge/Moulton Union
Pages 18-22:

1:30 PM **Polarimetric Microwave Inverse Scattering as Applied to Nondestructive Testing**
---K. J. LANGENBERG, M. BRANDFASS, UNIVERSITY OF KASSEL, DEPT. OF ELECTRICAL ENGINEERING, D-3500 KASSEL, FRG.

1:50 PM **A Hybrid Numerical and Analytical Procedure for Single Low-frequency Eddy-Current Inverse Scattering**
---M. WISMER AND R. LUDWIG, DEPARTMENT OF ELECTRICAL ENGINEERING, WORCESTER POLYTECHNIC INSTITUTE, WORCESTER, MASSACHUSETTS 01609

2:10 PM **Reconstruction of Internal Density Distributions in Porous Bodies From Laser Ultrasonic Data**
---YICHI LU, JEFF A GOLDMAN AND HAYDN N. G. WADLEY, INTELLIGENT PROCESSING OF MATERIALS LABORATORY, UNIVERSITY OF VIRGINIA, CHARLOTTESVILLE, VA 22903

2:30 PM **A Neural Network Approach for Solving Inverse Problems in NDE**
---I. ELSHAFIEY, L. UDPA, AND S. S. UDPA, DEPT. OF ELECTRICAL ENGINEERING AND COMPUTER ENGINEERING AND CENTER FOR NDE, IOWA STATE UNIVERSITY, AMES, IA 50011

2:50 PM **Microstructure Characterization in Composite Media Using Ultrasonic Tomography**
---R. A. KLINE AND Y. Q. WANG, SCHOOL OF AEROSPACE AND MECHANICAL ENGINEERING, UNIVERSITY OF OKLAHOMA, 865 ASP AVENUE, NORMAN, OK 73019

3:10 PM **COFFEE BREAK**

3:30 PM **A Layer-Stripping Approach to Impedance Imaging**
---MARGARET CHENEY, DAVID ISAACSON, DEPT. OF MATH. SCIENCES, RENSSELAER POLYTECHNIC INSTITUTE, TROY, NY 12180; ERKKI SOMERSALO, DEPT. OF MATH., UNIVERSITY OF HELSINKI, HELSINKI, FINLAND AND ELI L. ISAACSON, DEPT. OF MATH., UNIVERSITY OF WYOMING, LARAMIE, WYOMING 82071

3:50 PM **Real-Time B-Scan Ultrasonic Imaging Using a Digital Phased Array System**
---R. J. DUNKI-JACOBS AND L. J. THOMAS, CRD-GE, RIVER ROAD, SCHENECTADY, NY 12309

4:10 PM **Application of Critical Angle Imaging to the Characterization of Cast Stainless Steels**
---B. PERCY HILDEBRAND, MORRIS S. GOOD, AARON A. DIAZ, EDWARD R. GREEN, PACIFIC NORTHWEST LABORATORY, P. O. BOX 999, RICHLAND, WA 99352

4:30 PM **Ultrasonic Synthetic Aperture Holographic Imaging**
---RICHARD Y. CHIAO, THOMAS G. KINCAID*, AND ROBERT S. GILMORE, GE RESEARCH AND DEVELOPMENT CENTER, P. O. BOX 8, SCHENECTADY, NY 12301; *SIGNAMETRICS, INC., 49 FLETCHER AVE., LEXINGTON, MASSACHUSETTS 02173

4:50 PM **Imaging Flaws in Thin Metal Plates Using a Magneto-Optic Device**
---B. WINCHESKI*, D. R. PRABHU*, M. NAMKUNG, AND E. A. BIRT*, MS 231 NASA LANGLEY RESEARCH CENTER, HAMPTON, VA 23665

Tuesday, July 30, 1991

SESSION VII
NMR for NDE
B. Vander Heiden, Chairperson
Lancaster Lounge/Moulton Union
Pages 23-26:

8:30 AM **Magnetic Resonance Imaging and Spectroscopy: Advanced Tools for the Nondestructive Characterization of Materials**
---JEROME L. ACKERMAN, LEONCIO GARRIDO, JAMES R. MOORE, BETTINA PFLEIDERER AND YAOTANG WU, DEPARTMENT OF RADIOLOGY/NMR CENTER, MASSACHUSETTS GENERAL HOSPITAL AND HARVARD MEDICAL SCHOOL, CHARLESTOWN, MA 02129

9:10 AM **Nondestructive Evaluation of Energetic Materials via NMR Imaging**
---J. H. IWAMIYA AND S. W. SINTON, LOCKHEED PALO ALTO RESEARCH LAB, 3251 HANOVER ST., PALO ALTO, CA 94304-1191

9:30 AM **Multiple Pulse Line Narrowing: Approaches for Solid State NMR Imaging.**
---J. B. MILLER, D. G. CORY*, AND A. N. GARROWAY, CHEMISTRY DIVISION, CODE 6122, NAVAL RESEARCH LABORATORY, WASHINGTON, D.C. 20375-5000; *NRC/NRL POSTDOCTORAL ASSOCIATE; PRESENT ADDRESS: BRUKER INSTRUMENTS, BILLERICA, MA.

9:50 AM **Solid-State NMR Imaging in Two Dimensions with a Single RF-Gradient Coil.**
---MARGAT H. WERNER, JOHN A. MAROHN AND DANIEL P. WEITEKAMP, ARTHUR AMOS NOYES LABORATORY OF CHEMICAL PHYSICS, 127-72, CALIFORNIA INSTITUTE OF TECHNOLOGY, PASADENA, CA 91125; DAVID N. SHYKIND, QUANTUM MAGNETICS, INC., 11578 SORRENTO VALLEY ROAD, SUITE 30, SAN DIEGO, CALIFORNIA 92121.

10:10 AM **COFFEE BREAK**

10:30 AM **Applications of Nuclear Magnetic Resonance Imaging and Spectroscopy to Nondestructive Evaluation.**
---ALAN R. RATH, SPECTROSCOPY IMAGING SYSTEMS, 1120 AUBURN STREET, FREMONT, CA 94538.

10:50 AM **NMR Imaging of Advanced Composites**
---CHARLES G. FRY*, MARTIN J. LIZAK**, AND MARK S. CONRADI**, MCDONNELL DOUGLAS RESEARCH LABORATORIES, ST. LOUIS, MO 63166, AND *WASHINGTON UNIVERSITY, DEPARTMENT OF PHYSICS, ST. LOUIS, MO 63130

11:10 AM **Time-Sequenced Optical Nuclear Magnetic Resonance of Gallium Arsenide**
---STEVEN K. BURATTO, DAVID N. SHYKIND, QUANTUM MAGNETICS, INC., 11578 SORRENTO VALLEY ROAD, SUITE 30, SAN DIEGO, CA 92121, AND DANIEL P. WEITEKAMP, ARTHUR AMOS NOYES LABORATORY OF CHEMICAL PHYSICS, 127-72, CALIFORNIA INSTITUTE OF TECHNOLOGY, PASADENA, CA 92115

11:30 AM **Applications of Broadline and Imaging NMR on Solid Rocket Motor Materials**
---E. J. VANDERHEIDEN, M. J. SULLIVAN AND L. W. HAAS, HERCULES, INC., MS 2343L, MAGNA, UT 84044-0098

11:50 AM **DISCUSSION**

12:10 PM **LUNCH**

Tuesday, July 30, 1991

SESSION VIII
X-RAY INSTRUMENTS and TECHNIQUES
J. Gray, Chairperson
Smith Auditorium
Pages 27-31:

8:30 AM **Performance Modeling of Scintillator-based X-ray Imaging Systems**
---G. A. MOHR, W. T. TUCKER, AND M. K. KUEMAN, GENERAL ELECTRIC CORPORATE RESEARCH AND DEVELOPMENT, P. O. BOX 8, SCHENECTADY, NY 12301

8:50 AM **Performance Characterization of a Solid State X-Ray Imager for Real-Time Radiography**
---C. BUENO, M. D. BARKER, R. BETZ, R. C. BARRY, NDT TECHNOLOGY LABORATORY, RESEARCH AND DEVELOPMENT DIVISION, LOCKHEED MISSILES AND SPACE CO.

9:10 AM **Point Spread Function Estimation of X-Ray Image Intensifier Tubes**
---EDWARD R. DOERING*, JOSEPH N. GRAY**, AND JOHN P. BASART*, CENTER FOR NDE, *DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING, AND **DEPARTMENT OF MECHANICAL ENGINEERING, IOWA STATE UNIVERSITY, AMES, IA 50010

9:30 AM **Monochromatic X-Ray Beams for NDT**
---T. JENSEN, CENTER FOR NDE, ASC-II, IOWA STATE UNIVERSITY, AMES, IOWA 50011

9:50 AM **Design Requirements of Step Wedge for LSF Measurements in Radiography**
---AMOS NOTEA, YOSSI BUSHLIN, URI FELDMAN, QUALITY ASSURANCE AND RELIABILITY, TECHNION, HAIFA 32000, ISREAL

10:10 AM **COFFEE BREAK**

10:30 AM **Measurement of Internal Residual Strain Gradients in Metal Matrix Composites Using Synchrotron Radiation**
---TODD A KUNTZ AND DR. HAYDN N. G. WADLEY, DEPARTMENT OF MATERIALS SCIENCE, UNIVERSITY OF VIRGINIA, CHARLOTTESVILLE, VA 22903; DAVID R. BLACK, NATIONAL INSTITUTE OF STANDARDS & TECHNOLOGY, BLDG. 223, ROOM A163, GAITHERSBURG, MD 20899

10:50 AM **Quantitative Nondestructive Density Determinations of Very Light-Weight Carbon Foams**
---W. E. MODDEMAN, D. P. KRAMER, D. W. FIRSICH AND P. D. TRAINER, MOUND,* EG&G MOUND APPLIED TECHNOLOGIES, MIAMISBURG, OH 45343 AND M. E. HUGHES AND R. N. YANCEY, ARACOR**, WRIGHT-PATTERSON AIR FORCE BASE, DAYTON, OH 45433

11:10 AM **Correlation of X-Ray CT Measurements to Shear Strength in Pultruded Composite Material**
---GARY GEORGESON, RICHARD BOSSI, LARRY O'DELL, GEORGE LORSBACH AND JAMES NELSON, BOEING, P. O. BOX 3999, MS 87-60, SEATTLE, WA 98124-2499

11:30 AM **Coherent X-Ray Imaging for Corrosion Evaluation: A Preliminary Assessment**
---LARRY LAWSON, CENTER FOR QUALITY ENGINEERING AND FAILURE PREVENTION, NORTHWESTERN UNIVERSITY, ROOM 324, CATALYSIS BUILDING, 2137 N. SHERIDAN ROAD, EVANSTON, IL 60208-3020

11:50 AM **DISCUSSION**

12:10 PM **LUNCH**

SESSION IX
NDE of COMPOSITES
W. Murri, Chairperson
Kresge Auditorium
Pages 32-36:

8:30 AM **Ultrasonic Evaluation of Elastic Properties and Damage of Sic/RBSN Ceramic Composites**
---Y. C. CHU, M. HEFETZ, AND S. I. ROKHLIN, THE OHIO STATE UNIVERSITY, DEPARTMENT OF WELDING ENGINEERING, 190 WEST 19TH AVENUE, COLUMBUS, OH 43210 AND G. Y. BAAKLINI, NASA LEWIS RESEARCH CENTER, CLEVELAND, OHIO 44135

8:50 AM **A Comparison of Conventional and Advanced Ultrasonic Inspection Techniques in the Characterization of TMC Materials**
---MARK R. HOLLAND, SCOTT M. HANDLEY, JAMES G. MILLER, WASHINGTON UNIVERSITY, ST. LOUIS, MO, AND MARK K. REIGHARD, MCDONNELL AIRCRAFT COMPANY, ST. LOUIS, MO

9:10 AM **Surface Wave Techniques to Characterize CMC Materials**
---MANOHAR BASHYAM, GE AIRCRAFT ENGINES, M.D. Q45, OH 45215 AND JOSEPH L. ROSE, DREXEL UNIVERSITY, PA 19104

9:30 AM **Ultrasonic Characterization of an Interface in a SiC Fiber Metal Matrix Composite**
---P. JAGNOUX, R. FOUGERES, A VINCENT, GROUPE D'ETUDES DE METALLURGIE PHYSIQUE ET DE PHYSIQUE DES MATERIAUX, URA CNRS 341 - BAT. 502 - INSA - 69621 VILLEURBANNE, FRANCE

9:50 AM **Ultrasonic Evaluation of Silicon-Carbide Reinforced Aluminum Metal-Matrix Composite Billet Materials**
---P. K. LIAW AND R. E. SHANNON, WESTINGHOUSE SCIENCE & TECHNOLOGY CENTER, PITTSBURGH, PA 15235, Y. LU, IPM LABORATORY, UNIVERSITY OF VIRGINIA, CHARLOTTESVILLE, VA 22903, AND D. K. HSU, CENTER FOR NDE, IOWA STATE UNIVERSITY, AMES, IA 50011

10:10 AM **COFFEE BREAK**

10:30 AM **Fatigue Crack Growth Characterization in 2024 Al and 2014 Al/20% SiC Composite Using Ultrasonic Observations**
---D. K. REHBEIN, AND S. B. BINER, AMES LABORATORY-USDOE AND IOWA STATE UNIVERSITY, AMES, IA 50011

10:50 AM **Real-Time Ultrasonic Investigation of Damage Development in Ceramic-Matrix Composite Under Longitudinal Loading**
---S. C. WOOH AND I. M. DANIEL, NORTHWESTERN UNIVERSITY, EVANSTON, IL 60208

11:10 AM **Thermographic Characterization of Impact Damage in Carbon-Carbon Composites**
---WILLIAM P. WINFREE, MS 231, NASA LANGLEY RESEARCH CENTER, HAMPTON, VA 23665, Y. R. YAMAKI, LOCKHEED ENGINEERING AND SCIENCES COMPANY, HAMPTON, VA, AND B. T. SMITH, COLLEGE OF WILLIAM AND MARY, WILLIAMSBURG, VA.

11:30 AM **Measurement and Processing Effects on Residual Thermomechanical Stresses in Composites**
---J. W. KRYNICKI, R. E. GREEN, JR., AND D. C. NAGLE*, CENTER FOR NONDESTRUCTIVE EVALUATION, THE JOHNS HOPKINS UNIVERSITY, BALTIMORE, MD 21218, *MARTIN MARIETTA LABORATORIES, BALTIMORE, MD 21227

11:50 AM **Acoustic Emission Monitoring of a Fatigue Crack**
---D. M. GRANATA, W. R. SCOTT, J. DAVIS, AND E. U. LEE, NAVAL AIR DEVELOPMENT CENTER, WARMINSTER, PA

12:10 PM **LUNCH**

Tuesday, July 30, 1991

SESSION X
UT INTERFACES; UT THIN PLATES and TUBES - II

J. Achenbach, Chairperson
Cleaveland Hall, Room 108
Pages 37-41:

UT Interfaces

8:30 AM **Analysis of Guided Waves in an Asymmetric Sandwich Plate**
---R. L. BRATTON AND S. K. DATTA, DEPARTMENT OF MECHANICAL ENGINEERING AND CENTER FOR SPACE CONSTRUCTION, UNIVERSITY OF COLORADO, BOULDER, CO 80309-0427, AND W. M. KARUNASENA AND A. H. SHAH, DEPARTMENT OF CIVIL ENGINEERING, UNIVERSITY OF MANITOBA, WINNIPEG, CANADA R3T 2N2

8:50 AM **Ultrasonic Wave Propagation Through an Interface With a Step Discontinuity**
A. MINACHI, R. B. THOMPSON, CENTER FOR NONDESTRUCTIVE EVALUATION, IOWA STATE UNIVERSITY, AMES, IA 50010; M. S. GOOD AND A. A. DIAZ, BATTELLE PACIFIC NORTHWEST LABORATORIES

9:10 AM **Iterative Boundary Integral Solution for Curved Interface Ultrasonic Transmission**
---R. A. ROBERTS, CENTER FOR NDE, IOWA STATE UNIVERSITY, AMES, IA 50010

9:30 AM **Generalized Boundary Conditions for Imperfect Interface Between Two Solid Anisotropic Media**
---S. I. ROKHLIN AND W. HUANG, THE OHIO STATE UNIVERSITY, DEPARTMENT OF WELDING ENGINEERING, 190 WEST 19TH AVENUE, COLUMBUS, OH 43210

9:50 AM **The Interfacial Mass Detection with Lamb-Wave Sensors**
---JUNRU WU AND ZHEMIN ZHU*, DEPARTMENT OF PHYSICS, UNIVERSITY OF VERMONT, BURLINGTON, VT 05405, *INSTITUTE OF ACOUSTICS, NANJING UNIVERSITY, PEOPLE'S REPUBLIC OF CHINA

10:10 AM **COFFEE BREAK**

UT Thin Plates and Tubes - II

10:30 AM **Material Characterization of Composite Laminates Using Low Frequency Plate Wave Dispersion Data**
---AJIT K. MAL, MECHANICAL, AEROSPACE AND NUCLEAR ENGINEERING DEPARTMENT, UNIVERSITY OF CALIFORNIA, LOS ANGELES, CA 90024, MICHAEL R. GORMAN AND WILLIAM H. PROSSER, AERONAUTICS AND ASTRONAUTICS DEPARTMENT, NAVAL POSTGRADUATE SCHOOL, MONTEREY, CA 93943.

10:50 AM **Lamb Wave Mode Selection Guidelines for Defect Detection Optimization in Thin Plates**
---J. J. DITRI, J. L. ROSE, G. CHEN, DREXEL UNIVERSITY, PHILADELPHIA, PA 19104

11:10 AM **Analysis of Transient Lamb Waves in Metal Plates, Composite Panels, and Curved Members Via Laser and Fiber Optic Methods**
---NEAL A. SCHUMACHER, CHRISTIAN P. BURGER, AND PETER H. GIEN, DEPT. OF MECHANICAL ENGINEERING, TEXAS A&M UNIVERSITY, COLLEGE STATION, TX 77843

11:30 AM **Determination of the Flexural Modulus of Thin Films from Laser-Ultrasonic Measurement of Symmetric Lamb Waves**
---SARAH E. BOBBIN AND JAMES W. WAGNER, CENTER FOR NONDESTRUCTIVE EVALUATION, DEPARTMENT OF MATERIALS SCIENCE AND ENGINEERING, THE JOHNS HOPKINS UNIVERSITY, BALTIMORE, MD 21218

Tuesday, July 30, 1991

11:50 AM **Connection Machine Simulation of Ultrasonic Wave Propagation: Two Dimensional Case**
---P. P. DELSANTO, POLITECNICO DI TORINO, 10129 TORINO, ITALY; H. H. CHASKELIS, R. B. MIGNOGNA, T. V. WHITCOMBE, R. S. SCHECHTER, MECHANICS OF MATERIALS BRANCH, NAVAL RESEARCH LABORATORY, WASHINGTON, DC 20375-5000

12:10 PM **LUNCH**

Tuesday, July 30, 1991

SESSION XI - POSTERS
UT ANISOTROPIC MATERIALS, COMPOSITES,
BONDED MATERIALS, RADIOGRAPHY,
EDDY CURRENT and OTHER EM TECHNIQUES,
and NDE in MANUFACTURING
Pages 42-62:

1:30 PM

UT Anisotropic Materials

On-Axis Formulas for Ultrasonic Transducer Beams in Anisotropic Media
---BYRON P. NEWBERRY, DEPARTMENT OF AEROSPACE ENGINEERING, AND ENGINEERING MECHANICS, UNIVERSITY OF CINCINNATI, CINCINNATI, OH 45221

Validity of the Gauss-Hermite Beam Model in an Anisotropic, Layered Medium-Comparison to the Finite Element Method
---A. MINACHI, Z. YOU, R. B. THOMPSON, W. P. LORD, CENTER FOR NONDESTRUCTIVE EVALUATION, IOWA STATE UNIVERSITY, AMES, IA 50011

Sensitivity Analysis for Elastic Property Reconstruction in Anisotropic Media
---R. A. KLINE AND S. K. SAHAY, SCHOOL OF AEROSPACE AND MECHANICAL ENGINEERING, UNIVERSITY OF OKLAHOMA, NORMAN, OK 73019

Three Dimensional Representational Surfaces for Anisotropic Media
---R. A. KLINE AND S. K. SAHAY, SCHOOL OF AEROSPACE AND MECHANICAL ENGINEERING, UNIVERSITY OF OKLAHOMA, NORMAN, OK 73019

Correlation Study of Nondestructive Predictions of Formability Parameters with Destructive Measurements for Aluminum and Steel Sheet
---S. J. WORMLEY, E. P. PAPADAKIS AND R. B. THOMPSON, CENTER FOR NDE, IOWA STATE UNIVERSITY, AMES, IA 50011

Composites

Ultrasonic NDT of Fiberglass Sandwich Marine Composites
---HYUNJO JEONG AND DAVID K. HSU, CENTER FOR NDE, IOWA STATE UNIVERSITY, AMES, IA 50011

Ultrasonic Reflection and Transmission Study of Aramid/Aluminum Composites
---P. J. SHULL AND D. E. CHIMENTI, CENTER FOR NDE, JOHNS HOPKINS UNIVERSITY, BALTIMORE, MD 21218 AND A. H. NAYFEH, AEROSPACE ENGINEERING AND ENGINEERING MECHANICS, UNIVERSITY OF CINCINNATI, CINCINNATI, OH 45221

Lamb Wave Propagation in Multi-Layered Composite Plates
---W. P. ROGERS, R. BRATTON, AND S. K. DATTA, DEPT. OF MECHANICAL ENGINEERING, CAMPUS BOX 427, UNIVERSITY OF COLORADO, BOULDER, CO 80309

Acoustic Emission Investigation of Fiber Fractures in Composite Materials
---I. M. DANIEL, I. KOMSKY AND T.-M. WANG, CENTER FOR QUALITY ENGINEERING AND FAILURE PREVENTION, NORTHWESTERN UNIVERSITY, EVANSTON, IL 60208

Quantitative Characterization of Thick Composite Laminates Using Oblique Insonification
---C. -C. YIN, A. K. MAL AND Y. BAR-COHEN, MECHANICAL ENGINEERING DEPT., NATIONAL CHIAO TUNG UNIVERSITY, 1001 TA HSUEH ROAD, HSINCHU 30050, TAIWAN

NDE of Fracture-Induced Anisotropy
---JULIE A. HOOD, NAVAL RESEARCH LABORATORY, CODE 6380, WASHINGTON, D.C. 20375, AND MICHAEL SCHOENBERG, SCHLUMBERGER CAMBRIDGE RESEARCH, CAMBRIDGE, ENGLAND CB3 OEL

Ultrasonic Characterization of Woven Composites
---MARK BLODGETT, WRIGHT LABORATORY, WRIGHT-PATTERSON AFB, OHIO, 45433-6533, AND MARK RUDDELL, UNIVERSITY OF DAYTON RESEARCH INSTITUTE, 300 COLLEGE PARK DRIVE, DAYTON, OH 45469

Application of SAFT on Composites

---M. S. HUGHES, S. R. GHORAYEB, D. K. HOLGER, L. W. ZACHARY, R. B. THOMPSON, AND D. K. HSU, CENTER FOR NDE, IOWA STATE UNIVERSITY, AMES, IA 50011

Bonded Materials

A Comparative Study of Experimental and Simulated Ultrasonic Pulse-Echo Signals from Multilayered Structures
---M. N. ABEDIN*, D. R. PRABHU*, W. P. WINFREE, AND P. H. JOHNSTON, MS 231, NASA LANGLEY RESEARCH CENTER, HAMPTON, VA 23665, *Analytical Services and Materials, inc., 107 Research Drive, Hampton, VA 23666

Effects of Thin Layer Adherents on Ultrasonic Testing Results
---E. C. JOHNSON AND G. F. HAWKINS, THE AEROSPACE CORPORATION, M. S. M2/248, P. O. BOX 92957, LOS ANGELES, CA 90009

Ultrasonic NDE of Adhesively Bonded Aluminum Lap Joints
---THADD C. PATTON AND DAVID K. HSU, CENTER FOR AVIATION SYSTEMS RELIABILITY, IOWA STATE UNIVERSITY, AMES, IA 50011

Physically Based Feature Mapping Concepts in Bond Interface Evaluation
---D. JIAO, J. ROSE, AND N. HODIWALLA, DREXEL UNIVERSITY, MECHANICAL ENGINEERING AND MECHANICS DEPARTMENT, PHILADELPHIA, PA 19104

Experimental Study of Interface Properties Between Layer and Substrate
---RAY T. KO, PETER B. NAGY AND LASZLO ADLER, DEPARTMENT OF WELDING ENGINEERING, THE OHIO STATE UNIVERSITY, COLUMBUS, OH 43210

An Ultrasonic Testing Technique for Measurement of the Poisson's Ratio of Thin Adhesive Layers
---E. C. JOHNSON, J. D. POLLCHIK AND J. N. SCHURR, THE AEROSPACE CORPORATION, MAILSTOP M2/248, P. O. BOX 92957, LOS ANGELES, CA 90009

Quantitative Nondestructive Evaluation of Adhesive Lap Joints in Sheet Molding Compound by Adaptation of a Commercial Bond Tester.
---EMMANUEL P. PAPADAKIS, CENTER FOR NDE, IOWA STATE UNIVERSITY, AMES, IOWA 50011; GILBERT B. CHAPMAN, II, MATERIALS ENGINEERING, CHRYSLER CORPORATION, MADISON HEIGHTS, MICHIGAN 48071

Tuesday, July 30, 1991

Radiography

Computer Simulation of Steel Cord Radiograph Profiles
---E. C. GREENAWALD, GEO-CENTERS, INC., 10903 INDIAN HEAD HWY., FT. WASHINGTON, MD. 20744 AND C. F. PORANSKI, JR., NAVAL RESEARCH LAB, WASHINGTON DC

Unfocused Source of X-rays in a Microfocus X-Ray Tube
---W. D. FRIEDMAN, BP/AMERICA, 4440 WARRENSVILLE CENTER RD., CLEVELAND, OH 44128

Hybrid Lossless-lossy Compression of Industrial Radiographs
---AJAI NARAYAN AND TENSKAI V. RAMABADRAN, CENTER FOR NDE, DEPARTMENT OF ELECTRICAL ENGINEERING AND COMPUTER ENGINEERING, IOWA STATE UNIVERSITY, AMES, IOWA 50011

Radiographic Image Enhancement by Wiener Decorrelation
---Z. W. BELL, COMPUTING AND TELECOMMUNICATIONS DIVISION, AND B. W. GODFREY, DEVELOPMENT DIVISION, OAK RIDGE Y-12 PLANT, MANAGED FOR THE U.S. DEPARTMENT OF ENERGY BY MARTIN MARIETTA ENERGY SYSTEMS, INC. UNDER CONTRACT DE-AC05-840R21400, BUILDING 9103 MS 8141, P. O. BOX 2009, OAK RIDGE, TN 37831-8141

Quantitative Determination of Material Compositions of Composites Using Energy Sensitive X-Ray Measurements
---J. TING, T. JENSEN, J. N. GRAY, CENTER FOR NDE, IOWA STATE UNIVERSITY, AMES, IA 50010

Application of an X-ray Process Model for Inspection Optimization
J. GRAY, T. JENSEN, AND R. WALLINGFORD, CENTER FOR NONDESTRUCTIVE EVALUATION, IOWA STATE UNIVERSITY, AMES, IA 50011

Eddy Current and Other EM Techniques

Rotating, Orthogonal Coil, Differential Eddy Current Probe
---M. FREDERICK DERSCH, DTRC, CODE 2815, ANNAPOLIS, MD 21403

Cross-Correlation of Eddy Current Images for Detection of Fatigue Crack Propagation
---R. H. MOORE, J. M. GLASS, H. P. GROGER AND R. J. CHURCHILL, AMERICAN RESEARCH CORPORATION OF VIRGINIA, P. O. BOX 3406, RADFORD, VIRGINIA 24143

A Feedthrough Eddy-Current Transducer with Rotating Magnetic Field
---P. LEMBEYE, P. SALEMI, IRSID, 78105 ST. GERMAIN EN LAYE, FRANCE

Eddy Current Inspection of Weld Defects in Tubing
---G. KATRAGADDA AND W. LORD, ELECTRICAL ENGINEERING DEPARTMENT, IOWA STATE UNIVERSITY, AMES, IA 50011

Benchmark Problems in Eddy-Current NDE
---HAROLD A. SABBAGH, SABBAGH ASSOCIATES, INC., 4639 MORNINGSIDE DRIVE, BLOOMINGTON, IN 47401; STEPHEN K. BURKE, DEFENSE SCIENCE & TECHNOLOGY ORGANIZATION, MELBOURNE, AUSTRALIA

Skin Depth Considerations in Eddy Current NDT
---P. STUCKY AND W. LORD, ELECTRICAL ENGINEERING DEPARTMENT, IOWA STATE UNIVERSITY, AMES, IA 50011

Computer Simulations of Induced Surface Electromagnetics Fields Around Circular-Arc Cracks in Ferromagnetic Metals
---S. H. H. SADEGHI AND D. MIRSHEKAR-SYAHKAL, DEPARTMENT OF ELECTRONIC SYSTEMS ENGINEERING, UNIVERSITY OF ESSEX, COLCHESTER CO4 3SQ, UK

Significant Improvement of Remote Field Eddy Current Probe Performance with Modified Probe Structures
---Y. S. SUN, M. X. QU AND J. T. SI, DEPT. OF AUTOMATIC CONTROL, NANJING AERONAUTICAL INSTITUTE, 29 YADAO ST. NANJING, JIANGSU 210016, P. R. CHINA

OSEE Responses on D6AC Steel Due to Sample Preparation
---M. N. ABEDIN*, C. S. WELCH+, AND W. T. YOST, MS 231, NASA LANGLEY RESEARCH CENTER, HAMPTON, VA 23665, *ANALYTICAL SERVICES AND MATERIALS, INC., 107 RESEARCH DRIVE, HAMPTON, VA 23666, +PHYSICS DEPARTMENT, COLLEGE OF WILLIAM AND MARY, WILLIAMSBURG, VA 23185

Contact Free Outer an Inner Diameter Measurement of Cylindrical Conductive Tubes Using Long Coils
---B. DE LIMBURG STIRUM, J. DRIRA, TH. CARDINAEL, V. DUJARDIN AND B. DE HALLEUX, CATHOLIC UNIVERSITY OF LOUVAIN, MECHANICAL ENGINEERING DEPARTMENT, LOUVAIN-LA-NEUVE, BELGIUM

A Physical Model Underlying the Maxwell Equations, Application to Electromagnetic Problems
---B. DE HALLEUX, CATHOLIC UNIVERSITY OF LOUVAIN, MECHANICAL ENGINEERING DEPARTMENT, LOUVAIN-LA-NEUVE, BELGIUM

Simulation of Nondestructive Testing of Materials in Microwave Cavities
---J. S. WANG AND N. IDA, THE UNIVERSITY OF AKRON, DEPARTMENT OF EE, AKRON, OH 44325

NDE in Manufacturing

Production Parameters that Affect Practical Application of NDE Procedures.
---WARD D. RUMMEL, MARTIN MARIETTA ASTRONAUTICS, 8776 W. MOUNTAINVIEW LANE, LITTLETON, CO 80125.

Mathematical Methods to Set Up and Justify Industrial NDE Tests
---EMMANUEL P. PAPADAKIS, CENTER FOR NDE, IOWA STATE UNIVERSITY, 1915 SCHOLL ROAD, BLDG. II, AMES, IA 50011.

ASNT 50th Anniversary

Fifty Years of Improved Safety and Reliability Through NDT American Society for Nondestructive Testing
---VICKI PANHUISE, GARRETT TURBINE ENGINE CO., P. O. BOX 5217, PHOENIX, AZ 85010

3:00 **COFFEE BREAK**

Tuesday, July 30, 1991

SESSION XII
APPLICATIONS of NEURAL NETWORKS
L. Udpa, Chairperson
Lancaster Lounge/Moulton Union
Pages 63-66:

3:30 PM **IDA: An Architecture for an Intelligent Design Assistant for Assessing the Inspectability of Structures From a Description of Their Geometry**
---STEPHEN M. NUGEN, CENTER FOR NONDESTRUCTIVE EVALUATION; LESTER W. SCHMERR, JR., CENTER FOR NONDESTRUCTIVE EVALUATION AND AEROSPACE ENGINEERING AND ENGINEERING MECHANICS; BABAK FOROURAGHI, CENTER FOR NONDESTRUCTIVE EVALUATION AND COMPUTER SCIENCE DEPARTMENT, IOWA STATE UNIVERSITY, AMES, IA 50010

3:50 PM **Graphite Epoxy Defect Classification of Ultrasonic Signatures Using Statistical and Neural Network Methods**
---L. M. BROWN*, R. W. NEUMAN**, C. A. LEBOWITZ*, R. DENALE* AND F. G. ARCELLA*, *DAVID TAYLOR RESEARCH CENTER, ANNAPOLIS, MD 21402-5067; **THE JOHNS HOPKINS UNIVERSITY APPLIED PHYSICS LABORATORY, LAUREL, MD 20723-6099

4:10 PM **New Training Algorithms for Neural Networks**
---J. CHOW, L. UDPA, AND S. S. UDPA, CENTER FOR NDE, IOWA STATE UNIVERSITY, AMES, IA 50011

4:30 PM **Time Delay Neural Networks for the Classification of Ultrasonic NDT Signals**
---K. SHAHANI, L. UDPA, AND S. S. UDPA, DEPT. OF ELECTRICAL ENGINEERING AND COMPUTER ENGINEERING AND CENTER FOR NDE, IOWA STATE UNIVERSITY, AMES, IA 50011

4:50 PM **Neural Network for Crack-Depth Determination from Ultrasonic Backscattering Data**
---M. KITAHARA, TOKAI UNIVERSITY, SHIMIZU, SHIZUOKA 424, JAPAN; J. D. ACHENBACH, Q. C. GUO AND M. R. PETER, CENTER FOR QUALITY ENGINEERING AND FAILURE PREVENTION, NORTHWESTERN UNIVERSITY, EVANSTON, IL 60208; M. NOTAKE AND M. TAKADOYA, MITSUBISHI RESEARCH INSTITUTE, 2-3-6 OHTEMACHI, TOKYO 100, JAPAN.

5:10 PM **Acoustic Emission Applications on the NASA Space Station**
---M. A. FRIESEL, R. J. KURTZ, D. K. LEMON, J. F. DAWSON, P. H. HUTTON, R. S. BARGA, PACIFIC NORTHWEST LABORATORY, RICHLAND, WASHINGTON 99352

5:30 PM **The Application of Phase Quadrature Information to the Automated Detection and Classification of Defects in the Presence of Deterministic Noise of Similar Characteristics**
---DONALD L. BIRX AND STEPHEN J. PIPENBERG, SYSTEMS RESEARCH LABORATORIES, DAYTON, OHIO 45440

SESSION XIII
EDDY CURRENT ARRAYS
J. Moulder, Chairperson
Kresge Auditorium
Pages 67-69:

3:30 PM **Detection of Deep Flaw Inside a Conductor Using a SQUID Magnetometer**
---Y. P. MA AND J. P. WIKSWO, JR., DEPARTMENT OF PHYSICS & ASTRONOMY, VANDERBILT UNIVERSITY, NASHVILLE, TN 37235

3:50 PM **A Nondestructive Crack/Imperfection Detection System on a Silicon Chip**
---H. T. HENDERSON, K. P. KARTALIA, AND J. D. DURY, CENTER FOR MICROELECTRONIC SENSORS AND MICROSTRUCTURES, UNIVERSITY OF CINCINNATI, CINCINNATI, OH 45221

4:10 PM **A Linear Eddy-Current Array Driven by a Whip Excitation**
---JEFF C. TREECE AND HAROLD A. SABBAGH, SABBAGH ASSOCIATES, INC., 4639 MORNINGSIDE DRIVE, BLOOMINGTON, IN 47401

4:30 PM **Eddy Current Arrays for Defect Detection**
---D. C. HURLEY, K. H. HEDENGREN, AND J. D. YOUNG, GE CORPORATE RESEARCH & DEVELOPMENT, P. O. BOX 8, SCHENECTADY, NY 12301

4:50 PM **Surface Coverage Issues when Using Eddy Current Arrays**
---K. H. HEDENGREN, AND P. J. HOWARD, GE CORPORATE RESEARCH & DEVELOPMENT, P.O. BOX 8, SCHENECTADY, NY 12301

5:10 PM **Eddy Current Arrays and Data Imaging**
---JAY L. FISHER, AND JEFF S. STOLTE, SOUTHWEST RESEARCH INSTITUTE, 6220 CULEBRA ROAD, SAN ANTONIO, TX 78238

Tuesday, July 30, 1991

SESSION XIV
STRESS MEASUREMENTS
R. B. Thompson, Chairperson
Smith Auditorium
Pages 70-72:

3:30 PM **Summary Comments**
---R. B. THOMPSON, CENTER FOR NDE AND AMES LAB, IOWA STATE UNIVERSITY

3:50 PM **Ultrasonic Measurement of Stress in Rolled Sheets**
---WEI-YANG LU & CHI-SING MAN, UNIVERSITY OF KENTUCKY, LEXINGTON, KY 40506

4:10 PM **An EMAT System for Railroad Wheel Residual Stress Inspection**
---R. E. SCHRAMM, A. V. CLARK, JR., D. MITRAKOVIC* AND S. R. SCHAPS, NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY MATERIALS RELIABILITY DIVISION 325 BROADWAY, BOULDER, CO 80303, *NIST GUEST RESEARCHER: ON LEAVE FROM UNIVERSITY OF BELGRADE

4:30 PM **Experience with Two Ultrasonic-Based Measurement Techniques for Residual Stress Determination in Railroad Rails**
---DAVID UTRATA, ASSOCIATION OF AMERICAN RAILROADS, 3140 S. FEDERAL STREET, CHICAGO, IL 60616

4:50 PM **Overview of the LCR Technique for Ultrasonic Stress Measurement**
DON E. BRAY AND MALUR SRINIVASAN, DEPT. OF MECHANICAL ENGINEERING, TEXAS A&M UNIVERSITY, COLLEGE STATION, TX

5:10 PM **Effect of Surface Condition on SH Wave Stress Measurements**
---RON B. ALERS, CALIFORNIA POLYTECHNIC STATE UNIVERSITY, DEPT. OF MATERIALS ENGINEERING, SAN LUIS OBISPO, CA 93407

SESSION XV
MAGNETIC MATERIALS
D. Jiles, Chairperson
Cleaveland Hall, Room 108
Page 73:-76

3:10 PM **Magnetic Characterization of a Steel Sheet as a Function of the Degree of Recrystallization**
---J. F. BUSSIERE AND M. LORD, NATIONAL RESEARCH COUNCIL CANADA, INDUSTRIAL MATERIALS RESEARCH INSTITUTE, 75 BOUL. MORTAGNE, BOUCHERVILLE, QUEBEC J4B 6Y4 CANADA

3:30 PM **Magnetoacoustic Residual Stress Measurements in Railroad Wheels - Experience with Field Modeling and Component Testing**
---DAVID UTRATA, ASSOCIATION OF AMERICAN RAILROADS, 3140 S. FEDERAL STREET, CHICAGO, IL 60616

3:50 PM **Globus Model in Analysis of Hysteresis in Textured Materials**
---J. ZSARGO AND J. A. SZPUNAR, DEPARTMENT OF METALLURGICAL ENGINEERING, MCGILL UNIVERSITY, 3450 UNIVERSITY STREET, MONTREAL, PQ, CANADA H3A 2A7

4:10 PM **Magnetic NDE Techniques for Detecting Mechanical Changes in Materials**
---M. K. DEVINE, D. C. JILES, D. A. KAMINSKI, D. CHANDLER, CENTER FOR NDE, AMES, IA 50011

4:30 PM **Effects of Irradiation and Prestraining on the Magnetic Properties of ASTM A533 and Other Steels**
---M. K. DEVINE, J. APOSTAL AND D. C. JILES, CENTER FOR NDE, AMES, IA 50011, P. K. LIAW, WESTINGHOUSE SCIENCE AND TECHNOLOGY CENTER, PITTSBURGH, PA 15235

4:50 PM **Effects of Uniaxial Compressive Stress on Magnetic Field-Induced Motion of Active 90-Degree Domain Walls**
---M. NAMKUNG, D. UTRATA*, R. DENALE**, AND R. G. TODHUNTER***, MS 231 NASA LANGLEY RESEARCH CENTER, HAMPTON, VA 23665, *ASSOCIATION OF AMERICAN RAILROADS, 3140 S. FEDERAL STREET, CHICAGO, IL 60616, **DAVID TAYLOR RESEARCH CENTER, ANNAPOLIS, MD 21402, ***ANALYTIC SERVICES AND MATERIALS, INC. 107 RESEARCH DRIVE, HAMPTON, VA 23666

5:10 PM **Parameterization of Asymmetry in Magnetoacoustic Emission by Numerical Processes**
---E. A. BIRT*, M. NAMKUNG, R. DENALE**, AND J. L. GRAINGER*, NASA LANGLEY RESEARCH CENTER, MS 231, * AS&M INC. 107 RESEARCH DRIVE, HAMPTON, VA 23666, **DAVID TAYLOR RESEARCH CENTER, ANNAPOLIS, MD 21402

5:30 PM **Micromagnetic Surface Studies of Materials for NDE**
---L. B. SIPAHI*, AND D. C. JILES**; *CENTER FOR NDE AND DEPARTMENT OF PHYSICS, **CENTER FOR NDE, AMES LABORATORY AND DEPARTMENT OF MATERIALS SCIENCE AND ENGINEERING, IOWA STATE UNIVERSITY, AMES, IA 50011.

Wednesday, July 31, 1991

SESSION XVI
EDDY CURRENTS
T. Capabianco, Chairperson
Kresge Auditorium
Pages 77-81:

8:30 AM **Measurement and Calculation of Transient Eddy Currents in Layered Structures**
---J. R. BOWLER, DEPT. OF PHYSICS, UNIVERSITY OF SURREY, GUILDFORD SURREY G72 5XH, UK AND D. J. HARRISON, MOD (PE) ROYAL AEROSPACE EST., MATERIALS & STRUCTURES DEPT., X32 BUILDING, FARNBOROUGH, HANTS. GU14 6TD, UK

8:50 AM **Through-Transmission Impedance Measurements on Moving Metallic Sheets**
---ARNOLD H. KAHN, NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY, GAITHERSBURG, MD 20899, MICHAEL L. MESTER, BABCOCK AND WILCOX, CLEVELAND, OH 44685-0190.

9:10 AM **Numerical Modeling of Probe Velocity Effects for Electromagnetic NDE Methods**
---Y. K. SHIN AND W. LORD, ELECTRICAL ENGINEERING DEPARTMENT, IOWA STATE UNIVERSITY, AMES, IA 50011

9:30 AM **Theory of Eddy Currents in Metal Matrix Composites**
---R. E. BEISSNER, SOUTHWEST RESEARCH INSTITUTE, 6220 CULEBRA ROAD, SAN ANTONIO, TX 78238

9:50 AM **A Study of Eddy Current Corner Crack Inspection**
---N. NAKAGAWA, S. MITRA, AND J. C. MOULDER, CENTER FOR NDE, IOWA STATE UNIVERSITY, AMES, IA 50011

10:10 AM **COFFEE BREAK**

10:30 AM **Probability of Detection Models for Eddy Current NDE Methods**
---S. N. RAJESH, L. UDPA, S. S. UDPA, AND N. NAKAGAWA, FAA, CENTER FOR AVIATION SYSTEMS RELIABILITY, IOWA STATE UNIVERSITY, AMES, IA 50011

10:50 AM **Real Time Gauging and Conductivity Measurement of Cylindrical Structures Using Inverted Multifrequency Eddy Current**
---JOHN WALLACE, CASTING ANALYSIS CORP., WEYERS CAVE, VA 24486 AND CHIBUIKE IHEAGWARA, MAGNETIC ANALYSIS CORP., 535 S. AVE., MT. VERNON, NY 10550

11:10 AM **Thickness and Conductivity of Layers on Metals from Eddy Current Measurements**
EROL UZAL, JOHN C. MOULDER AND JAMES H. ROSE, CENTER FOR NDE, IOWA STATE UNIVERSITY, AMES, IA 50011

11:30 AM **Eddy Current and Four-Probe DC Methods for Conductivity Measurements in Thin Sheets of Low-Conductivity Materials.**
---M. GVISHI, VISITING SCIENTIST, ISRAEL MINISTRY OF DEFENSE, P. O. 2250, HAIFA 31021, ISRAEL, A. H. KAHN, NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY, GAITHERSBURG, MD 20899, M. L. MESTER, BABCOCK AND WILCOX, CLEVELAND, OHIO 44685-0190.

11:50 AM **Eddy Current Crack Signals**
---S. ROSS AND W. LORD, ELECTRICAL ENGINEERING DEPARTMENT, IOWA STATE UNIVERSITY, AMES, IA 50011

12:10 PM **LUNCH**

Wednesday, July 31, 1991

SESSION XVII
NDE for ADHESIVE BONDS
J. Cantrell, Chairperson
Lancaster Lounge/Moulton Union
Pages 82-86:

8:30 AM **A Combined Theoretical and Experimental Ultrasonic NDE Investigation of Adhesively Bonded Metal-to-Metal Materials**
---R. LUDWIG, J. M. SULLIVAN, WORCESTER POLYTECHNIC INSTITUTE, WORCESTER, MA 01609 AND R. ANASTASI, U.S. ARMY MATERIALS TECHNOLOGY LABORATORY, WATERTOWN, MA 02172

8:50 AM **Application of Guided Acoustic Waves to Delamination Detection**
---KEUN J. SUN, DEPARTMENT OF PHYSICS, COLLEGE OF WILLIAM AND MARY, WILLIAMSBURG, VA 23185

9:10 AM **Ultrasonic Evaluation of Environmentally Degraded Adhesive Joints**
---B. LI, M. HEFETZ, AND S. I. ROKHLIN, THE OHIO STATE UNIVERSITY, DEPARTMENT OF WELDING ENGINEERING, 190 WEST 19TH AVENUE, COLUMBUS, OH 43210

9:30 AM **The Detection of a Weak Adhesive/Adherend Interface in Bonded Joints by Ultrasonic Reflection Measurements**
---TOM PIALUCHA AND PETER CAWLEY, DEPARTMENT OF MECHANICAL ENGINEERING, IMPERIAL COLLEGE, LONDON SW7 2BX, U.K.

9:50 AM **Frequency-Domain Ultrasonic NDE of Adhesively-Bonded Joints**
---VIKRAM K. KINRA AND SUSAN HANNEMAN, DEPARTMENT OF AEROSPACE ENGINEERING, TEXAS A&M UNIVERSITY, COLLEGE STATION, TX 77843-3141.

10:10 AM **COFFEE BREAK**

10 30 AM **An Ultrasonic Scanning Technique for the Quantitative Determination of the Cohesive Properties of Adhesive Joints**
---PAUL N. DEWEN AND PETER CAWLEY, DEPARTMENT OF MECHANICAL ENGINEERING, IMPERIAL COLLEGE, LONDON SW7 2BX, U.K.

10:50 AM **Quantitative Evaluation of Adhesive Interface Layer Properties Using Ultrasonic Dispersion Techniques**
---K. BALASUBRAMANIAM, C. ISSA AND R. SULLIVAN, DEPARTMENT OF AEROSPACE ENGINEERING AND ENGINEERING MECHANICS, MISSISSIPPI STATE UNIVERSITY, MS 39762

11:10 AM **The Examination of Adhesive Bonds Using Optically-Generated Periodic Surface Acoustic Waves**
---A. C. BUSHELL, C. EDWARDS, H. NAKANO*, S. B. PALMER, DEPT. OF PHYSICS, UNIVERSITY OF WARWICK, COVENTRY CV4 7AL, UK, *NATIONAL RESEARCH LABORATORY OF METROLOGY, 1-4, 1-CHOME, UMEZONO, TSUKUBA, IBARAKI, JAPAN

11:30 AM **Assessment of Aircraft Structural Integrity by Detecting Disbonds Through Ultrasonic Scanning**
---M. N. ABEDIN*, D. R. PRABHU*, AND W. P. WINFREE, MS 231, NASA LANGLEY RESEARCH CENTER, HAMPTON, VA 23665, *ANALYTICAL SERVICES AND MATERIALS, INC. 107 RESEARCH DRIVE, HAMPTON, VA 23666

11:50 AM **Assessing the Integrity of Structural Adhesive Bonds by the Measurement of Acoustic Properties**
---VADIVEL JAGASIVAMANI, ANALYTICAL SERVICES AND MATERIALS, INC., HAMPTON, VA 23666 AND ALPHONSO C. SMITH, NASA LANGLEY RESEARCH CENTER, MAIL STOP 231, HAMPTON, VA 23665-5225

Wednesday, July 31, 1991

SESSION XVIII
SIGNAL PROCESSING - UT
S. Neal, Chairperson
Smith Auditorium
Pages 87-91:

8:30 AM **Adaptive Array Processing for Real-Time Medical Ultrasound Imaging**
---M. O'DONNELL, DEPARTMENT OF ELECTRICAL ENGINEERING AND COMPUTER SCIENCE, UNIVERSITY OF MICHIGAN, ANN ARBOR, MI 48109-2122

9:10 AM **Wavelets and Their Application to Digital Signal Processing in Ultrasonic NDE**
---B. DEFACIO, C. R. THOMPSON, DEPARTMENT OF PHYSICS AND ASTRONOMY; AND S. P. NEAL, DEPARTMENT OF MECHANICAL AND AEROSPACE ENGINEERING, UNIVERSITY OF MISSOURI-COLUMBIA, COLUMBIA, MO 65211

9:30 AM **Split Spectrum Technique as a Preprocessor for Ultrasonic Nondestructive Evaluation**
---PRASANNA KARPUR, RESEARCH INSTITUTE, UNIVERSITY OF DAYTON, 300 COLLEGE PARK AVENUE, DAYTON, OH 45469-0127

9:50 AM **Split Spectrum Processing with Computationally Efficient Sinusoidal FIR Filters**
---ORLANDO J. CANELONES, PRASANNA KARPUR, RESEARCH INSTITUTE, UNIVERSITY OF DAYTON, 300 COLLEGE PARK AVENUE, DAYTON, OH 45469-0127

10:10 AM **COFFEE BREAK**

10:30 AM **Rank Determination of Order Statistic Fibers for Ultrasonic Flaw Detection**
---XING LI, JIAN-QIANG XIN, KEVIN DONOHUE AND NIHAT M. BILGUTAY, ELECTRICAL & COMPUTER ENGINEERING DEPARTMENT, DREXEL UNIVERSITY, PHILADELPHIA, PA 19104

10:50 AM **Coherent Flaw Reflectivity Estimation in Nonstationary Noise**
---KEVIN D. DONOHUE, DEPARTMENT OF ELECTRICAL ENGINEERING, UNIVERSITY OF KENTUCKY, LEXINGTON, KY 60506; JOHN M. BRESSLER, DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING, DREXEL UNIVERSITY, PHILADELPHIA, PA 19104

11:10 AM **Characterization of Materials Using Grain Backscattered Ultrasonic Signals**
---MYUNG-HYUN YOON AND TENKASI V. RAMABADRAN, CENTER FOR NDE AND DEPARTMENT OF ELECTRICAL ENGINEERING AND COMPUTER ENGINEERING, IOWA STATE UNIVERSITY, AMES, IA 50011

11:30 AM **On the Use of Wigner Distributions and Wavelet Transforms in Ultrasonic NDE.**
---C. H. CHEN AND JIANN-CHING GUEY, SOUTHEASTERN MASSACHUSETTS UNIVERSITY, ELECTRICAL/COMPUTER ENGINEERING DEPT., N. DARTMOUTH, MA 02747.

11:50 AM **Ultrasonic Signal Processing of Adhesive Bonding Data Employing Chirp-Z Transform and Adaptive Filtering Techniques**
---V. K. NAIR, D. DAI, R. LUDWIG, AND J. M. SULLIVAN, WORCESTER POLYTECHNIC INSTITUTE, WORCESTER, MA 01609

12:10 PM **LUNCH**

SESSION XIX
NDE of CIVIL STRUCTURES and MATERIALS
H. Reis, Chairperson
Cleaveland Hall, Room 108
Pages 92-96

8:30 AM **Characterization of West Virginia Hardwood Using Acoustic Emission and Vibration Methods**
---H. L. CHEN, H. W. ZHOU, H. GANGARAO, DEPARTMENT OF CIVIL ENGINEERING, WEST VIRGINIA UNIVERSITY, MORGANTOWN, WV 26506.

8:50 AM **Electromagnetic Properties of Large-Grain Materials Measured with Large Coaxial Sensors.**
---GREGORY P. OTTO AND WENG C. CHEW, ELECTROMAGNETICS LABORATORY, DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING, UNIVERSITY OF ILLINOIS, URBANA, IL 61801.

9:10 AM **Preliminary Results of Using Microwaves for Detecting Steel Bar Preferred Orientation in Concrete Slabs and Detection of Breakage in These Bars.**
---R. ZOUGHI, G. L. CONE AND P. NOWAK*, ELECTRICAL ENGINEERING DEPARTMENT, COLORADO STATE UNIVERSITY, FT. COLLINS, CO 80513, *DEPARTMENT OF CIVIL ENGINEERING, COLORADO STATE UNIVERSITY, FT. COLLINS, CO 80523.

9:30 AM **The Feasibility of CT and DR Characterization of Cement Solidified Low Level Nuclear Waste.**
--- RICHARD T. BERNARDI, DIRECTOR OF APPLICATIONS, BIO-IMAGING RESEARCH, INC., 425 BARCLAY BOULEVARD, LINCOLNSHIRE, IL 60069.

9:50 AM **Study of Discontinuities Evolution in Metallic Structures Under Dynamic Stress by Ultrasonic Examination**
---D. STOENESCU AND O. TEODORESCU, INSTITUTE FOR RESEARCH AND TECHNOLOGICAL DESIGN IN TRANSPORTS, INCERTRANS, BUCHAREST, CALEA GRIVITEI 393, SECTOR 1 ROMANIA

10:10 **COFFEE BREAK**

10:30 AM **Defect Imaging Using Long-Distance Ultrasonic Testing**
---D. J. CHINN, H. A. DIETERMAN, DEPARTMENT OF CIVIL ENGINEERING, APPLIED MECHANICS, DELFT UNIVERSITY OF TECHNOLOGY, STEVINWEG 1, MC/GCL, 2628 CN DELFT, THE NETHERLANDS.

10:50 AM **The State-of-the-Art of Nondestructive Evaluation of Military Runways.**
---MARK ANDERSON, APPLIED RESEARCH ASSOCIATES, P.O. BOX 40128, TYNDALL AFB, FL 32403.

11:10 AM **A Visual Inspection System for Evaluating the Interior Surface of Valve Flanges on Hazardous Material Storage Container Tops**
---CHRIS A PICKETT, DEVELOPMENT DIVISION, MARTIN MARIETTA ENERGY SYSTEMS, INC., OAK RIDGE Y-12 PLANT, OAK RIDGE, TENNESSEE 37831

11:30 AM **Nondestructive Evaluation of the Granite Veneer at the Bronx Museum of the Arts**
---HERMANT S. LIMAY, WISS, JANNEY, ELSTNER ASSOCIATES, INC., NORTHBROOK, IL; MARK R. KRUEGER AND DIANE S. KAESE, WISS, JANNEY, ELSTNER ASSOCIATES, INC., PRINCETON, NJ

11:50 **DISCUSSION**

12:10 **LUNCH**

Wednesday, July 31, 1991

SESSION XX
LASER ULTRASONICS
H. Ringermacher, Chairperson
Smith Auditorium
Pages 97-100:

1:30 PM **Pulsed Lasers for Quantitative Ultrasonic NDE**
---D. A. HUTCHINS, DEPARTMENT OF ENGINEERING, UNIVERSITY OF WARWICK, COVENTRY, CV4 7AL, ENGLAND

2:10 PM **Inspection of Components having Complex Geometries using Laser-Based Ultrasound**
---R. C. ADDISON, JR. AND A. D. W. MCKIE, ROCKWELL INTERNATIONAL SCIENCE CENTER, 1049 CAMINO DOS RIOS, THOUSAND OAKS, CA 91360

2:30 PM **Elastic Constants for Unidirectional Boron-epoxy Composites.**
---C. M. SCALA AND P. A. DOYLE, DSTO AERONAUTICAL RESEARCH LAB, 506 LORIMER ST., FISHERMENS BEND, AUSTRALIA 3207.

2:50 PM **Long Cavity Laser Excitation and Digital Filtering of Narrowband Ultrasound for Enhanced Signal-to-Noise Ratio**
---J. B. DEATON, JR. J. W. WAGNER, AND J. B. SPICER, CENTER FOR NONDESTRUCTIVE EVALUATION, THE JOHNS HOPKINS UNIVERSITY, BALTIMORE, MD 21218

3:10 PM **COFFEE BREAK**

3:30 PM **Analysis of Laser Ultrasonic Measurements of Surface Waves on Elastic Spheres**
---L. S. KOO AND K. L. TELSCHOW, IDAHO NATIONAL ENGINEERING LABORATORY, EG&G IDAHO, INC. IDAHO FALLS, ID 83415-2209

3:50 PM **Effects of Laser Source Parameters on the Generation of Narrow Band and Directed Laser Ultrasound**
---J. B. SPICER, J. W. WAGNER, AND J. B. DEATON, JR. CENTER FOR NONDESTRUCTIVE EVALUATION, THE JOHNS HOPKINS UNIVERSITY, BALTIMORE, MD 21218

4:10 PM **Ultrasonic Characterization of Laser Ablation**
---J. A. SMITH AND K. L. TELSCHOW, IDAHO NATIONAL ENGINEERING LABORATORY, EG&G IDAHO, INC., IDAHO FALLS, ID 83415-2209

4:30 PM **Generation of Dispersive Acoustic Waves by the Phase Velocity Scanning of a Laser Beam**
---KAZUSHI YAMANAKA, YOSHIHIKO NAGATA AND TOSHIO KODA, MECHANICAL ENGINEERING LABORATORY, NAMIKI 1-2, TSUKUBA, IBARAKI, 305 JAPAN

Wednesday, July 31, 1991

SESSION XXI
TOMOGRAPHY and UT SCATTERING - I
J. Murphy, Chairperson
Lancaster Lounge/Moulton Union
Pages 101-105:

Tomography

1:30 PM **Measurement of the Center-of-Gravity Using X-Ray Computed Tomography**
---RICHARD BOSSI, ALAN CREWS, JAMES NELSON, THE BOEING COMPANY, P. O. BOX 3999, MS 87-60, SEATTLE, WA 98124-2499

1:50 PM **Detection Sensitivity of X-Ray CT Imaging for NDE of Green-State Ceramics**
---N. GOPALSAMI, PH. RIZO,** W. A. ELLINGSON, AND D. M. TRACEY*, MATERIALS AND COMPONENTS TECHNOLOGY DIVISION, ARGONNE NATIONAL LABORATORY, 9700 S. CASS AVENUE, ARGONNE, IL, **LETI, CEA/CENG, GRENOBLE, FRANCE, AND *NORTON ADVANCED CERAMICS, NORTHBORO, MA.

2:10 PM **Computed Tomography Imaging for Nondestructive Evaluation**
---CLAUDIA V. KROPAS, WL/MLLP, WRIGHT-PATTERSON AFB, OH; MICHAEL E. HUGHES, ARACOR, P. O. BOX 1835, FAIRBORN, OH.

2:30 PM **Development of an Advanced 3D Cone Beam Tomographic System**
---P. SIRE, P. RIZO, M. MARTIN, P. GRANGEAT, GENG-LETI-DSYS-SETIA, BP 85X, 38041 GRENOBLE CEDEX, FRANCE; MORISSEAU P., INTERCONTROLE, 13, RUE DU CAPRICORNE, SILIC 433, 94583 RUNGIS CEDEX, FRANCE

2:50 PM **Dynamic Thermal Tomography: New NDE Technique to Reconstruct Inner Solids Structure by Using the Multiple IR Image Processing**
---V. VAVILOV, TOMSK POLYTECHNICAL INSTITUTE, USSR, 634004, TOMSK; X. MALDAGUE, UNIVERSITE LAVAL, ELECTRICAL ENGINEERING DEPARTMENT, QUEBEC, G1K 7P4, CANADA; R. L. THOMAS, L. D. FAVRO, INSTITUTE FOR MANUFACTURING RESEARCH, WAYNE STATE UNIVERSITY, DETROIT, MICHIGAN 48202

3:10 PM **COFFEE BREAK**

UT Scattering - I

3:30 PM **Scattering of Acoustic and Elastic Waves by Cracklike Objects: The Role of Hypersingular Integrals**
---G. KRISHNASAMY AND F. J. RIZZO, DEPARTMENT OF THEORETICAL AND APPLIED MECHANICS, UNIVERSITY OF ILLINOIS, URBANA, IL 61801

3:50 PM **A Discretized Green's Function for a 3-D Fluid Loaded Elastic Halfspace with a Surface Breaking Crack**
---D. E. BUDRECK, DEPT. OF AEROSPACE ENGINEERING AND ENGINEERING MECHANICS, DEPT. OF MATHEMATICS AND CENTER FOR NDE; R. A. ROBERTS, CENTER FOR NDE, IOWA STATE UNIVERSITY, AMES, IA 50011

4:10 PM **Transient Scattering of Rayleigh-Lamb Waves by Surface-Breaking and Buried Cracks in a Plate**
---S.-W. LIU AND S. K. DATTA, DEPARTMENT OF MECHANICAL ENGINEERING, AND CIRES, UNIVERSITY OF COLORADO, BOULDER, CO 80309-0427, AND A. H. SHAH, DEPARTMENT OF CIVIL ENGINEERING, UNIVERSITY OF MANITOBA, WINNIPEG, CANADA R3T 2N2

Wednesday, July 31, 1991

4:30 PM **Diffraction of Rayleigh Waves by "Kinked" Surface Cracks**
---I. C. TSIRONIS, DEPT. OF MECHANICAL ENGINEERING, NDE CENTRE, UNIVERSITY COLLEGE LONDON, TORRINGTON PLACE, LONDON WCIE 7JE, UNITED KINGDOM AND L. J. BOND, ON LEAVE FROM UNIVERSITY COLLEGE LONDON, NOW AT NIST, BOULDER AND UNIVERSITY OF COLORADO AT BOULDER

4:50 PM **Rayleigh Wave Scattering from Three-Dimensional Hemispherical Depressions and Surface Slots**
---R. J. BLAKE, SERC DARESBURY LABORATORY, DARESBURY, WARRINGTON WA44AD; L. J. BOND, DEPT. MECHANICAL ENGINEERING, UNIVERSITY OF BOULDER AT COLORADO, COLORADO 80309-0427

SESSION XXII
DEFECT SIZING
A. Mal, Chairperson
Cleaveland Hall, Room 108
Pages 106-110:

1:30 PM **Phase Shift Determination of Scattered Far-Fields and Its Application to an Inverse Problem**
---M. KITAHARA, FACULTY OF MARINE SCIENCE AND TECHNOLOGY, TOKAI UNIVERSITY, SHIMIZU, SHIZUOKA 424, JAPAN; K. NAKAGAWA, TOTAL SYSTEM INSTITUTE, ASAGAYA-MINAMI, SUGINAMI-KU, TOKYO 166, JAPAN

1:50 PM **Ultrasonic Flaw Classification Using A Quasi-Pulse-Echo Technique**
---CHIEN-PING CHIOU AND LESTER W. SCHMERR, CENTER FOR NONDESTRUCTIVE EVALUATION AND DEPARTMENT OF AEROSPACE ENGINEERING AND ENGINEERING MECHANICS, IOWA STATE UNIVERSITY, AMES, IOWA 50011

2:10 PM **Flaw Characterization and Sizing Using Sensitivity Analysis and the Boundary Element Method**
---G. KRISHNASAMY, DEPARTMENT OF THEORETICAL AND APPLIED MECHANICS AND D. A. TORTORELLI, DEPARTMENT OF MECHANICAL ENGINEERING, UNIVERSITY OF ILLINOIS, URBANA, IL 61801

2:30 PM **Ultrasonic Measurements and Modelling of Cracks Ligaments Using Corner Effect**
---P. CALMON, CEA, 91191 GIF SUR YVETTE CEDEX, FRANCE, AND O. ROY, INTERCONTROLE, SILIC 433, 94583 RUNGIS, FRANCE

2:50 PM **Errors in Determining the Flaw Centroid by Using Area Functions**
---J. YANG AND L. J. BOND, DEPARTMENT OF MECHANICAL ENGINEERING, UNIVERSITY COLLEGE LONDON, TORRINGTON PLACE, LONDON WCIE 7JE, UK.

3:10 PM **COFFEE BREAK**

3:30 PM **Ultrasonic Flaw Sizing-Some New Approaches**
---SUNG-JIN SONG AND LESTER W. SCHMERR, JR., CENTER FOR NDE AND THE DEPARTMENT OF AEROSPACE ENGINEERING AND ENGINEERING MECHANICS, IOWA STATE UNIVERSITY, AMES, IA 50011

3:50 PM **Application of High Resolution Inversion of Ultrasonic Data to the Imaging of Multi-Layered Composite Structures**
---K. I. MCRAE, DEFENCE RESEARCH ESTABLISHMENT PACIFIC, FMO, CFB ESQUIMALT, VICTORIA, B.C., CANADA

4:10 PM **Automation of Disbond Detection in Aircraft Adhesive Joints Through Thermal Image Processing**
---D. R. PRABHU, ANALYTICAL SERVICES AND MATERIALS, INC. AND W. P. WINFREE, NONDESTRUCTIVE EVALUATION SCIENCES BRANCH, MS 231, NASA LANGLEY RESEARCH CENTER, HAMPTON, VA 23665

4:30 PM **Real-Time Eddy Current Monitoring of Fatigue Crack Growth**
---T. E. CAPOBIANCO, ELECTROMAGNETIC TECHNOLOGY DIVISION, NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY, 325 BROADWAY, BOULDER, CO.

4:50 PM **DISCUSSION**

Wednesday, July 31, 1991

SESSION XXIII
NDE of METAL BONDS
G. Thomas, Chairperson
Kresge Auditorium
Pages 111-115:

1:30 PM **Experimental Investigation of the Interaction of Elastic Longitudinal and Shear Waves with a Solid-Solid Interface for Different Contacts**
---M. DE BILLY AND F. LEOMY, GROUPE DE PHYSIQUE DES SOLIDES, UNIVERSITE PARIS 7, TOUR 23, 2 PLACE JUSSIEU, 75251 PARIS CEDEX 05 FRANCE

1:50 PM **Ultrasonic Determination of Dissimilar Interface Strength in Diffusion Bonds**
---G. C. OJARD, M. S. HUGHES, D. K. REHBEIN AND O. BUC[illegible], CENTER FOR NONDESTRUCTIVE EVALUATION, IOWA STATE UNIVERS[illegible]Y, AMES, IOWA 50011

2:10 PM **Assessment of Bond Quality Between Metal Components**
---PHILIPPE GUY AND ALAIN JUNGMAN, GROUP DE PHYSIQUE DES SOLIDS, UNIVERSITE' PARIS 7, TOUR 23, 2 PLACE JUSSIEU, 75251, PARIS CEDEX 05, FRANCE AND ADNAN H. NAYFEH, DEP. AEROSPACE ENG., UNIVERSITY OF CINCINNATI, CINCINNATI, OH 45221

2:30 PM **Reflection of Ultrasonic Waves From Imperfect Diffusion Bonds**
---I. YALDA-MOOSHABAD, F. J. MARGETAN, T. A. GRAY, AND R. B. THOMPSON, CENTER FOR NONDESTRUCTIVE EVALUATION, IOWA STATE UNIVERSITY, AMES, IA 50010

2:50 PM **Coherent and Incoherent Scattering of Ultrasonic Waves from a Rough Solid-Solid Interface**
---CLAUDIO PECORARI, DANIEL A. MENDELSOHN*, GABOR BLAHO AND LASZLO ADLER, DEPT. OF WELDING ENGINEERING, 190 W. 19TH AVE., COLUMBUS, OH 43210, *DEPT. OF ENGINEERING MECHANICS, 155 W WOODRUFF AVE., COLUMBUS, OH 43210

3:10 PM **COFFEE BREAK**

3:30 PM **Photoinductive Imaging Studies of Cu-Ni Diffusion Bonds**
---S. MITRA, G. C. OJARD, N. NAKAGAWA AND J. C. MOULDER, CENTER FOR NDE, IOWA STATE UNIVERSITY, AMES, IA 50011

3:50 PM **Ultrasonic Inspection of Brazed Titanium Samples with Complex Shape**
---JOACHIM BAMBERG, MTV DAUTSCHE AEROSPACE, DAUCHAUER STRAPE 665, 8000 MUNCHEN 50, GERMANY

4:10 PM **Application of Laser Shearography Technique to Characterization of Weld Integrity of Aerospace Pressure Vessels**
---L. D. MELVIN, M. NAMKUNG, AND D. S. DANWICKE*, MS 231, NASA LANGLEY RESEARCH CENTER, HAMPTON, VA 23665, *ANALYTIC SERVICES AND MATERIALS, INC. 107 RESEARCH DRIVE, HAMPTON, VA 23666

4:30 PM **Ultrasonic Inspection of Thin Metal Butt Welds**
---DANIEL P. MAZZONE, SYSTEMS RESEARCH LABORATORIES, INC., NDE DIVISION, 2800 INDIAN RIPPLE ROAD, DAYTON, OHIO 45440

4:50 PM **DISCUSSION**

SPECIAL EVENING SESSION
S. Udpa, Chairperson
Kresge Auditorium
Page 116:

8:00 PM **Comments Regarding ASNT 50th Year Anniversary**
VICKI PANHUISE, GARRETT TURBINE ENGINE CO., P. O. BOX 5217, PHOENIX, AZ 85010

8:20 PM **FHWA: Research and Development Program**
---ROBERT L. NICKERSON, CHIEF, STRUCTURES DIVISION, OFFICE OF OPERATION & RESEARCH DEVELOPMENT, FEDERAL HIGHWAY ADMINISTRATION, HNR-10, 6300 GEORGETOWN PIKE, MCLEAN, VA 22170

9:00 PM **DISCUSSION**

Thursday, August 1, 1991

SESSION XXIV
IMAGE and SIGNAL PROCESSING
W. Friedman, Chairperson
Smith Auditorium
Pages 117-121:

8:30 AM **Limited Data Tomography Using a Minimal Support Constraint**
---R. A. ROBERTS, CENTER FOR NDE, IOWA STATE UNIVERSITY, AMES, IA 50010

8:50 AM **Application of Two-Dimensional Matched Filters to X-Ray Radiographic Flaw Detection and Enhancement**
---R. M. WALLINGFORD, E. M. SIWEK AND J. N. GRAY, CENTER FOR NDE, IOWA STATE UNIVERSITY, AMES, IA 50011

9:10 AM **Study of Microstructural Characteristics Using Mathematical Morphology**
---MATHEW S. CHACKALACKAL AND JOHN P. BASART, CENTER FOR NDE AND DEPT. OF ELEC. AND COMPUTER ENG., IOWA STATE UNIVERSITY, AMES, IA 50011

9:30 AM **A True Wiener Filter Implementation for Improving Signal to Noise and Resolution in Acoustic Images**
---KENNETH W. MITCHELL, ROBERT S. GILMORE, GENERAL ELECTRIC CORPORATE RESEARCH & DEVELOPMENT CENTER, SCHENECTADY, NY

9:50 AM **Influence of Filtering Techniques on Holographic Images in Non-Destructive Testing**
---L. V. BERNUS, F. MOHR, R. REIMANN, T. SCHMEIDL, H. SCHOBER, SIEMENS AG KWU GROUP, HAMMERBACHERSTR. 12 + 14, W-8520 ERLANGERN

10:10 AM **COFFEE BREAK**

10:30 AM **Ultrasonic Application of Wavelet Decomposition Coherent Grain Noise Suppression and Flaw Detection.**
---XIANG XIE AND C. H. CHEN SOUTHEASTERN MASSACHUSETTS UNIVERSITY, ELECTRICAL/COMPUTER ENGINEERING DEPT., N. DARTMUTH, MA 02747.

10:50 AM **Temporal Leakage and Its Effects on Resolution in Deconvolution of Ultrasonic Signals**
---M. S. O'BRIEN AND S. M. KRAMER, ONTARIO HYDRO RESEARCH DIVISION, 800 KIPLING AVE., K4174, TORONTO, ONTARIO, CANADA M8Z 5S4

11:10 AM **Cycle Stacking of EMAT Signals.**
---N. C. BANIK, T. D. WILLIAMSON, INC., RESEARCH AND ENGINEERING DEPARTMENT, P. O. BOX 2299, TULSA, OK 74101.

11:30 AM **Fast Pattern Recognition Method for Eddy Current Testing**
---K. GROTZ AND T. W. GUETTINGER, INSTITUT DR. FOERSTER, IN LAISEN 70, D-7410 REUTLINGEN, WEST GERMANY.

11:50 AM **Signal/Noise Analysis for Quantification NDE Capabilities in Complex Geometries.**
---WARD D. RUMMEL, MARTIN D. RUMMEL, 8776 W. MOUNTAINVIEW LANE, LITTLETON, CO 80125, AND MICHAEL FOLEY, MARTIN MARIETTA ASTRONAUTICS, P. O. BOX 179, MS T330, DENVER, CO 80201.

12:10 PM **LUNCH**

SESSION XXV
THERMAL TECHNIQUES and APPLICATIONS
R. Thomas, Chairperson
Cleaveland Hall, Room 108
Pages 122-126:

8:30 AM **Analytic Calculations and Numerical Simulations of Box-Car Thermal Wave Images of Planar Subsurface Scatterers.**
---D. CROWTHER, L. D. FAVRO AND R. L. THOMAS, DEPARTMENT OF PHYSICS, WAYNE STATE UNIVERSITY, DETROIT, MI 48202.

8:50 AM **Numerical Solutions for Heat Flow in Adhesive Lap Joints**
---P. A. HOWELL, ANALYTICAL SERVICES & MATERIALS, INC., HAMPTON, VA 23665, AND W. P. WINFREE, MS 231, NASA LANGLEY RESEARCH CENTER, HAMPTON, VA 23665

9:10 AM **Theoretical Calculations and Experimental Results of Thermal Diffusivity Measurement of Polymer Foils Using Low-Frequency Thermal Wave Method With IR Detection**
---J. RANTALA*, J. JAARINEN**, J. HARTIKAINEN***, AND M. LUUKKALA*, *UNIVERSITY OF HELSINKI, DEPT. OF PHYSICS, SILTAVUORENPENGER 20 D, SF-00170 HELSINKI, FINLAND, **NESTE, CORPORATE R&D, INNOPOLI 52 5TH FL, P.O.B. 356, SF-02151 ESPOO, FINLAND, ***FINNISH NAVAL HEADQUARTERS, TECHNICAL R&D OFFICE, P.O.B. 105, SF-00201 HELSINKI, FINLAND

9:30 AM **IR Thermal Wave Tomographic Studies of Structural Composites.**
---L. D. FAVRO, H. J. JIN, Y. X. WANG, T. AHMED, X. WANG, P. K. KUO, AND R. L. THOMAS, DEPARTMENT OF PHYSICS, WAYNE STATE UNIVERSITY, DETROIT, MI 48202.

9:50 AM **Thermal Wave Characterization of IC Metal Lines.**
---ALLAN ROSENCWAIG, THERMA-WAVE, INC., 47320 MISSION FALLS COURT, FREMONT, CA 94539.

10:10 AM **COFFEE BREAK**

10:30 AM **Bonds NDE Using Stimulated IR Thermography**
---PH. DELPECH, A. DEOM, D. BALAGEAS AND D. BOSCHER, ONERA, 29 AV. DE LA DIVISION LECLERC, F92322 CHATILLON CEDEX, FRANCE

10:50 AM **Time-Resolved Infrared Radiometry (TRIR) for Characterization of Impact Damage in Composite Materials**
---J. W. MACLACHLAN SPICER, W. D. KERNS, L. C. AAMODT, AND J. C. MURPHY, THE JOHNS HOPKINS UNIVERSITY, CENTER FOR NDE AND APPLIED PHYSICS LABORATORY, LAUREL, MO 20723-6099

11:10 AM **Fast Photothermal Inspection of Plasma-Sprayed Coatings of Primary Circulation Seal Rings of a Nuclear Reactor**
---R. LEHTINIEMI, J. HARTIKAINEN, J. RANTALA, J. VARIS, AND M. LUUKKALA, DEPT. OF PHYSICS, UNIVERSITY OF HELSINKI, SILTAVUORENPENGER 20 D, SF-00170 HELSINKI, FINLAND

11:30 AM **Comparison of Heating Protocols for Detection of Disbonds in Lap Joints**
---WILLIAM P. WINFREE, NASA LARC, MS 231, HAMPTON, VA 23665, B. SCOTT CREWS, AND P. A. HOWELL, ANALYTICAL SERVICES & MATERIALS, INC., HAMPTON, VA 23665

11:50 AM **DISCUSSION**

12:10 PM **LUNCH**

Thursday, August 1, 1991

SESSION XXVI
MATERIAL PROPERTIES
(PLASTICS, CERAMICS, and OTHERS)
S. Datta, Chairperson
Kresge Auditorium
Pages 127-131:

8:30 AM **Line-Focus Acoustic Microscopy to Measure SAW Dispersion and Anisotropy in Thin-Film Coated Materials**
---JIN O. KIM AND JAN D. ACHENBACH, CENTER FOR QUALITY ENGINEERING AND FAILURE PREVENTION, NORTHWESTERN UNIVERSITY, EVANSTON, IL 60208-3020

8:50 AM **SAW Dispersion in Diamond Films on Silicon by Acoustic Microscopy.**
---R. D. WEGLEIN, CONSULTANT, 6317 DREXEL AVENUE, LOS ANGELES, CA 90048; JIN O. KIM, CENTER FOR QE & FP, NORTHWESTERN UNIVERSITY, EVANSTON, IL 60208.

9:10 AM **Ultrasonic Assessment of Thermal Damage in Ceramics**
---M. HEFETZ AND S. I. ROKHLIN, THE OHIO STATE UNIVERSITY, DEPARTMENT OF WELDING ENGINEERING, 190 WEST 19TH AVENUE, COLUMBUS, OH 43210

9:30 AM **Acoustoelastic Technique for Structural Plastics**
---NISAR SHAIKH, DEPT. OF ENGINEERING MECHANICS AND CENTER FOR MATERIAL RESEARCH AND ANALYSIS, UNIVERSITY OF NEBRASKA, LINCOLN

9:50 AM **Ultrasonic Monitoring of Phase Transformations During Processing of $YBa_2Cu_3O_z$**
---EVA DRESCHER-KRASICKA, H. THOMAS YOLKEN, W. CRAIG CARTER AND DIDIERE DE FONTAINE*, THE NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY, GAITHERSBURG, MARYLAND, *UNIVERSITY OF CALIFORNIA, BERKELEY

10:10 AM **COFFEE BREAK**

10:30 AM **Thermal Diffusivity Measurement of Diamond Materials**
---LANHUA WEI, P. K. KUO, AND R. L. THOMAS, DEPARTMENT OF PHYSICS, WAYNE STATE UNIVERSITY, DETROIT, MI 48202

10:50 AM **Critical Current Measurements of High Tc Superconductors in a Scanning Low Temperature Cryostat**
---K. L. TELSCHOW AND T. K. O'BRIEN, IDAHO NATIONAL ENGINEERING LABORATORY, EG&G IDAHO, INC., IDAHO FALLS, ID 83415-2209

11:10 AM **A Study of Dislocation Starting Stresses in Alkali-Halides Using a New Ultrasonic Method.**
---E. K. NAIMI, MOSCOW INSTITUTE OF STEEL AND ALLOYS, MOSCOW, LENINGSKII PROSPEKT, 4, U.S.S.R.

11:30 AM **On the Characterization of Torsional Creep Properties of Viscoelastic Materials**
---I. EMRI AND P. METLIKOVIC, UNIVERSITY OF LJUBLJANA, FACULTY OF MECHANICAL ENGINEERING, MURNIKOVA 2, 61000 LJUBLJANA, SLOVENIA, YUGOSLAVIA

11:50 AM **Detection and Characterization of Fatigue Cracks in Thin Metal Plates by Low Frequency Resonant Modal Analysis**
---B. WINCHESKI*, M. NAMKUNG, NASA LANGLEY RESEARCH CENTER, MS 231, HAMPTON, VA 23665, AND E. A. BIRT*, *AS&M INC., 107 RESEARCH DRIVE, HAMPTON, VA 23666

SESSION XXVII
UT SCATTERING - II
K. Langenberg, Chairperson
Lancaster Lounge/Moulton Union
Pages 132-136:

8:30 AM **Scattering of Waves from Multilayered Anisotropic Piezoelectric Cylinders**
---ADNAN H. NAYFEH AND YANG QIAN, DEPARTMENT OF AEROSPACE ENGINEERING AND ENGINEERING MECHANICS, UNIVERSITY OF CINCINNATI

8:50 AM **Wave Reflection and Refraction at a Slightly Undulating Interface**
---JIANMIN QU, SCHOOL OF MECHANICAL ENGINEERING, GEORGIA INSTITUTE OF TECHNOLOGY, ATLANTA, GA 30332.

9:10 AM **BIE Analysis of Elastic Wave Scattering by a Nonlinear Interface**
---S. HIROSE, DEPT. OF CIVIL ENGINEERING, FACULTY OF ENGINEERING, OKAYAMA UNIVERSITY, OKAYAMA 700, JAPAN; M. KITAHARA, SCHOOL OF MARINE SCIENCE AND TECHNOLOGY, TOKAI UNIVERSITY, SHIMIZU, SHIZUOKA 424, JAPAN

9:30 AM **Ultrasonic Scattering from Anisotropic Shells**
---JOHN MITTLEMAN*, R. B. THOMPSON**, AND R. ROBERTS**, *NAVAL COASTAL SYSTEMS CENTER, 1 CODE 5130, PANAMA CITY, FL 32410, **CENTER FOR NDE, IOWA STATE UNIVERSITY, AMES, IA 50011

9:50 AM **Ultrasonic Backscatter From Microstructure**
---JAMES H. ROSE, CENTER FOR NDE, IOWA STATE UNIVERSITY, AMES, IOWA 50011

10:10 AM **COFFEE BREAK**

10:30 AM **Effects of Surface Roughness on Ultrasonic Flaw Signals**
---PETER B. NAGY AND LASZLO ADLER, DEPT. OF WELDING ENGINEERING, THE OHIO STATE UNIVERSITY, COLUMBUS, OH 43210 AND JAMES R. ROSE, CENTER FOR NDE, IOWA STATE UNIVERSITY, AMES, IOWA 50011

10:50 AM **Effects of Surface Roughness on Ultrasonic Backscatter**
---JAMES H. ROSE, CENTER FOR NDE, IOWA STATE UNIVERSITY, AMES, IOWA 50011, PETER B. NAGY AND LASZLO ADLER, DEPT. OF WELDING ENGINEERING, THE OHIO STATE UNIVERSITY, COLUMBUS, OH 43210

11:10 AM **Relationship of Microstructure to Backscattered Ultrasonic Noise**
---R. B. THOMPSON, F. J. MARGETAN, AND K. HAN, CENTER FOR NDE, IOWA STATE UNIVERSITY, 1915 SCHOLL RD., AMES, IA 50010

11:30 AM **Theoretical Predictions and Experimental Measurements of Echo Responses From Angled Targets**
---A. LHEMERY*, *ECOLE CENTRALE DE PARIS, LABORATOIRE MSS-MAT URA 850 C.N.R.S., 92295, CHATENAY-MALABRY CEDEX, FRANCE; J. P. WEIGHT, THE CITY UNIVERSITY, DEPT. OF E.E.I.E., NORTHAMPTON SQUARE, EC1 VOHB LONDON, ENGLAND AND R. RAILLON*

11:50 AM **Calculated and Measured Ultrasonic Response of an Elastic Cylinder Embedded in an Elastic Medium**
---R. C. ADDISON, JR. AND A. N. SINCLAIR*, ROCKWELL INTERNATIONAL SCIENCE CENTER, P. O. BOX 1085, THOUSAND OAKS, CA 91360, *DEPARTMENT OF MECHANICAL ENGINEERING, UNIVERSITY OF TORONTO, TORONTO, CANADA

12:10 PM **LUNCH**

Thursday, August 1, 1991

SESSION XXVIII - POSTERS
MATERIALS PROPERTIES, ACOUSTIC and ULTRASONIC TECHNIQUES and SYSTEMS, OPTICAL and LASER TECHNIQUES, THERMAL TECHNIQUES, IMAGING, SIGNAL PROCESSING, TOMOGRAPHY
Pages 137-158

1:30 PM

Material Properties

Acoustic Emission Monitoring of Aging Aircraft Structures
---S. L. MCBRIDE, DEPARTMENT OF PHYSICS, ROYAL MILITARY COLLEGE OF CANADA, KINGSTON, ONTARIO, CANADA K7K 5LO

Sample Preparation Techniques and Material Property Measurements of Hard Alpha Titanium Samples
---LISA J. H. BRASCHE, FRANK MARGETAN, AND R. BRUCE THOMPSON, CENTER FOR NONDESTRUCTIVE EVALUATION, AND CENTER FOR AVIATION SYSTEMS RELIABILITY, IOWA STATE UNIVERSITY, AMES, IOWA 50011

Determination of Elastic Constants Using Acousto-Ultrasonic Technique
---A. MINACHI AND D. K. HSU, CENTER FOR NONDESTRUCTIVE EVALUATION, IOWA STATE UNIVERSITY, AMES, IA 50011

Nondestructive Measurements of Plating Thicknesses of Copper and Nickel on Shim Stock and Nickel on Steel
---OTTO H. ZINKE, INTERNATIONAL VALIDATORS, INC., FAYETTEVILLE, AR 71701 AND ROGER W. DERBY, QUALITY CONTROL INSTRUMENTS, OAK RIDGE, TN 37830

Ultrasonic Evaluation of the Hydration of Thin Porous Aluminum Oxide Membranes
---M. HEFETZ, W. HUANG, AND S. I. ROKHLIN, THE OHIO STATE UNIVERSITY, DEPARTMENT OF WELDING ENGINEERING, 190 WEST 19TH AVENUE, COLUMBUS, OH 43210

Real-Time Evaluation of Ultrasonic Weld Inspections
---L. M. BROWN AND R. DENALE, DAVID TAYLOR RESEARCH CENTER, METALS AND WELDING DIVISION, ANNAPOLIS, MD 21402-6067

On-Line X-Ray System for Texture Measurement and Analysis in Steels
---B. BLANDFORD AND J. A. SZPUNAR, DEPT. OF MINING AND METALLURGICAL ENGINEERING, MCGILL UNIVERSITY, 3450 UNIVERSITY STREET, MONTREAL, CANADA H2A 2A7

Measurement Model for Ultrasonic Inspectability of Slots in Tubes
---T. A. GRAY AND F. AMIN, CENTER FOR NONDESTRUCTIVE EVALUATION, IOWA STATE UNIVERSITY, AMES, IA 50011

Ultrasonic Assessment of Axial Fatigue Life Testing on Heavy Gauge Aerospace Aluminum Plate Containing Microporosity
---W. V. JOHNSON. H. GHAZIARY, KAISER ALUMINUM & CHEMICAL CORPORATION, CENTER FOR TECHNOLOGY, P. O. BOX 877, PLEASANTON, CA 94566

Crack Depth Measurement in Thin-Walled Tubing by Time-of-Flight Diffraction
---K. -E. LINDENSCHMIDT* AND M.D.C. MOLES, ONTARIO HYDRO RESEARCH DIVISION, 800 KIPLING AVENUE, TORONTO, ONTARIO, CANADA, *NOW AT UNIVERSITY OF TORONTO

P-Version Finite Element Modelling for NDE
---CAMILLE A ISSA, KRISHNAN BALASUBRAMANIAM AND WENG-LUNG LIU, DEPARTMENT OF AEROSPACE ENGINEERING, MISSISSIPPI STATE UNIVERSITY, MISSISSIPPI STATE, MS 39762

Comparison of the Different Mathematical Models of Acoustoelasticity and Experimental Validation
---A. KHEDER AND B. DE HALLEUX, CATHOLIC UNIVERSITY OF LOUVAIN, MECHANICAL ENGINEERING DEPARTMENT, LOUVAIN-LA-NEUVE, BELGIUM

Influence of the Precipitations on Phase Transition of TiNi Alloy.
---GUO-WANG LI, JIN QIAN, YUAN-TI HUANG, DEPT. OF PHYSICS, BEIJING UNIVERSITY OF SCIENCE & TECHNOLOGY, BEIJING 100083, P. R. CHINA.

Study on Crystalline Kinetics of Metallic Glasses Fe_{39} Ni_{39} Si_8 B_{12} Mn_2 and Fe_{40} Ni_{40} P_{14} B_6.
---GUO-WANG LI, DEPT. OF PHYSICS, BEIJING UNIVERSITY OF SCIENCE & TECHNOLOGY, BEIJING 100083, P. R. CHINA.

Acoustic and Ultrasonic Techniques and Systems

Identification of Acoustic Emission With Specific Cracking Events
---J. BART BOODEY, DIANE M. GRANATA, I. P. PEREZ, AND WILLIAM R. SCOTT, NAVAL AIR DEVELOPMENT CENTER, WARMINSTER, PA 18974

A Modified Self-Calibrating Technique for an Ultrasonic Bridge
---I. N. KOMSKY AND J. D. ACHENBACH, CENTER FOR QUALITY ENGINEERING AND FAILURE PREVENTION, NORTHWESTERN UNIVERSITY, EVANSTON, IL 60208

A Frequency Domain Technique for Ultrasonic NDE of Sub-Half-Wavelength Structures.
---VASUDEVAN R. IYER AND VIKRAM K. KINRA, DEPARTMENT OF AEROSPACE ENGINEERING, TEXAS A&M UNIVERSITY, COLLEGE STATION, TEXAS 77843.

A Modelling and Experimental Study of the Efficiency of PVDF Film Transducers and Their Waveforms in Cylindrical Geometry
---ZHONG ZHANG AND DAVID K. HSU, AMES LABORATORY, IOWA STATE UNIVERSITY, AMES, IA 50011

Numerical Simulations of an EMAT Receiver System in the Time Domain
---X. -W. DAI AND R. LUDWIG, DEPARTMENT OF ELECTRICAL ENGINEERING, WORCESTER POLYTECHNIC INSTITUTE, WORCESTER, MA 01609 AND R. PALANISAMY, TIMKEN RESEARCH, THE TIMKEN COMPANY, CANTON, OH 44706

An EMAT Subsystem for Weld Inspection
---A. V. CLARK, S. R. SCHAPS, C. M. FORTUNKO, MATERIALS RELIABILITY DIVISION, NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY, BOULDER, CO

Realtime Ultrasonic Waveform Acquisition System
---RALPH HEWES, RICHARD HOGLE, LEWIS THOMAS, GENERAL ELECTRIC CORPORATE RESEARCH AND DEVELOPMENT, SCHENECTADY, NY 12301

Optical and Laser Techniques

Measurements of Local Surface Wave Speeds by a Dual-Probe Laser Interferometer
---J. HUANG, AND J. D. ACHENBACH, CENTER FOR QUALITY ENGINEERING AND FAILURE PREVENTION, NORTHWESTERN UNIVERSITY, EVANSTON, IL 60208

Thursday, August 1, 1991

A Description of an Improved Homodyne Laser Interferometer
---A. C. BUSHELL, C. EDWARDS, S. B. PALMER, DEPT. OF PHYSICS, UNIVERSITY OF WARWICK, COVENTRY, CV4 7AL, UK

Embedded Fiber Optic Sensors for Cable Evaluation
---KENT A. MURPHY, RICHARD O. CLAUS, RUSSELL G. MAY, AND CHRISTOPHER KOOB, FIBER & ELECTRO-OPTICS RESEARCH CENTER, BRADLEY DEPARTMENT OF ELECTRICAL ENGINEERING, VIRGINIA TECH, BLACKSBURG, VA 24061-0111

Sapphire Fiber Interferometer for Microdisplacement Measurements at High Temperature
---KENT A. MURPHY, SHARI FETH, ASHISH M. VENGSARKAR, AND RICHARD O. CLAUS, FIBER & ELECTRO-OPTICS RESEARCH CENTER, BRADLEY DEPARTMENT OF ELECTRICAL ENGINEERING, VIRGINIA TECH, BLACKSBURG, VA 24061-0111

Thermal Techniques

Thermal Wave Generation
---RAVI S. MACHIRAJU, PETER GIEN, AND CHRISTIAN BURGER, TEXAS A&M UNIVERSITY, MECHANICAL ENGINEERING DEPT., COLLEGE STATION, TEXAS 77843-3123

Thermal Wave Lock-in Imaging of Cracks in Cu Microbridges Embedded in Polyimide*
---L. CHEN, T. AHMED, H. J. JIN, X. WANG, P. K. KUO, L. D. FAVRO, AND R. L. THOMAS, DEPARTMENT OF PHYSICS, WAYNE STATE UNIVERSITY, DETROIT, MI 48202 AND A. DEMANA AND J. THOMES, EG&G MOUND APPLIED TECHNOLOGIES, 1 MOUND ROAD, MIAMISBURG, OH 45343-3000

Transportable Photothermal NDE Equipment for On Site Measurements
---J. VARIS, J. HARTIKAINEN, R. LEHTINIEMI, J. RANTALA, AND M. LUUKKALA, DEPT. OF PHYSICS, UNIVERSITY OF HELSINKI, SILTAVUORENPENGER 20 D, SF-00170 HELSINKI, FINLAND

Flying Laser Spot Thermal Wave IR Imaging.
---Y. Q. WANG, P. CHEN, P. K. KUO, L. D. FAVRO, AND R. L. THOMAS, DEPARTMENT OF PHYSICS, WAYNE STATE UNIVERSITY, DETROIT, MI 48202.

Imaging, Signal Processing, Tomography

X-Ray Cone Beam Tomography with Two Tilted Circular Trajectories.
---PH. RIZO, P. GRANGEAT, P. SIRE, P. LEMASSON, S. DELAGENIERE, C.E.A/C.E.N.G/LETI/DSYS/SETIA, 85X AVENUE DES MARTYRS, GRENOBLE CEDEX, FRANCE 38041

Sharpness of Edges at Different Film Orientations in Film Based Tomography
---YOSSI BUSHLIN, AMOS NOTEA, QUALITY ASSURANCE AND RELIABILITY, TECHNION, HAIFA 32000, ISRAEL AND ASGER LINDEGAARD-ANDERSEN, LABORATORY OF APPLIED PHYSICS, DTH, 2800 LYNGBY, DENMARK

Ultrasonic Image Enhancement Using Order Statistic and Morphological Filters
---M. A. MOHAMED AND J. SANIIE, ILLINOIS INSTITUTE OF TECHNOLOGY, ELECTRICAL AND COMPUTER ENGINEERING DEPARTMENT, CHICAGO, IL 60616

Reduced-Parameter Deconvolution and its Application to an EC Probe Model
---J. H. SEDO, ONTARIO HYDRO RESEARCH DIVISION, 800 KIPLING AVE., KR174, TORONTO, ONTARIO, CANADA M8Z 5S4

Error Analysis and Ultrasonic Scattering Amplitude Estimation Using the Wiener Filter with Limited Prior Information
---M. A. ENRIGHT, COMPUTER SCIENCES CORPORATION, HERDON, VA 22071; P. L. SPECKMAN, DEPT. OF STATISTICS; AND S. P. NEAL, DEPARTMENT OF MECHANICAL AND AEROSPACE ENGINEERING, UNIVERSITY OF MISSOURI-COLUMBIA, COLUMBIA, MO 65211

A Model Based Approach to Acoustic Noise Power Spectrum Estimation for Normal Incidence Ultrasonic Testing
---M. D. RUSSELL AND S. P. NEAL, DEPT. OF MECHANICAL AND AEROSPACE ENGINEERING, UNIVERSITY OF MISSOURI-COLUMBIA, COLUMBIA, MO 65211

The Application of Seismic Tomographic Imaging in Nondestructive Testing of Piles.
---YANG XIN SHE, INSTITUTE OF GEOPHYSICS, ACADEMIA SINICA, P. O. BOX 9701, BEIJING 100101, P. R. CHINA.

Comparison of Neural Network and Markov Random Field Image Segmentation Techniques.
---FRED G. SMITH, KAREN R. JEPSEN, AND PETER F. LICHTENWALNER, MCDONNELL AIRCRAFT COMPANY, M/S 1021310, ST. LOUIS, MO 63166-0516.

Artificial Neural Networks for Classification of Impact Damage in Composites
---PRASANNA KARPUR, UNIVERSITY OF DAYTON RESEARCH INSTITUTE, DAYTON, OH 45469-0127, T. RAJU DAMARIA, ELECTRICAL ENGINEERING DEPARTMENT, UNIVERSITY OF KENTUCKY, LEXINGTON, KY, AND PRAMODE K. BHAGAT, NDE BRANCH, MATERIALS DIRECTORATE, WRIGHT PATTERSON AFB

A Fourier Domain SAFT Algorithm for Ultrasonic NDE
---M. YAMANO, S. GHORAYEB, Z. YOU, W. LORD AND JOEL MONTGOMERY, ELECTRICAL ENGINEERING DEPARTMENT, IOWA STATE UNIVERSITY, AMES, IA 50011

A Finite Element Simulation of Ultrasonic SAFT Reconstruction
---S. GHORAYEB, M. YAMANO, Z. YOU AND W. LORD, ELECTRICAL ENGINEERING DEPARTMENT, IOWA STATE UNIVERSITY, AMES, IA 50011

Ultrasonic 3-D Day Tracing
---I. YALDA-MOOSHABAD, T. A. GRAY, CENTER FOR NONDESTRUCTIVE EVALUATION, IOWA STATE UNIVERSITY, AMES, IA 50010

Application of Artificial Neural Networks to Thermal Detection of Disbonds
---D. R. PRABHU, P. A. HOWELL, H. I. SYED, ANALYTICAL SERVICES AND MATERIALS, INC. AND W. P. WINFREE, NONDESTRUCTIVE EVALUATION SCIENCES BRANCH, MS 231, NASA LANGLEY RESEARCH CENTER, HAMPTON, VA 23665

Signal Processing Applications to the In-Service Inspection of a CF-18 Aircraft
---K. I. MCRAE, A. G. MCCRAY AND T. L. MILLER, DEFENCE RESEARCH ESTABLISHMENT PACIFIC, FMO, CFB ESQUIMALT, VICTORIA, BC, CANADA

3:00 PM COFFEE BREAK

Thursday, August 1, 1991

SESSION XXIX
NDE for THICK COMPOSITES
C. Fortunko, Chairperson
Kresge Auditorium
Pages 159-162

3:30 PM **Reflection of Elastic Waves by a Periodic Surface Profile of Small Amplitude**
---LAURENCE J. JACOBS, ENGINEERING SCIENCE AND MECHANICS PROGRAM, AND JIANMIN QU, SCHOOL OF MECHANICAL ENGINEERING, GEORGIA INSTITUTE OF TECHNOLOGY, ATLANTA, GA 30332

3:50 PM **Ultrasonic Determination of Layer Orientation in Multilayer Multidirectional Composite Laminates**
---I. KOMSKY, I. M. DANIEL, AND Y.C. LEE, CENTER FOR QUALITY ENGINEERING AND FAILURE PREVENTION, NORTHWESTERN UNIVERSITY, EVANSTON, IL 60208

4:10 PM **Wave Attenuation in Thick Graphite/Epoxy Composites**
---AJIT K. MAL, MECHANICAL AEROSPACE AND NUCLEAR ENGINEERING DEPARTMENT, UNIVERSITY OF CALIFORNIA, LOS ANGELES, CA 90024-1597, AND YOSEPH BAR-COHEN, MAIL CODE C1-1L8 (36-90), DOUGLAS AIRCRAFT COMPANY, LONG BEACH, CA 90846-0001

4:30 PM **Interferometric Measurements of Elastic-Wave Velocities in Thick Composites**
---C. M. FORTUNKO, NIST, MATERIALS RELIABILITY DIVISION, 325 BROADWAY, BOULDER, CO 80303 AND C. M. TELLER, TEXAS RESEARCH INSTITUTE, INC., 9063 BEE CAVES ROAD, AUSTIN, TX 78733

4:50 PM **Wide Field-of-View Ultrasonic Arrays for Thick Composites**
---DALE W. FITTING ANC CHRISTOPHER M. FORTUNKO, NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY, INSTITUTE OF MATERIALS SCIENCE AND ENGINEERING, MATERIALS RELIABILITY DIVISION, BOULDER, CO 80303

5:10 PM **Elevated Temperature Deformation Analysis of Composites**
---JAMES NELSON, BOEING, P. O. BOX 3999, MS 87-60, SEATTLE, WA 98124-2499

5:30 PM **Condition Monitoring Techniques for Composite Wind Turbine Blades**
---L. J. BOND, NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY AND UNIVERSITY OF COLORADO AT BOULDER, CO; N. AFTAB, NDE CENTER, DEPT. OF MECHANICAL ENGINEERING, UNIVERSITY COLLEGE, LONDON, UK, B. R. CLAYTON, DEPT. OF MECHANICAL ENGINEERING, UNIVERSITY OF NOTTINGHAM, NOTTINGHAM, UK, A.G. DUTTON, A. D. IRVING, AND N. H. LIPMAN, ENERGY RESEARCH UNIT, RUTHERFORD APPLETON LABORATORY, OXON, UK

SESSION XXX
NEW TECHNIQUES
F. Iddings, Chairperson
Smith Auditorium
Pages 162-165:

3:30 PM **Thermoelastic Characterization of Stress During Crack Growth**
---ELLIOT CRAMER, NASA LANGLEY RESEARCH CENTER, MAS 231, HAMPTON, VA 23665-5225; DAVID S. DAWICKE, ANALYTICAL SERVICES AND MATERIALS, INC., NASA LANGLEY RESEARCH CENTER, MS 188E, HAMPTON, VA 23665-5225; CHRISTOPHER S. WELCH, PHYSICS DEPT., COLLEGE OF WILLIAM & MARY, WILLIAMSBURG, VA.

3:50 PM **Some Critical Issues on Thermoelastic Stress Analysis of Graphite Epoxy Laminates**
---CHARLES E. BAKIS, DEPT. OF ENGINEERING SCIENCE & MECHANICS, THE PENNSYLVANIA STATE UNIVERSITY, UNIVERSITY PARK, PA AND KIN LIAO, DEPT. OF ENGINEERING SCIENCE & MECHANICS, VIRGINIA POLYTECHNIC INSTITUTE & STATE UNIVERSITY, BLACKSBURG, VA

4:10 PM **Time Resolved Elastic Waves Generated by Modulated Ion Beams**
---B. C. DEEMER AND J. C. MURPHY, THE JOHNS HOPKINS UNIVERSITY APPLIED PHYSICS LABORATORY, LAUREL, MD 20723-6099, AND T. CLAYTOR AND J. TESSMER, LOS ALAMOS NATIONAL LABORATORY, LOS ALAMOS, NM

4:30 PM **Optically Stimulated Electron Emission: Current-Voltage Response and Spectral Sensitivity**
---C. S. WELCH, PHYSICS DEPARTMENT, COLLEGE OF WILLIAM AND MARY, WILLIAMSBURG, VA 23185; M. N. ABEDIN, AS&M, INC., HAMPTON, VA 23665 AND W. T. YOST, MS 231, NASA LANGLEY RESEARCH CENTER, HAMPTON, VA 23665

4:50 PM **Nondestructive Evaluation of Porous Materials by Using Airborne Ultrasonic Waves**
---PETER B. NAGY AND LASZLO ADLER, DEPARTMENT OF WELDING ENGINEERING, THE OHIO STATE UNIVERSITY, COLUMBUS, OH 43210

5:10 PM **Time-Domain Ultrasonic Measurement of the Thickness of a Sub-Half-Wavelength Layer.**
---C. ZHU AND V. K. KINRA, DEPARTMENT OF AEROSPACE ENGINEERING, TEXAS A&M UNIVERSITY, COLLEGE STATION, TX 77843.

5:30 PM **DISCUSSION**

Thursday, August 1, 1991

SESSION XXXI
OPTICAL TECHINIQUES
J. Wagner, Chairperson
Lancaster Lounge/Moulton Union
Pages 166-169:

3:30 PM **Advanced Shearography NDT**
---JOHN W. NEWMAN, LASER TECHNOLOGY, INC., 1055 WEST GERMANTOWN PIKE, NORRISTOWN, PENNSYLVANIA 19403

3:50 PM **Nondestructive Evaluation Using Shearing Interferometry**
---TOM CHATTERS AND SRIDHAR KRISHNASWAMY, CENTER FOR QUALITY ENGINEERING AND FAILURE PREVENTION, NORTHWESTERN UNIVERSITY, EVANSTON, IL 60208

4:10 PM **Computed Speckle Decorrelation (CSD) and its Application for Fatigue Damage Monitoring**
---J. SCOTT STECKENRIDER AND JAMES W. WAGNER, CENTER FOR NONDESTRUCTIVE EVALUATION, MATERIALS SCIENCE AND ENGINEERING DEPARTMENT, THE JOHNS HOPKINS UNIVERSITY, BALTIMORE, MD 21218

4:30 PM **Light Scatterometry as an NDE Technique for Damage Evaluation of Infrared Ge Window after Rain Drop Erosion**
---R. MONROE, M. THOMAS, D. PRICE, I. PEREZ, W. R. SCOTT, M. WILSON, NAVAL AIR DEVELOPMENT CENTER, WARMINSTER, PA 18974-5000

4:50 PM **Nanosecond Scale Optical Pulse Separations for Holographic Investigation of High Speed Transient Events**
---MICHAEL J. EHRLICH AND JAMES W. WAGNER, CENTER FOR NONDESTRUCTIVE EVALUATION, DEPARTMENT OF MATERIALS SCIENCE AND ENGINEERING, THE JOHNS HOPKINS UNIVERSITY, BALTIMORE, MD 21218

5:10 PM **The Random/RMS Full-Field NDE Technique Employing Scanning Laser Doppler Vibrometry.**
--- D. E. OLIVER, OMETRON, INC. 44873 FALCON PLACE, SUITE 118, STERLING, VA 22170; DOUGLAS D. BURLEIGH, GENERAL DYNAMICS, P. O. BOX 85990 MZ 43-8560, SAN DIEGO, CA 92138.

5:30 PM **A Theory of Error in Photothermal Measurement of Weak Absorption of Optical Thin Film**
---BAIXUAN SHI*, KEI WU*, WENBIN CHEN* AND G. G. SIU**, *DEPARTMENT OF OPTICAL ENGINEERING, ZHEJIANG UNIVERSITY, HANGZHOU, PEOPLE'S REPUBLIC OF CHINA, **DEPARTMENT OF APPLIED SCIENCE, CITY POLYTECHNIC OF HONG KONG, HONG KONG

SESSION XXXII
ELECTROMAGNETIC TECHNIQUES
(MOSTLY MICROWAVE)

W. Lord, Chairperson
Cleaveland Hall, Room 108
Pages 170-173:

3:30 PM **Three-Dimensional FEM-BEM Computation of Electromagnetic Responses of Flaws**
---J. S. WANG AND N. IDA, THE UNIVERSITY OF AKRON, DEPARTMENT OF EE, AKRON, OH 44325

3:50 PM **Microwave Scattering Properties of Dielectric Cylindrical Bodies with Defects.**
---R. ZOUGHI AND N. QADDOUMI, ELECTRICAL ENGINEERING DEPARTMENT, COLORADO STATE UNIVERSITY, FT. COLLINS, COLORADO 80523.

4:10 PM **Analysis of Microstrip Patch Antennas for Dielectric Measurement**
---H. R. HASSANI AND D. MIRSHEKAR-SYAHKAL, DEPARTMENT OF ELECTRONIC SYSTEMS ENGINEERING, UNIVERSITY OF ESSEX, COLCHESTER CO4 3SQ, UK

4:30 PM **Exact Solution of Fields Outside an Open-Ended Rectangular Waveguide for Microwave Thickness Measurement of Dielectric Slabs.**
---S. GANCHEV, S. BAKHTIARI AND R. ZOUGHI, ELECTRICAL ENGINEERING DEPARTMENT, COLORADO STATE UNIVERSITY, FT. COLLINS, CO 80523.

4:50 PM **Microwave Imaging of Defects in Graphite Reinforced Composite Materials.**
--- R. P. FLAM, B. W. DEATS, FLAM & RUSSELL, INC., 506 PRUDENTIAL ROAD, HORSHAM, PA 19044.

5:10 PM **Measurement of Crack Depth in a Transition Weld Using ACPD**
---R. COLLINS, D. H. MICHAEL AND R. P. CLARK*, NDE CENTRE, DEPT. OF MECHANICAL ENGINEERING, UNIVERSITY COLLEGE, LONDON, GOWER ST., LONDON WC1E 7JE; *ROLLS-ROYCE & ASSOCIATES, DERBY, UNITED KINGDOM

5:30 PM **Three Dimensional Modeling of the DC Potential Drop Method Using Finite Element and Boundary Element Analysis**
---S. NATH, T. J. RUDOLPHI AND W. LORD, COLLEGE OF ENGINEERING, IOWA STATE UNIVERSITY, AMES, IA 50011

Friday, August 2, 1991

SESSION XXXIII
NEW SYSTEMS
W. Rummel, Chairperson
Kresge Auditorium
Pages 174-178:

8:30 AM **Nondestructive Magneto Inductive Testing of Rolled Plate and Sheet Quantitatively Determines Their Mechanical Properties and Reduces the Need for Traditional Destructive Tests**
---B. LUTZ, INSTITUT DR. FOERSTER INSTRUMENTS, INC. PGH PA USA, MR. HAIDER, VOEST-ALPINE STAHL LINZ GES. M.G.H., AUSTRIA, E. L. MOSER, VOEST-ALPINE STAHL LINZ GES M.B.H. AUSTRIA

8:50 AM **SQUID Based System for Passive NDE of Ferromagnetic Materials During Deformation**
---R. B. MIGNOGNA, R. S. SCHECHTER AND K. E. SIMMONDS, MECHANICS OF MATERIALS BRANCH, NAVAL RESEARCH LABORATORY, WASHINGTON, DC 20375-5000; H. WEINSTOCK, AIR FORCE OFFICE OF SCIENTIFIC RESEARCH, WASHINGTON, DC 20334-6448

9:10 AM **A Host-X-Unix Based Image and Data Processing System for NDE Applications**
---RALPH HEWES, GEOFFREY KELLY, AND LEWIS THOMAS III, GENERAL ELECTRIC CORPORATE RESEARCH AND DEVELOPMENT, SCHENECTADY, NY 12301

9:30 AM **Spreadsheet-Like Image Analyzer**
---PAUL D. WILLSON, U.S. ARMY AMCCOM, AMSMC-QAH-T, BLDG. 62, PICATINNY ARSENAL, NJ 07806-5000

9:50 AM **High Resolution Ultrasonic Volume Scanning System Used to Inspect Composite Airplane Parts**
---WILLIAM P. MOTZER, BOEING COMMERCIAL AIRPLANE GROUP, ADVANCED CONCEPTS NONDESTRUCTIVE TEST, MS 73-30, P.O. BOX 3707, SEATTLE, WA 98124-2207

10:10 AM **COFFEE BREAK**

10:30 AM **Spartacus: A New System of Data Acquisition and Treatment for Ultrasonic Examination**
---PH. BENOIST, F. CARTIER, N. CHAPUIS, G. PINCEMAILLE, CEA - 91191 GIF SUR YVETTE CEDEX, FRANCE

10:50 AM **PFS-GAP: A Large-Area Ultrasonic Gap Profile Measurement System**
---L. F. BROWN, ATOCHEM SENSORS, INC., P. O. BOX 799, VALLEY FORGE, PA 19482

11:10 AM **The Concept and Implementation of Scan Plan Within the Integrated Design, NDE, and Manufacturing Sciences**
---PETER JEONG, CENTER FOR NDE, IOWA STATE UNIVERSITY, AMES, IA 50011

11:30 AM **Emerging QNDE for Large Area Scanning.**
---FRANK A. IDDINGS, SOUTHWEST RESEARCH INSTITUTE, 6220 CULEBRA ROAD, SAN ANTONIO, TX 78228.

11:50 AM **A Novel Micro-Spot Dielectric Film Measurement System.**
---D. L. WILLENBORG, S. M. KELSO, J. L. OPSAL AND A. ROSENCWAIG, THERMA-WAVE, INC., FREMONT, CA 94539.

12:10 PM **LUNCH**

SESSION XXXIV
UT TRANSDUCERS, CALIBRATION, and STANDARDS
J. Heymann, Chairperson
Lancaster Lounge/Moulton Union
Pages 179-183:

8:30 AM **A New Conservation Law Description of an Electromagnetic Acoustic Transducer in the Time Domain**
---R. LUDWIG AND X. -W. DAI, DEPARTMENT OF ELECTRICAL ENGINEERING, WORCESTER POLYTECHNIC INSTITUTE, WORCESTER, MA 01609 AND R. PALANISAMY, TIMKEN RESEARCH, THE TIMKEN COMPANY, CANTON, OH 44706

8:50 AM **Production of a Diffractionless Ultrasonic Beam**
---BYRON P. NEWBERRY, JEFFREY C. MCKAIN AND MARK A. PREISCHEL, DEPT. OF AEROSPACE ENGINEERING AND ENGINEERING MECHANICS, UNIVERSITY OF CINCINNATI, CINCINNATI, OH 45221

9:10 AM **A Near-Field Measurement Model for Ultrasonic Reference Standards**
---LESTER W. SCHMERR, JR., CENTER FOR NDE AND THE DEPARTMENT OF AEROSPACE ENGINEERING AND ENGINEERING MECHANICS, IOWA STATE UNIVERSITY, AMES, IA 50011 AND ALEXANDER SEDOV, SCHOOL OF ENGINEERING, LAKEHEAD UNIVERSITY, THUNDER BAY, ONTARIO, CANADA P7B 5E1

9:30 AM **A Geometrical Interpretation of the Echo Formation of Short Pulses on Simple Shaped Targets**
---D. DEVADDER, R. RAILLON, A. LHEMERY, LABORATOIRE MECHANIQUE U.R.A. 850 C.N.R.S., ECOLE CENTRALE PARIS, 92295 CHATENAY-MALABRY, FRANCE

9:50 AM **Self-Calibrating Ultrasonic Technique for R/T Measurements**
---J. D. ACHENBACH, I. N. KOMSKY, Y. C. LEE, CENTER FOR QUALITY ENGINEERING AND FAILURE PREVENTION, NORTHWESTERN UNIVERSITY, EVANSTON, IL 60208

10:10 AM **COFFEE BREAK**

10:30 AM **NDE of Cylindrically Symmetric Components with Piezofilm Transducers**
---DAVID K. HSU AND ZHONG ZHANG, AMES LABORATORY, IOWA STATE UNIVERSITY, AMES, IA 50011

10:50 AM **Procedure for Alignment of Ultrasonic Beam for NDE Applications**
---N. K. BATRA, R. B. MIGNOGNA, K. E. SIMMONDS, NAVAL RESEARCH LABORATORY, WASHINGTON, D.C.

11:10 AM **Optimum Implementation of the Specified Notches for Ultrasonic Detection of Longitudinal Defects on Steel Tubes.**
---PHU-AN NGO, BERNARD BISIAUX, VALLOUREC RESEARCH CENTER, 59620 AULNOYE, FRANCE.

11:30 AM **Standardization for the Quantitative Ultrasonic Evaluation of Polymer Composites**
---J. TED MILLER, ET AL, LOCKHEED AERONAUTICAL SYSTEMS CO., MARIETTA, GA 30063

11:50 AM **New Concepts for Characterization of Ultrasonic Transducers**
---P. JAGNOUX*, G. MANGENET*, E. GUILLOT**, *SNECMA, LABORATOIRE D'ETUDE EN CND, BP 81, 91003 EVRY CEDEX, FRANCE, **ESPCI, 10 RUE VAUQUELIN, 75005 PARIS, FRANCE

12:10 PM LUNCH

Friday, August 2, 1991

SESSION XXXV
MATERIAL PROPERTIES (METALS)
O. Buck, Chairperson
Smith Auditorium
Pages 184-188:

8:30 AM **A Comparative Study Between DC and RF Surface Resistivity Measurements**
---D. D. PALMER AND P. R. WIMS, MCDONNELL DOUGLAS CORPORATION, P. O. BOX 516, ST. LOUIS, MO 63166

8:50 AM **Response of Tensile and Bending Specimens Using an AC Magnetic Bridge**
---WILLIAM F. SCHMIDT, UNIVERSITY OF ARKANSAS AND OTTO H. ZINKE, INTERNATIONAL VALIDATORS, INC., FAYETTEVILLE, AR

9:10 AM **Effect of Preferred Grain Orientation and Grain Elongation on Ultrasonic Wave Propagation in Stainless Steel**
---S. AHMED AND R. B. THOMPSON, CENTER FOR NDE, IOWA STATE UNIVERSITY, AMES, IA 50011

9:30 AM **X-Ray Diffraction and Acoustic Prediction of Elastic and Plastic Anisotropy of fcc Metal Sheet.**
---K. J. KOZACZEK, C. O. RUUD, J. C. CONWAY, JR., C. J. YU, PENN STATE UNIVERSITY, 155 MRL, UNIVERSITY PARK, PA 16802, J. HIRSCH, VAW ALUMINUM, BONN, GERMANY.

9:50 AM **Measurement of Hydrogen in Zr-2.5%Nb Using High Accuracy Velocity Ratio Measurements**
---H. DOUGLAS MAIR, ONTARIO HYDRO, 800 KIPLING AVE., TORONTO, CANADA, M8Z 5S4

10:10 AM **COFFEE BREAK**

10:30 AM **On the Relationship between Fracturing of a Microcracking Solid and the Change of its Elastic Stiffness**
---MARK KACHANOV, DEPARTMENT OF MECHANICAL ENGINEERING, TUFTS UNIVERSITY, MEDFORD, MA 02155

10:50 AM **Acoustic Emissions From Titanium Aluminides Produced During Microhardness Testing**
---J. BART BOODEY, DIANNE M. GRANATA, I. PEREZ, WILLIAM R. SCOTT, AND M. WILSON, NAVAL AIR DEVELOPMENT CENTER, WARMINSTER, PA 18974

11:10 AM **Microstructural Noise in Titanium Alloys and Its Influence on the Detectability of Hard-Alpha Inclusions**
---F. J. MARGETAN AND R. B. THOMPSON, CENTER FOR NONDESTRUCTIVE EVALUATION, IOWA STATE UNIVERSITY, 1915 SCHOLL RD., AMES, IA 50011

11:30 AM **Effects of Interstitial Oxygen on the Ultrasonic Properties of Titanium Alloys**
---R. B. THOMPSON, F. J. MARGETAN, J. H. ROSE, CENTER FOR NDE, IOWA STATE UNIVERSITY, AMES, IOWA 50011; N. K. BATRA, NAVAL RESEARCH LABORATORY, WASHINGTON, DC 20375

11:50 AM **DISCUSSION**

12:00 PM **LUNCH**

Friday, August 2, 1991

SESSION XXXVI
NONLINEAR TECHNIQUES in MATERIAL CHARACTERIZATION
L. Adler, Chairperson
Cleaveland Hall, Room 108
Pages 189-193

8:30 AM **Nonlinear Acoustics and How She Grew**
M. A. BREAZEALE, NATIONAL CENTER FOR PHYSICAL ACOUSTICS, UNIVERSITY OF MISSISSIPPI, UNIVERSITY, MS 38677

9:10 AM **Acoustic Nonlinearity in Plastics**
---PETER B. NAGY AND LASZLO ADLER, DEPARTMENT ON WELDING ENGINEERING, THE OHIO STATE UNIVERSITY, COLUMBUS, OH 43210

9:30 AM **Determination of Nonlinearly Viscoelastic Behavior of Adhesive Bonds**
---OJUS PARIKH AND J. D. ACHENBACH, CENTER FOR QUALITY ENGINEERING AND FAILURE PREVENTION, NORTHWESTERN UNIVERSITY, 2137 N. SHERIDAN RD., EVANSTON, IL 60208-3020

9:50 AM **Nonlinear Elastic Effects on the Energy Flux Deviation of Ultrasonic Waves in GR/EP Composites**
---WILLIAM H. PROSSER, R. D. KRIZ*, DALE W. FITTING+, NASA LANGLEY RESEARCH CENTER, HAMPTON, VA 23665, *VIRGINIA TECH, BLACKSBURG, VA 24061, +NIST, BOULDER, CO 80303-3328

10:10 AM **COFFEE BREAK**

10:30 AM **Surface Acoustic Wave Nonlinearities in Surface Sounding**
---ADRIANO ALIPPI, DEPT OF ENERGETICS, UNIVERSITY OF ROME, ITALY, INSTITUTE OF ACOUSTICS, CNR, ROME, ITALY

10:50 AM **Parametric Beam Formation in Rock**
---P. A. JOHNSON AND T. M. HOPSON, GEOLOGICAL ENGINEERING GROUP, MS D443, LOS ALAMOS NATIONAL LABORATORY, LOS ALAMOS, NM 87545; B. P. BONNER, EARTH SCIENCES DEPARTMENT, L-201, LAWRENCE LIVERMORE NATIONAL LABORATORY, LIVERMORE, CA 94550; AND T. J. SHANKLAND, GEOPHYSICS GROUP, MS D447, LOS ALAMOS NATIONAL LABORATORY, LOS ALAMOS, NM 87545

11:10 AM **Nonlinear Acoustics and the Thermal Expansivity of Glass**
---JOHN H. CANTRELL AND WILLIAM T. YOST, NASA LANGLEY RESEARCH CENTER, HAMPTON, VIRGINIA 23665-5225

11:30 AM **Pulsed Phase-Locked Loop Methods for Measuring Acoustic Nonlinearity**
---WILLIAM T. YOST AND JOHN H. CANTRELL, NASA LANGLEY RESEARCH CENTER, HAMPTON, VIRGINIA 23665-5225

11:50 AM **Measurement of the Displacement Amplitudes of a Harmonically Distorted Ultrasonic Wave Using a Fluid-Coupled Contact Transducer**
---G. E. DACE, R. B. THOMPSON, AND O. BUCK, CENTER FOR NDE, IOWA STATE UNIVERSITY, AMES, IA 50011

12:10 PM **DISCUSSION**

ADJOURN

See you next year at La Jolla

NEXT YEAR'S MEETING

WILL BE AT

UNIVERSITY OF CALIFORNIA, SAN DIEGO

LA JOLLA, CALIFORNIA

JULY 19 - 24, 1992

Monday

Monday, July 29, 1991

9:00 AM	SESSION I	DOE ENVIRONMENTAL RESTORATION and WASTE MANAGEMENT **J. Corones**, Chairperson Morrell Gymnasium Page 1:
10:30 AM	SESSION II	ENVIRONMENTAL MONITORING AND SENSORS **R. Barna**, Chairperson Morrell Gymnasium Page 2:
1:30 PM	SESSION III	SENSORS **R. O. Claus**, Chairperson Smith Auditorium Pages 3-7:
1:30 PM	SESSION IV	NDE OF COMPOSITES (MOSTLY FIBER MATRIX) **D. Chimenti**, Chairperson Kresge Auditorium Pages 8-12:
1:30 PM	SESSION V	UT THIN PLATES and TUBES-1 **P. Nagy**, Chairperson Cleaveland Hall Pages 13-17:
1:30 PM	SESSION VI	IMAGING and INVERSION TECHNIQUES **R. Gilmore**, Chairperson Lancaster Lounge/Mouton Union Pages 18-22:

The Impact of Waste Characterization on Environmental Restoration and Waste Management Activities in the Department of Energy

---DR. C. W. FRANK, ASSOCIATE DIRECTOR, OFFICE OF TECHNOLOGY DEVELOPMENT, DEPT. OF ENERGY, ROOM 7A049, EM-50, 1000 INDEPENDENCE AVE., SW, WASHINGTON, D.C. 20585

---The legacy of the Department of Energy (DOE) nuclear weapons and materials production is radioactive, hazardous, and mixed wastes in over 100 identified sites across the United States. In November 1989, Secretary Watkins established the Office of Environmental Restoration and Waste Management (EM) to manage the Department's remediation activities. Each cleanup site is unique. Nondestructive evaluaution techniques, such as chemical analysis, remote sensing, and biological markers will play a major role in EM site characterization activities. This paper describes DOE's efforts in addressing key technical and regulatory problems. Current practices, regulatory influences, and limitations of current techniques will be discussed as well as emerging technologies. EM's needs for nondestructive evaluation and related technologies is pervasive. The scope of DOE problems (and opportunities) can best be seen by considering three major needs: buried waste, underground storage tanks, and the remediation of volatile organic compounds in saturated soil. Buried waste, often in a container, must be properly mapped using remote sensing, acoustic, electromagnetic, and possibly other techniques. The contents of the containers should be established noninvasively. For underground storage tanks, contents are usually imperfectly known. The physical characterization of the contents, including the presence of hydrogen accumulations, needs to be established for the highly heterogenous contents of the tanks. Safety and cost consideration require the utilization of robotic technologies for buried waste and tanks, and instruments hardened against the harsh chemical and radiation environments are needed for tanks. Characterization allowing alternatives to drilling very large numbers of wells must be found. Methods of monitoring the remediation process itself are needed. Cultural and institutional barriers will also be discussed, since these must be overcome if development and implementation of characterization technologies is to be effective. Such barriers include conventional approaches to education, technology integration, and the adversarial relationship between advocates of the environment and various other institutions.

Issues in Global Environmental Monitoring
---G. BRUCE WIERSMA, COLLEGE OF FOREST RESOURCES, UNIVERSITY OF MAINE, ORONO, MAINE 04469

---The scientific community and the public are becoming increasingly aware of global environmental issues. These issues range from the long-range transport of acidic compounds, climate change, ozone depletion, to the long-range transport of other toxic compounds such as heavy metals. A large number of efforts and a great amount of money are currently being spent for both research and monitoring concerning these problems. This research and monitoring requires instrumentation and analytical techniques. By definition, these problems require a much larger geographic view than previous environmental studies, and this requires large, widely dispersed sampling and research networks. Traditional pollution instrumentation is limiting, is not always appropriate for such networks and in many cases, researchers have to make do with what is there. There is an opportunity and a need for new creative solutions to making environmental measurements in an economical fashion.

Tiny Chips, Big Jobs: Microscale Devices and Environmental Probing
---RICHARD M. WHITE, BERKELEY SENSOR & ACTUATOR CENTER AND DEPARTMENT OF ELECTRICAL ENGINEERING AND COMPUTER SCIENCES, UNIVERSITY OF CALIFORNIA, BERKELEY, CA 94720

---Imaginations worldwide have been stimulated by reports and pictures of tiny silicon chips containing microstructures that can sense and even move. The components are now mostly in place to make microsystems for measuring many physical, chemical, and biological quantities. These microsystems might also incorporate pumps, valves, and other elements that could transport, measure and cause the chemical reaction of fluid and solid components. Sophisticated state-of-the-art electronic circuitry will be integrated in these systems for control, signal conditioning and data collection. These microsystems will be inexpensive provided they are used in large enough quantities--perhaps one million per year. Environmental monitoring could be a sufficiently large market, along with transportation and medicine. We will consider the prospects for using such microdevices for environmental probing through means such as detecting chemical vapors in a gaseous ambient, sensing chemical and biochemical components in rivers and oceans, measuring fluid viscosity and density of microliter samples, and complete chemical analyses via miniaturized low-power analytical instruments.

UHF Modulation and Fourier Transform Differential Time Domain Techniques for Measuring Strain Via Fiber Optics

---J. S. SCHOENWALD, SCIENCE CENTER, R. H. MESSINGER, SPACE SYSTEMS DIVISION, ROCKWELL INTERNATIONAL CORPORATION, 4049 CAMINO DOS RIOS, THOUSAND OAKS, CA 91360

---We describe fiber optic sensor system for spatially resolving strain levels of 10^{-6} between closely spaced regions within composite samples. The phase-amplitude response of swept ultra-high frequency (UHF) amplitude modulated laser light transmitted through composite embedded optical fibers to measure strain in test structures subject to tensile loading. This is accomplished by embedding multiple optical fibers of various penetration lengths. The phase-magnitude characteristics of the reflected signals from three fibers are determined by a UHF network analyzer. A fast Fourier transform (FFT) performed on the network analyzer yields a transmission-mode time domain image of the reflection from the fiber ends, which appears as distinct reflections. By use of a signal subtraction process, small strains are detectable and differences between strain in closely spaced regions around a defect should be resolvable. A description of the system and results to date will be described. --- This work is supported by the Rockwell International Independent Research and Development Program.

Composite Embedded Optical Fiber Sensors for Strain, Damage and Cure Monitoring

---R. M. MEASURES, K. KIU, M. LEBLANC, T. VALIS, D. HOGG, B. PARK, M. OHN AND A. DAVIS, UNIVERSITY OF TORONTO INSTITUTE FOR AEROSPACE STUDIES, 4925 DUFFERIN ST., DOWNSVIEW, ONTARIO, M3H-5T6, CANADA AND THE ONTARIO LASER AND LIGHTWAVE RESEARCH CENTRE

---An overview of our advances toward fiber optic based smart structures will be presented. Damage assessment within composites has been undertaken with two different techniques: optical fibers have been damage sensitized so they fracture when the composite is critically loaded or they have been made into very sensitive strain sensors that can detect acoustic energy associated with the formation of internal damage. We shall report the results of impact tests on the first full scale *aircraft* composite *leading edge* instrumented with a "fiber optic damage assessment system" comprising a multilayered, embedded grid of 250 - optical fibers. We shall also report on the correlation of *acoustic emission* signals, detected by embedded interferometric fiber optic sensors, to specific delaminations and cracks within Kevlar/epoxy specimens and our development and calibration of the first practical *optical strain rosette*. We will discuss their performance when embedded within composites and review our recent work on *cure monitoring* with embedded fiber optic sensors.

High Temperature Fabry-Perot Based Strain Sensor for Ceramic Cross Flow Filters

---K. A. MURPHY, C. E. KOOB, A. J. PLANTE, A. M. VENGSARKAR AND R. O. CLAUS, FIBER & ELECTRO-OPTICS RESEARCH CENTER, BRADLEY DEPARTMENT OF ELECTRICAL ENGINEERING, VIRGINIA TECH, BLACKSBURG, VA 24061-0111

---We report results from a research program to develop fiber optic sensor based instrumentation methods to allow the in situ analysis of ceramic cross flow (CXF) filters. Ceramic cross flow filters, constructed of a porous ceramic (alumina or silicon nitride) material, are analogous to cross-flow heat exchangers, except gas is passed between channels instead of thermal energy (heat). Information from such instrumentation is needed to determine how the filters perform during operation, how subsequent filter and combustor designs may be improved based on the knowledge of such performance, and how and where damage and degradation occur. Fiber sensor-instrumented filters were tested in a combustor at the Westinghouse Science and Technology Center in Pittsburgh, PA. These tests were performed using silica optical fibers capable of withstanding the high temperature and harsh chemical environment of the combustor. The sensor used was an extrinsic Fabry-Perot cavity created between the ends of two longitudinally aligned fibers and is described in detail below. The extrinsic Fabry-Perot fiber optic sensors have been used to measure thermal strains in ceramic cross-flow filters with accuracies of 0.1 μm/m. The single ended approach of the reflective Fabry-Perot sensors is well suited for high thermal strain measurements, the results obtained show that the output of the fiber sensor tracks the temperature changes exactly as expected and shows no noticeable time lag between the measurand and the output signal.

Quantitative Evaluation of Steel Corrosion in Microenvironments Using the Corrosion Coulometer

---RICHARD D. GRANATA, ZETTLEMOYER CENTER FOR SURFACE STUDIES; WILLIAM D. MICHALERYA, ATLSS RESEARCH CENTER, LEHIGH UNIVERSITY, BETHLEHEM, PA; ROGER H. WILDT, BETHLEHEM STEEL CORP., BETHLEHEM, PA; HENRY LEIDHEISER, JR., VENICE, FL; BRENDAN W. O'MALLEY, JR., NEW YORK, NY

---A corrosion sensor has been developed which monitors the corrosivity due to atmospheric conditions such as dust, debris, humidity, condensation and electrolytic species. The corrosion coulometer integrates current generated by a corroding material (steel) connected to an adjacent anode. Design parameters enable customizing the monitor for response to specific conditions. Results from field studies and laboratory development will be related to use in steel structure evaluations.

Investigations of Extensional and Torsional Acoustic Wave Thin Rod Sensors

---M. VIENS[1], Y. LIU[1], Z. WANG[2], C. K. JEN[2], AND J. D. N. CHEEKE[1,3], [2]IMI, NATIONAL RESEARCH COUNCIL, BOUCHERVILLE, QUEBEC, CANADA J4B 6Y4; [1]DEPT. OF PHYSICS, UNIVERSITY OF SHERBROOKE, SHERBROOKE, QUEBEC, CANADA J1K 241; [3]SIRICON, MONTREAL, QUEBEC, CANADA H3G 1M8

---Experimental investigations of extensional and torsional acoustic wave thin rod sensors are presented. Using two 5MHz compressional bulk wave transducers, a miniature thin rod acoustic delay-line oscillator has been constructed. The medium-term (0.1 sec.) stability of that device is 1 part per 10 million. Magnetostrictive transducers have also been used in a thin rod acoustic delay-line to generate torsional and extensional waves. Preliminary temperature sensing measurements were carried out on these devices. Analysis of the effects of a liquid surrounding such thin rod sensors is also given. Special attention is focused on the region where the product of frequency and the rod radius is small (<500 m/s). --- Financial support from the Institute for Chemical Science and Technology is acknowledged.

Active Corrosion Site Detection Scheme Using Optical Fibers

---R. D. REMPT, BOEING DEFENSE & SPACE GROUP, MS/87-60, P. O. BOX 3999, SEATTLE, WA 98072

---A detection scheme is described which senses the magnetic field gradients arising from the minute currents present at active corrosion sites at or near the surface of aircraft skins. The scheme employs an optical fiber Machzehnder interferometric sensor. The magnetic field is coupled to the fibers by means of magnetostrictive glass. Construction and checkout of laboratory detector are described along with its quantitative response to currents simulating those at active corrosion sites. Plans for increasing the sensitivity of the detector are also presented. The concept basically "inverts" the magnetic anomaly detection technology for finding ferrous objects at large distances, to detecting minute currents at very small distances of the order of 3-4mm.

Smart Materials Used in Frequency Selective Passive Pressure Sensors

---J. R. LHOTA, P. M. SHEAFFER, AND G. F. HAWKINS, THE AEROSPACE CORPORATION, M2/248, P. O. BOX 92957, LOS ANGELES, CA 90009.

---A low-cost passive system which senses and records the maximum pressure excursion in a specific frequency range was recently designed and tested. The system uses microballoons mixed into grease as a pressure sensing smart material. The frequency selection was achieved by using a fluidic filter. The fundamentals behind the design, the design details, and the launch performance will be presented. The system was designed, built, and deployed to passively record the maximum gas pressure in a selected frequency range at a number of positions on the pad during a Titan IV launch. The design fundamentals and data obtained during a recent launch will be presented.

Calibration and Characterization of Eddy Current Probes by Photoinductive Field Mapping

---J. C. MOULDER, M. W. KUBOVICH, M. S. HUGHES, S. MITRA, AND A. DEGERATU, CENTER FOR NDE, IOWA STATE UNIVERSITY, AMES, IA 50011

---We describe a prototype instrument for calibrating and characterizing eddy current probes based on photoinductive (PI) mapping of the probe's electric field distribution. A pulsed 0.5-W infrared diode laser, focused on one side of a thin gold film in contact with the face of the probe, is raster-scanned across the active area of the probe. Photoinductive signals proportional to the square of the electric field in the gold film are detected by synchronous demodulation of the eddy current probe impedance signal obtained from a standard commercial eddyscope. By displaying the photoinductive signal recorded as the laser is scanned over the probe face, maps of the eddy current distribution in the gold film can be obtained having a spatial resolution of approximately 200 μm. We illustrate the capabilities of the instrumented with representative scans of a variety of eddy current probes: absolute, differential, reflection, and uniform field probes. We also show the effects of changing probe liftoff and operating frequency on eddy current distribution and illustrate the changes caused by an intervening layer of metal. The potential of this technique for probe calibration and standardization is demonstrated with studies of the correlation between PI measurements and eddy current signals obtained by measuring EDM slots. This work was supported by the Center for Advanced Technology Development and the Center for Aviation Systems Reliability at Iowa State University.

Optimization of Sound Pulse Generation for Photoacoustic Sensing Applications

---MARKKU OKSANEN, DEPARTMENT OF PHYSICS, UNIVERSITY OF HELSINKI, SILTAVUORENPENGER 20 D, SF00170 HELSINKI, FINLAND AND JUNRU WU, DEPARTMENT OF PHYSICS, UNIVERSITY OF VERMONT, BURLINGTON, VT 05405.

---Photoacoustically generated sound pulses are currently used in several NDT, NDE and sensing applications, often because this offers a method to generate ultrasound without touching the sample. If fiber optics are used the sound source can be made completely dielectric. Our study addresses the optimal conditions for sound generation for sensing purposes using a low power 4μJ / pulse, 10 kHz repetition rate solid state pumped Nd: YAG laser. The effects of optical and elastic material parameters of the sample, laser pulse duration and repetition rate, and laser beam size on the sample are discussed. When laser pulse width and repetition rate are fixed, theoretical results indicate that in the thermoelastic regime a volume source, ie. an illuminated cylinder, offers higher useable sound pressure than a surface source ie. an illuminated disk at the interface of a transparent and nontransparent layer. This work is supported by BF Goodrich Simmonds Precision Aircraft Systems, Vergennes VT.

Small Flaw Detection With a Magnetic Recording Head Probe

---T. E. CAPOBIANCO, ELECTROMAGNETIC TECHNOLOGY DIVISION, NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY, 325 BROADWAY, BOULDER, CO.

---We have developed a novel eddy current probe, utilizing a read/write head from a computer hard drive, that provides a significant increase in spatial resolution for small flaw detection. We have used this recording head probe to detect flaws in both high and low conductivity alloys (7075-T6 aluminum and Inconel 718). The aluminum flaws were fatigue cracks about 1 mm long on the surface and the Inconel flaws were electrical-discharge-machined (EDM) notches approximately 0.1 to 0.25 mm long. In the case of the flaws in Inconel, we were unable to detect these defects with our convention single coil and differential coil probes.

Acoustic Emission from Internal Delamination of a Four-Ply Plate

---E. RHIAN GREEN, DEPARTMENT OF ENGINEERING, UNIVERSITY OF LEICESTER, LEICESTER, LE1 7RH, UK

---In order to interpret the acoustic emission accompanying delamination, it is necessary to derive the Green's function solution for a line impulse acting on any interface. This paper extends our earlier solutions [1] and reports the Green's function for a line impulse acting in turn at each of the three interfaces within a four layer, cross-ply carbon fiber composite laminate. Each layer is modelled as a transversely isotropic elastic continuum and are perfectly bonded. Using the integral transform formalism and the propagator matrix technique, the governing equations are solved to yield analytic expressions for the stress and displacement transforms at any level in the laminate. These are inverted numerically using residue theory for the frequency inversion, followed by integration along each branch of the plate dispersion equation. Numerical results are presented for a range of orientations of the line source relative to the core fiber direction. These show the displacement levels at the outer surfaces and at various depths within the plate at fixed times as functions of distance from the location of the line source.

Transient Response of a Laminated Composite Plate

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---Transient response of a multilayered laminated plate has been studied here with a view to model radiation from acoustic emission in a composite plate. In this study we have focused our attention on the effect of layering on the surface response in a laminated plate in both time and frequency domains. The source is modeled as a line vertical force on the surface of the plate. Thus the resulting problem is two dimensional (plane strain). Comparison of the response of a cross-ply plate with a few laminae with that of a statically equivalent homogeneous plate shows considerable differences. For short pulses the response is fairly complicated because of reflections from the interfaces between the plies. Dispersion of waves in the plate is also analyzed. It is found that homogenized model predictions for the low order modes agree with those of the layered model. However, they diverge when high order modes are considered. This is consistent with the transient response comparisons.

Ultrasonic Evaluation of Damage Zones in Glass/PVC and Glass/Vinylester Composites

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---Damage zones in plastic composites reinforced with chopped glass fibers were evaluated with focused beams of ultrasound. Two material systems were studied: injection molded glass/PVC and glass/vinylester SMC plates. The size and shape of the damage zones in translucent glass/PVC were mapped out with ultrasonic scans and found to be in good agreement with optical micrographs. The damage zone parameters were correlated to the glass content and the amount of impact modifiers in the PVC composite. Damages were induced by static loading of a notched specimen and by compression using a spherical indentor. Finite element calculations of the stress distribution were also compared to the experimentally measured damage zone parameters. Work supported by the National Science Foundation under a "Tie Program" with Case Western Reserve University.

Ultrasonic Evaluation of Anisotropic Damage Induced in Glass/Epoxy Composites by Water Immersion.

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---The water immersion of composite materials, made with polymeric matrix induces a damage such that their mechanical properties weaken. This paper presents the anisotropic damage effects on glass fibers/epoxy matrix composites which is measured from velocities and attenuation of ultrasonic waves. The measurements of velocities and attenuations as a function of the direction of waves propagation inside the composites leads to the identification of orthotropic viscoelastic constants. This model permits the investigation of attenuation in any direction. Samples of these materials were characterized in their initial state and after immersion in hot water during six months. The damage is revealed by the weakening of some elastic constant and growth of the initial anisotropic attenuation. From the velocities evolution and to link initial and damaged states, a model of anisotropic damage, based on a fourth order diagonal tensor, was tested with success. The direction which is the most affected is the perpendicular to the fibers. This observation was confirmed by the evolution of longitudinal modes attenuation in this direction. Meanwhile, in this same direction, the variation of shear modes attenuation depends of the polarization. It is shown than anisotropic attenuation is an anisotropic damage indicator more sensitive than velocities and brings more informations about the internal structure of composites.

Non Destructive Inspection for Carbon-Carbon with Adapted Coating for Oxidation.

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---During reentry in the atmosphere, HERMES space plane will be exposed to very high temperature in oxidizing conditions (up to 1800°C and low pressure). The concerned parts are mainly the nose cap and the leading edges for which AEROSPATIALE develops carbon/carbon material with adapted coating for oxidation. The manned systems designed to withstand the whole conditions 30 times without damaging, need maximum reliability. The non destructive testing is a necessary tool to assure these requirements during the fabrication and life of vehicles. This paper presents the main features of the investigated and developed methods: 1) Eddy current for coating thickness measurement. We will show the influence of parameters such as the fibers, the matrix, the substrate, the protection and the oxidation degree of the material; 2) Ultrasonics, pulse thermography and compton scattering for structural integrity. We will present images we obtained on samples and wing leading edges with defects. We will compare also the defects dimensions we measured with these methods via in particular modelisation with real dimensions we measured by micrography after the testings. Morever, we will give the needs we have or wing leading edges and noses testings and for future non destructive testing facilities.

Thermal and Ultrasonic Evaluation of Porosity in Composite Laminates

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---Porosity in graphite/epoxy composites is one of the chief fabrication defects investigated using nondestructive measurements. Recent developments have focused on the use of ultrasonics and thermal measurements to infer the degree of porosity in composite laminate panels. For the work reported here, panels were constructed with varying degrees of porosity by varying the pressure applied during the cure. Quasiisotropic panels of Hercules AS4/3501-6 prepreg tape were cured at 100 psi (manufacturer's recommended), 5 psi, 10 psi, and 20 psi to achieve porosities ranging from less than 1% to approximately 4%. Thermal diffusivity through the thickness of the panels was measured. Also, the frequency dependence of the ultrasonic attenuation coefficient and the internal ultrasonic backscatter were measured. We will present these results and relate the measurements to models of the thermal and ultrasonic processes involved.

Application of Acoustic Emission to Studying Fiber Fragmentation as a Process in Single Fiber Composites

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---Studies of fiber fragmentation during the extension of single fiber composites can provide data, as a function of time, of fiber length and strength useful for comparison with stochastic models of such processes. The results are also useful in understanding the relationships between strength, microstructure and materials processing. This paper describes a technique which uses laser calibration and acoustic emission time of arrival methods to determine the fracture source location to an accuracy of about 150 μm. Simultaneous measurement of the load drop provides the segment fracture strength. If an estimate can be made of the effective length over which the fiber segment is loaded in shear, the interface strength can then be calculated approximately from the shear lag relationship. This permits determination of the secular order of the fragmentation process in opaque materials such as metal matrix composites. Further information on the nature of the emission source(s) in these samples, such as the occurrence of multiple fractures during a single event, or the type of fracture--whether shear or tensile--was obtained by post-mortem examination of the elongated specimens.

Thermographic Characterization of Stress Induced Damage in Composites

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---This paper examines thermographic characterization of stress induced damage in composites. Results of tests performed on $[+45, -45, 0, 90]_S$ composite coupons are presented. Thermographic measurements are performed during both static and cyclic loading of the composite specimens. Effective through thickness diffusivity images are obtained. These images yield real time images of the progression of damage in the composite. From the diffusivity images, the effective contact resistivity of the delamination is determined. The thermographic technique is advantageous over currently used approaches in that it can be used in situ. The technique does not require interruption of the test or removal from the load frame as with ultrasound or dye penetrant x-ray.

Quantitative Measurement of Delamination Area in Low-Velocity Impacted Composites Using Acoustic Microscopy

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---A C-Scan mode acoustic microscope (C-SAM) was used to nondestructively measure the delamination areas in impacted glass/epoxy composite plates which had been subjected to low-velocity impact. It has been recognized that delamination is the major damage mode in thin composite plates subjected to low-velocity impact and is mainly attributed to bending stress. Accordingly, the quantitative measurement of delamination area is very important in investigating the relationship between delamination area and impact energy in order to understand the impact resistance of a composite plate. Conventional methods for delamination area measurement involve time-consuming slicing and polishing of the impacted specimens. Instead, C-SAM produces layer-by-layer images of delamination at each interface in the order of seconds and can quantitatively measure the total delamination areas. In addition, a cross-sectional view and a 3-D view of the delaminations throughout the composite plate can be provided by the Quantitative B-Scan Analysis mode and the Time-of-Flight Image ode, respectively. Experimental results have verified previous findings on the linear relationship between delamination area and impact energy.

The Effect of Exposure to Hot, Wet Conditions on the Dynamic Properties of Fibre Reinforced Plastics

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---Two carbon fibre reinforced polymers, an epoxy resin and PEEK, have been exposed to steam and the resultant changes in the specific damping capacity and the elastic moduli in flexure and in torsion have been determined. These changes were correlated with the uptake of moisture and the reduction in interlaminar shear strength. The carbon fibre reinforced PEEK composite was found to be little affected by steam. For the carbon fibre-epoxy system, however, although the longitudinal flexural properties were not significantly altered, the shear properties were. There was a decrease of about 13% in the shear modulus and in increase of more than 50% in the shear damping when 2% moisture had been absorbed. The corresponding reduction in interlaminar shear strength was 18%. The torsional damping capacity is shown to be sensitive to the condition of the material; its evaluation could be used as the basis of nondestructive assessment of degradation due to absorbed moisture.

Complex Ray Analysis of Non-Specular Reflection of Bounded Beams from Multilayer Fluid-Immersed Elastic Structures

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---The excitation of various types of leaky waves in layered elastic media by bounded beams incident from an exterior fluid at or near the phase-matching angle is of interest for NDE applications. In particular, much attention has been given to the non-specular reflection of the beams under such conditions of incidence. While various methods have been employed to study and clarify these phenomena in plane layered environments, much less has been done on the corresponding effects when the layers ar curved. To extend the plane layer results to these more general conditions, it is desirable to employ analytic modeling that adapts the wave phenomenology locally from planar to curved geometries. Because the phenomena occur in the range of high frequencies, ray field modeling affords an attractive option. Since the input field is a bounded beam, complex rays are required which, for the case of quasi-Gaussians, can be taken to generated by a point source at a complex location. To establish the algorithm, complex ray field tracing has been applied first to the plane layered environment. The resulting formulas for the reflected beam field, which are valid at all observation angles and distances, reduce to the paraxial non-specular results in the literature when subjected to that approximation. Having thus verified the validity of the method, the complex ray algorithm is being extended to circular cylindrical geometry. Analytical and numerical results will be presented.

Surface Wave Propagation in Fiber Composite Laminates

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---It is well known that, for an infinite plate of isotropic elastic material, the phase velocity of the fundamental mode of both symmetric and anti-symmetric Rayleigh-Lamb waves asymptote the velocity of Rayleigh surface waves in the limit as the wavelength tends to zero. The limiting velocity of all higher modes is that of shear waves in the material. For a multi-layered plate, the limiting velocity of the generalized Rayleigh-Lamb waves either exhibits the same behavior as a single plate in relation to the elastic properties of one of the surface layers, or the phase velocity of each mode asymptotes the shear wave speed of one of the internal layers. The latter behaviour occurs when the shear wave speed of the internal layer is less than the Rayleigh wave speeds of the surface layers. For a fiber composite laminate in which each layer is modelled as a transversely isotropic elastic continuum, this limiting behavior is dependent on the direction of propagation of the Rayleigh-Lamb waves in relation to the fibber orientations. Thus, at some angles of propagation, the fundamental modes will exhibit a surface wave limiting behaviour whereas they fail to do so at others. In the latter event, numerical results for a number of different laminates have indicated the existence of surface waves associated with a finite range of wavelengths for the higher modes of propagation. This paper examines the occurrence and the extent of these ranges in relation to the depth and properties of the various layers of the laminate.

Elastic Wave Propagation in Homogeneous and Layered Transversely-Isotropic Media: Gaussian Wave Packets and Green's Function.

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---The increasing use of composites and composite laminates requires extensive efforts in developing NDE methods for these sophisticated materials. The main problem, especially with respect to algorithmic imaging, arises from their anisotropic nature which causes the splitting of phase- and group velocity directions; in layered structures additional difficulties are associated with multiple reflection and transmission. For unidirectional composites, exhibiting transversely-isotropic symmetry, plane wave solutions of the elastodynamic equation of motion were derived yielding slowness- and group velocity diagrams. The propagation of Gaussian wave packets in unidirectional homogeneous and layered structures has been calculated for arbitrary layer orientations; the results are shown as time domain wavefront snapshots. Finally, an integral representation of the Green's function for the transversely-isotropic medium has been derived via spatial Fourier-transforms, being particularly convenient to provide the basis for imaging in terms of Diffraction Tomography.

Lamb Waves for the NDE of Composite Laminates

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---The NDE of large plate-like structures, such as composite laminates demands a quick, long range testing technique. The acousto-ultrasonic method employs Lamb waves propagating between two transducers placed on the surface of the structure to detect defects located between the transducers, and while the distance between the transducers is usually limited to a few centimetres, Lamb waves will propagate over longer distances so the method may have the potential to be used as a long range test. In this paper, the propagation of the s_0 Lamb wave and its interaction with defects in composite laminates is studied by the finite element method. The predicted time responses are used to carry out standard acousto-ultrasonic analysis, and a quantitative measurement of the propagating modes is also obtained by a 2D FFT analysis which has been developed at Imperial College. It has been shown that the mode conversion produced by defects is readily detected by the 2D FFT method. However, the a_0 mode generated by mode conversion is highly dispersive and the results with the simple acousto-ultrasonic analysis are very sensitive to the position of the receiving transducer with respect to the defect. These results help to explain the problems with the acousto-ultrasonic technique which have been reported by previous authors. The results indicate that standard acousto-ultrasonic signal processing is unlikely to be useful in a long range test, but that the 2D FFT method can be used successfully over long propagation distances. Corresponding experiments have also been carried out on cross ply laminates using array transducers, and good agreement has been obtained between the results of the experimental and numerical studies.

Guided Waves in Composite and Homogeneous Tubes: Effect of Material Properties

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---Graphite fiber wound composite tubes and homogeneous aluminum tubes are being investigated for truss structures to be used in space. Because of the adverse environmental conditions (radiation, impact and thermal cycling) degradation of these materials is of concern. The object of this study is to analyze the effect various material properties and ply lay-ups on ultrasonic guided waves in these tubes. Dispersion of these waves has been investigated using a wave propagation based stiffness method. Composite tubes with different, ply lay-ups are compared in order to determine at what frequencies the ply lay-up affects the character of the propagating modes and the coupling of these modes. Results for composite tubes are found to be different than for homogeneous tubes. Pulse propagation in the tubes has also been studied using the guided modes. Comparison of model studies with experiments is found to be quite good.

Viscoelasticity influence on frequency dependence of the ultrasonic transmission through plates of composite materials

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---Composite materials exhibit a viscoelastic orthotropic behavior. Recent papers about propagation in thin anisotropic plates do not take into account the attenuation. In this paper, we present the anisotropic attenuation effects on the ultrasonic transmission. For that, transmission and reflection of plane waves through thin immerged viscoelastic orthotropic plates are computed with a method which considers the multiple reflections/refractions of heterogeneous plane waves at both interfaces liquid/solid and solid/liquid. A sample made with unidirectional carbon fibers and epoxy matrix, was previously characterized from specular echo transmission. The nine complex elastic constants are the set of data to compute transmission and reflection coefficients. From experimental investigations, the evolution of attenuation as a function of frequency was found linear for various angles of incidence. So this simple model permits the computations for the whole frequency spectrum. To test the model, computed transmission coefficients are compared to experimental results for various incidence and azimuthal angles. These coefficients calculated as function of the incidence angle, present maxima and minima. The dispersion curves which represent the maxima positions plotted as function of the frequency-thickness product, are presented with the effects of anisotropic attenuation. The attenuation leads to limited or severe repercussions on the modes positions and their appearances/disappearances in function of the azimuthal and incidence angles and the nature of modes.

Effect of a Damping Layer on the Transient Response of a Laminated Plate

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---The propagation of stress waves due to impulsive loading in a laminated plate is governed by the plate dispersion equation which relates the frequency to the wavenumber for the propagation of infinite trains of time harmonic waves under traction free conditions on the plate surfaces. This paper is concerned with investigating the difference in response between a three ply elastic plate and a similar plate in which the internal layer consists of a viscoelastic damping material. The dispersion equation for a three layered plate in which the interior layer is viscoelastic and the two outer layers are elastic, shows significant differences from that of a triple layered elastic plate. In the latter case the dispersion equation possesses a set of curves for the propagating modes which exhibit the terracing structure associated with a single elastic plate. For the laminate with the interior damping layer there exist two quite separate sets of curves. One set is associated with a virtually independent motion of the two elastic outer layers with little or no damping. The other set involves high damping and is associated with a motion which is essentially confined to the internal viscoelastic layer. The number of curves of each set within the first ten roots depends on the relative thickness of the inner and outer layers.

Wavefield Produced in a Composite Laminate by a Concentrated Surface Force

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---The elastodynamic field generated in a unidirectional composite plate by a concentrated dynamic surface load is calculated by means of a semi-analytical method. The material of the plate is modeled as a transversely isotropic and dissipative (visco-) elastic solid and both the two-dimensional line load and the three-dimensional point load cases are considered. The resulting boundary-value problems are solved by means of standard Fourier transform techniques; the inversions are carried out numerically. The wavefields obtained from the exact calculations are compared to those obtained from approximate plate theories and the range of applicability of the approximate theory is determined from this comparison. Applications of the results to point source-point receiver type NDE techniques are indicated.

Finite Element Study of Lamb Wave Interactions with Hole and Through-Thickness Defects in Thin Metal Plate

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---The purpose of this research is to use Finite Element Modeling (FEM) to qualitatively characterize the interaction of Lamb waves with simple defects in thin metal plates. Previous experimental work on laser based thermo-elastic generation and fiber optic detection of Lamb waves has been successfully modeled for defect free plates. To fully exploit the benefits of Lamb wave NDE techniques, it is necessary to develop models of Lamb waves interacting with a wide variety of geometries and defects to guide the experimental research and to efficiently generate many different scenarios too train a neural network. The authors have used finite element modeling as a preliminary study of cracks located inside drilled holes and embedded in the plate thickness by providing simulated time histories to train a neural network that determines the crack characteristics of an unknown defect from the reflected Lamb wave. By using different force application schemes in the models, broad band wave packets have been generated for Zero'th Order anti-symmetric (AO), symmetric (SO) Lamb waves and a combination of both types of waves. Initial results show that the location and in-plane depth of a crack located inside a drilled hole and in the through thickness of a plate has distinguishable effects on the amplitude, phase, and arrival times of the AO, SO, and combination wave packet displacement time histories.

Acousto-Ultrasonic Wave Propagation in Fiber-Reinforced Composite Materials.

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---The objective of this paper is to identify through analysis and experiment how the AU (acousto-ultrasonic) waves propagate through composite materials. The analytical and experimental study of AU waves are described. The waves are modeled as plane waves propagating in the plane of an infinite plate whose surfaces are stress free. The experiments using the normal incidence technique confirm that a frequency exists where the change in mode takes place. This study investigates two different composite systems (graphite/epoxy and glass/epoxy) and four types of laminates (unidirectional, quasi-isotropic, angle-ply, and cross-ply). The input frequency, stacking sequence, propagation direction, and materials all significantly influence the dispersion characteristics.

Polarimetric Microwave Inverse Scattering as Applied to Nondestructive Testing

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---Electromagnetic waves can be applied to nondestructive testing of materials provided the electrical conductivity is within a range to ailow for a significant displacement current. The development of algorithmic imaging is then concerned with the inverse scattering problem of arbitrarily polarized microwaves. Based on the vector version of the backpropagation principle, a generalized Porter-Bojarski integral equation can be derived, which relates polarimetrically measured data with the equivalent (current density) sources describing the defects. Its solution can be obtained applying distributional analysis and dyadic algebra; the result is an explicit reconstruction formula for the current density within the Kirchhoff approximation. It is applied to synthetic data and compared to a scalar inversion formula. Increasing conductivity of the material yields the transition from microwaves to eddy currents. The corresponding transition of imaging concepts will be discussed.

A Hybrid Numerical and Analytical Procedure for Single Low-frequency Eddy-Current Inverse Scattering

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---Eddy current imaging techniques using single frequency signals have shown only limited success for the reconstruction of crack width and thickness profiles primarily for one-dimensional and axisymmetric geometries. Because of the diffusive nature of the induced low frequency eddy currents which are described by parabolic partial differential equations the imaging process differs from high frequency wave propagation methods which require solutions to hyperbolic differential equations. On the basis that both diffusive and wave phenomena can be described by the same Green's function with either a complex or real wave number, an integral formulation for the low frequency magnetic vector potential in two dimensions is presented. By employing an iterative Born approximation algorithm and the method of moments, a solution for the reconstruction of different conductivity profiles in a metallic full and half-space is developed. To make this formulation amenable to complex geometries, finite element analysis techniques are utilized to compute the integral kernel. The inversion process is tested with synthetic data generated by the numerical solution for a generic surface-breaking defect configuration.

Reconstruction of Internal Density Distributions in Porous Bodies From Laser Ultrasonic Data

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---Density gradients can be induced during the consolidation processing of P/M components. Since ultrasonic velocity depends upon density, the time of flight of an ultrasonic pulse sampled along a ray path depends upon the density. In this report, 2-D density reconstructions from laser ultrasonic data are investigated for a square sample containing a low density (slow) cylinder and a cylindrical sample with three rings of different density. A comparison is made between the reconstructions obtained by a filtered backprojection algorithm and a nonlinear least-square algorithm. Advantages and disadvantages of both approaches are discussed in the context of insitu sensing.

A Neural Network Approach for Solving Inverse Problems in NDE

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---A major aspect of research in Nondestructive Evaluation is related to the solution of the inverse problems, which involves the estimation of the shape, size and location of a defect using information contained in the measured test signal. In general, most inverse problems can be reduced to solving Fredholm integral equations of the first kind. Both direct and indirect methods of solution have been proposed. This paper presents a new and powerful technique for solving integral equations appearing in inverse problems using Hopfield networks. The major advantage of this method lies in the inherent stability of the network structure thereby ensuring global convergence of the algorithm. The parameters of the Hopfield network are chosen using coefficients of the error minimization equation obtained from the integral equation. An implementation of the network using analog circuit elements is given. Simulation results confirming the validity of the approach are presented.

Microstructure Characterization in Composite Media Using Ultrasonic Tomography
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---While tomographic techniques for radiographic image reconstruction are well established, similar development for ultrasonic data lags far behind. This is particularly true for anisotropic media where the directional dependence of material properties presents an additional complication in analyzing the acoustic data. Recently, we have presented a possible approach to treating this problem for composite materials where the anisotropy could be effectively modeled using composite micromechanics equations. This approach allows using composite micromechanics equations. This approach allows iterative tomographic image reconstruction through a suitably modified algebraic reconstruction technique (ART). In this work we present recent advances which we have made in both the experimental and analytical aspects of the problem. Experimentally, we have successfully obtained tomographic images from unidirectionally reinforced composite media with a differential cure state where the stiffness of the matrix (Young's modulus) was the tomographic variable of interest. Analytically, we have extended our analysis to permit multiparameter image reconstruction using data from all three possible modes of propagation, not just the quasilongitudinal mode as in the original problem formulation. Results from these efforts will be presented.

A Layer-Stripping Approach to Impedance Imaging
---MARGARET CHENEY, DAVID ISAACSON, DEPT. OF MATH. SCIENCES, RENSSELAER POLYTECHNIC INSTITUTE, TROY, NY 12180; ERKKI SOMERSALO, DEPT. OF MATH., UNIVERSITY OF HELSINKI, HELSINKI, FINLAND AND ELI L. ISAACSON, DEPT. OF MATH., UNIVERSITY OF WYOMING, LARAMIE, WYOMING 82071

---The impedance imaging problem is to find the internal electrical properties of a body from measurements made on the exterior. Generally such systems apply currents to the body through electrodes attached to the body's surface, measure the corresponding voltages on these same electrodes, and from these data, reconstruct and display an approximation to the internal conductivity of permittivity distribution. This talk will outline a layer-stripping approach to solving the reconstruction problem. The idea here is to first use the boundary measurements to find the conductivity on the boundary, and then use this information to "strip away" a layer of the medium near the boundary. In other words, we use the boundary conductivity to synthesize the measurements that would have been made if the electrodes could have been placed a short distance inside the boundary. The procedure is then repeated, and the medium is stripped away, layer by layer.

Real-Time B-Scan Ultrasonic Imaging Using a Digital Phased Array System

---R. J. DUNKI-JACOBS AND L. J. THOMAS, CRD-GE, RIVER ROAD, SCHENECTADY, NY 12309

---In order to apply phased array technology to ultrasonic imaging and characterization of materials, several obstacles must be overcome. These complications result from two differences between the typical medical imaging problem and NDE: the wide variation in velocity of sound with different materials; and the ability of many solids to support shear waves. In this presentation we will discuss our initial results using 96 channel fully digital beamformer system. This system provides exceptional flexibility in beamforming parameters, allowing dynamic focusing (assuming the velocity of sound is known) in a wide variety of materials. Images of Al blocks will be presented which demonstrate the real-time b-scan capability of this system and the large depth of field possible using dynamic focusing. The theoretical ability to distinguish between longitudinal wave and shear wave echos from a flaw using the information available from the array will also be discussed.

Application of Critical Angle Imaging to the Characterization of Cast Stainless Steels

---B. PERCY HILDEBRAND, MORRIS S. GOOD, AARON A. DIAZ, EDWARD R. GREEN, PACIFIC NORTHWEST LABORATORY, P. O. BOX 999, RICHLAND, WA 99352

---Surface waves excited on a liquid/solid boundary can be used to examine material properties in the near-surface region of the solid. The method involves a focused ultrasonic source producing longitudinal waves at an average angle of incidence equal to the so-called "Rayleigh" critical angle. At this angle, an incident longitudinal wave excites a surface wave on the liquid-solid boundary, extracting a large fraction of the energy from the incident beam. The remaining energy, reflected at an equal but opposite angle is intercepted by a point-like receiver and recorded. Because the surface wave penetrates the solid to approximately one shear wavelength λ_b and the focused spot on the solid has the approximate area λ_b^2 the total insonified volume is $\lambda_b \lambda_L^2$ Because the critical angle is a sensitive function of the Poisson ratio and the shear velocity of the solid, small material property changes in the solid will produce large changes in the phase and amplitude of the received signal.

Ultrasonic Synthetic Aperture Holographic Imaging
---RICHARD Y. CHIAO, THOMAS G. KINCAID*, AND ROBERT S. GILMORE, GE RESEARCH AND DEVELOPMENT CENTER, P. O. BOX 8, SCHENECTADY, NY 12301; *SIGNAMETRICS, INC., 49 FLETCHER AVE., LEXINGTON, MASSACHUSETTS 02173

---Ultrasonic pulse-echo imaging has become an important tool in NDE. The lateral resolution of such images is limited by the aperture size of the transducer, while the depth resolution is limited by the pulse width. In addition, for a given aperture diameter, the lateral resolution degrades with depth as given by the Rayleigh and other criteria. In this paper we discuss a method to increase the effective aperture through aperture synthesis. Waveform data, collected from a transducer scanned near the surface of the sample, is coherently processed to yield a synthesized aperture which can be focussed to any depth. By increasing the contributing scanned area with increasing reconstruction depth, the lateral resolution-cell size can be maintained constant throughout the material thickness tested. The advantage of this imaging method over conventional B-Scan and C-Scan imaging is that a resolution-cell size may be synthesized to inspect material which could not be produced by any known transducer technologies. The synthetic aperture method allows efficient volume inspection by trading off scan time with processing time, the latter of which is constantly improving with increasing computing power. The data collection and processing algorithm used in this work are described in detail. Results obtained with experimental and synthetic data are presented to verify the performance of this imaging method. ---
All work performed at, and funded by, General Electric Research and Development Center.

Imaging Flaws in Thin Metal Plates Using a Magneto-Optic Device
---B. WINCHESKI*, D. R. PRABHU*, M. NAMKUNG, AND E. A. BIRT*, MS 231 NASA LANGLEY RESEARCH CENTER, HAMPTON, VA 23665

---Utilizing the Faraday Effect of rotating the polarization of light as it passes through a magneto-optic crystal, it is possible to directly visualize flaws by mapping the magnetic fields produced by eddy current flows. In this paper, a study using a magneto-optic device based on this principle is presented. Various defects such as corrosion, EDM notches, and fatigue cracks in thin aluminum alloy plates were imaged by varying the frequency of eddy currents and the strength of the bias field. The variation in contrast between flawed and flaw-free regions is shown as a function of the bias field and frequency. Some image enhancement techniques applicable to the process of automating flaw detection are presented, along with processed binary images that clearly demarcate flaw regions. The variation of contrast was also investigated using samples with different levels of corrosion. In addition, contrast variation in images from samples with various depths and lengths of EDM notches were studied.

Tuesday

Tuesday, July 30, 1991

8:30 AM	SESSION VII	NMR for NDE **B. Vander Heiden**, Chairperson Lancaster Lounge/Mouton Union Pages 23-26:
8:30 AM	SESSION VIII	X-RAY INSTRUMENTS and TECHNIQUES **J. Gray**, Chairperson Smith Auditorium Pages 27-31:
8:30 AM	SESSION IX	NDE of COMPOSITES **W. Murri**, Chairperson Kresge Auditorium Pages 32-36:
8:30 AM	SESSION X	UT INTERFACES; UT THIN PLATES and TUBES-II **J. Achenbach**, Chairperson Cleaveland Hall Pages 37-41
1:30 PM	Session XI	POSTERS - UT ANISOTROPIC MATERIALS, COMPOSITES BONDED MATERIALS, RADIOGRAPHY, EDDY CURRENT and OTHER EM TECHNIQUES, and NDE in MANUFACTURING Pages 42-62
3:30 PM	Session XII	APPLICATIONS of NEURAL NETWORKS **L. Udpa**, Chairperson Lancaster Lounge/Moulton Union Pages 63-66
3:30 PM	Session XIII	EDDY CURRENT ARRAYS **J. Moulder**, Chairperson Kresge Auditorium Pages 67-69
3:30 PM	Session XIV	STRESS MEASUREMENTS **R. B. Thompson**, Chairperson Smith Auditorium Pages 70-72
3:10 PM	Session XV	Magnetic Materials **D. Jiles**, Chairperson Cleaveland Hall Pages 73-76

Magnetic Resonance Imaging and Spectroscopy: Advanced Tools for the Nondestructive Characterization of Materials

---JEROME L. ACKERMAN, LEONCIO GARRIDO, JAMES R. MOORE, BETTINA PFLEIDERER AND YAOTANG WU, DEPARTMENT OF RADIOLOGY/NMR CENTER, MASSACHUSETTS GENERAL HOSPITAL AND HARVARD MEDICAL SCHOOL, CHARLESTOWN, MA 02129

---Magnetic resonance imaging (MRI) and *in-situ* magnetic resonance spectroscopy (MRS) hold enormous potential for detailed quantitative nondestructive chemical characterization of materials. Conventional chemical analysis techniques typically either scramble information on the spatial distribution of chemical constituents, or else require destructive sampling of predetermined positions within the specimen. On the other hand, conventional image-producing QNDE techniques--radiography, computed tomography or ultrasound, for instance--are poor in their ability to reflect precise information on chemistry or molecular dynamics. Such information on spatially dependent chemistry is critical for a thorough understanding of the complex chemical and energy transport processes which occur in the production of a "real world" material. A central thrust of our research program is to explore and develop routine methods for multinuclear MRI and MRS analysis of several classes of materials of biological and nonbiological interest. This talk will introduce the principles of these NMR methods, and then discuss several of our own applications encompassing porosity, defects, binders and inorganic phases of ceramics; composite elastomeric materials; and natural bone and synthetic bioceramics.

Nondestructive Evaluation of Energetic Materials via NMR Imaging

---J. H. IWAMIYA AND S. W. SINTON, LOCKHEED PALO ALTO RESEARCH LAB, 3251 HANOVER ST., PALO ALTO, CA 94304-1191

---A few laboratories are exploring applications of NMR imaging to materials sciences. Most of the effort to data has involved the development of techniques capable of overcoming problematic limitations such as low sensitivity or complications arising from differences in material susceptibility. Such limitations lead to unacceptable long data acquisition times, poor spatial resolution and image artifacts. We will briefly review these techniques and present some examples of their application to "real" materials, e.g. solid rocket propellants and shaped charges, and other issues found in the aerospace industry. It is observed that such materials display characteristics, e.g., relaxation behavior, linewidth and susceptibility differences, which can pose problems if not taken into account. These issues as they relate to solid rocket propellants and composites and methods for investigating them will be discussed. The use of NMR imaging to study microstructural features such as the local chemical composition or particle alignment in propellants and their relation to bulk properties will be presented. This research is supported by the Lockheed Independent Research Fund.

Multiple Pulse Line Narrowing: Approaches for Solid State NMR Imaging.

---J. B. MILLER, D. G. CORY*, AND A. N. GARROWAY, CHEMISTRY DIVISION, CODE 6122, NAVAL RESEARCH LABORATORY, WASHINGTON, D.C. 20375-5000; *NRC/NRL POSTDOCTORAL ASSOCIATE; PRESENT ADDRESS: BRUKER INSTRUMENTS, BILLERICA, MA.

---Multiple pulse line narrowing techniques improve resolution and sensitivity in solid state NMR imaging. For example, pulse sequences which remove homonuclear dipolar broadening have been used to image proton-containing materials. Further enhancements in resolution and sensitivity are obtained by removing inhomogeneous interactions such as chemical shift, susceptibility, and heteronuclear dipolar broadening. We have designed pulse sequences providing efficient line narrowing over large spectral widths by taking into account the experimenter's control over the amplitude and time dependence of the gradient-induced resonance offset. We describe methods for imaging solids employing multiple pulse line narrowing. Experimental requirements for implementing these imaging schemes are examined. We illustrate these methods with images of polymer samples.

Solid-State NMR Imaging in Two Dimensions with a Single RF-Gradient Coil.

---MARGAT H. WERNER, JOHN A. MAROHN AND DANIEL P. WEITEKAMP, ARTHUR AMOS NOYES LABORATORY OF CHEMICAL PHYSICS, 127-72, CALIFORNIA INSTITUTE OF TECHNOLOGY, PASADENA, CA 91125; DAVID N. SHYKIND, QUANTUM MAGNETICS, INC., 11578 SORRENTO VALLEY ROAD, SUITE 30, SAN DIEGO, CALIFORNIA 92121.

---Recently we demonstrated that NMR images of solids can be obtained by delivering rf-gradient pulses in the windows of multiple-pulse line-narrowing sequences which average away all of the static contributions to the linewidth, thereby increasing sensitivity and spatial resolution. The key experimental development was a method of active high-power Q-switching which eliminates the coupling of the homogeneous and gradient rf coils. We have implemented a scheme in which the two dimensions of imaging transverse to the static field are encoded by the two orthogonal components of a single rf gradient. Selection of one component or the other is achieved by a $\pi/2$ phase shift of the rf phase relative to that of the homogeneous pulses. This phenomenon may e understood with coherent averaging theory and its range of applicability has been studied with exact numerical simulations on several coupled spins. This arrangement allows the solid-state analogs of versatile imaging sequences based on Fourier zeugmatography and eliminates the need for sample rotation and back projection methods.

Applications of Nuclear Magnetic Resonance Imaging and Spectroscopy to Nondestructive Evaluation.

---ALAN R. RATH, SPECTROSCOPY IMAGING SYSTEMS, 1120 AUBURN STREET, FREMONT, CA 94538.

---Nuclear Magnetic Resonance (NMR) is a well established technique for nondestructive analysis of both animate and inanimate materials. It is a tool which can be used to obtain information about molecular structure and motion, as well as other chemical and physical properties. The advent of Magnetic Resonance Imaging (MRI), an extension of NMR, has provided us with a powerful imaging modality which is unique in its ability to provide spatially resolved information about a wide variety of chemical, physical, and temporal properties. Though biomedical applications have been the major impetus in the development of MRI, it is rapidly proving itself as a technique which must begin to be included in the everyday toolkit of materials investigation. We will present a number of nondestructive evaluation. These include monitoring of polymer curing and solvent invasion; quantitation of water and oil content; detection of physical flaws, cracks and defects; measurement of diffusion coefficient, flow, and porosity; and other applications in the fields of materials, agriculture, and petrophysics.

NMR Imaging of Advanced Composites

---CHARLES G. FRY*, MARTIN J. LIZAK**, AND MARK S. CONRADI**, MCDONNELL DOUGLAS RESEARCH LABORATORIES, ST. LOUIS, MO 63166, AND *WASHINGTON UNIVERSITY, DEPARTMENT OF PHYSICS, ST. LOUIS, MO 63130

---Various approaches for the nondestructive evaluation of composite structures by NMR imaging will be presented. Nuclei that are rigidly bound within organic matrix and ceramic composites can be used to image physical and chemical heterogeneities that occur during processing. Various technical problems, however, have to date kept such studies in a research phase. Use of invasive fluids, on the other hand, brings NMR imaging closer to routine NDE. Relatively good quality images of flaws in monolithic and composite ceramics can be obtained by imbibing the material with flourinated gas. Large features such as delaminations, large voids and cracks, and heterogeneous distributions of matrix and fibers can be seen directly in the NMR images.

Time-Sequenced Optical Nuclear Magnetic Resonance of Gallium Arsenide

---STEVEN K. BURATTO, DAVID N. SHYKIND, QUANTUM MAGNETICS, INC., 11578 SORRENTO VALLEY ROAD, SUITE 30, SAN DIEGO, CA 92121, AND DANIEL P. WEITEKAMP, ARTHUR AMOS NOYES LABORATORY OF CHEMICAL PHYSICS, 127-72, CALIFORNIA INSTITUTE OF TECHNOLOGY, PASADENA, CA 92115

---A new method of optical detection of nuclear magnetic resonance is demonstrated in which optical nuclear polarization, spin resonance, and optical detection are separated into distinct sequential periods and separately optimized by varying the optical, rf and static fields. Experiments on the bulk ^{69}Ga resonance of GaAs in a sample volume of 10^{-7} cm^3 show that sites imperceptibly perturbed by the optically relevant defect are optically observable when the rf is applied in the dark, in contrast to previous methods of optical detection where linewidths at least 20 times broader were observed. Optical Knight shifts and broadening due to polarized photocarriers are also observable by leaving the light on during the NMR. A signal-to-noise analysis is given which relates the sensitivity to readily measured material properties of bulk and quantum-well samples. In combination with double resonance methods, applications to dilute defects appear promising, even at single-crystal interfaces.

Applications of Broadline and Imaging NMR on Solid Rocket Motor Materials

---E. J. VANDERHEIDEN, M. J. SULLIVAN AND L. W. HAAS, HERCULES, INC., MS 2343L, MAGNA, UT 84044-0098

---Various examples of broadline and imaging NMR on solid rocket motor materials will be presented. Imaging was used as a noninvasive method to study solid propellant, resins and insulator materials. NMR imaging scans have revealed such properties as mix inhomogeneity, "soft" propellant features, susceptibility to liquid migration, and the curing of the binder, insulator and resin. High resolution (50-μm) and 3-dimensional NMRI images of propellant (and simulates) and other "rubber" like materials were obtained. Broadline methods were investigated for low cost in-process monitoring of the manufacturing processes. Application such as cure monitoring and moisture uptake look very promising.

Performance Modeling of Scintillator-based X-ray Imaging Systems

---G. A. MOHR, W. T. TUCKER, AND M. K. KUEMAN, GENERAL ELECTRIC CORPORATE RESEARCH AND DEVELOPMENT, P. O. BOX 8, SCHENECTADY, NY 12301

---The development of practical, high-performance x-ray detectors for industrial NDE systems inevitably requires trade-offs among factors such as resolution, sensitivity, and inspection throughput. To develop a basis for making design decisions, we have developed a statistical approach to analyze the performance of scintillator-based x-ray imaging systems. The resulting model has enabled us to quantitatively assess the impact of employing optical systems to transfer the light produced by a scintillator to a remote photodetector array. The analysis also allows us to predict the degradation in system performance indicators, such as signal-to-noise and contrast-to-noise ratios, at each step in the process of converting x-ray transmission properties of an object into a digital image or radiograph. Thus the model provides a framework for evaluation of various engineering options in the design of x-ray detector systems for industrial NDE applications.

Performance Characterization of a Solid State X-Ray Imager for Real-Time Radiography

---C. BUENO, M. D. BARKER, R. BETZ, R. C. BARRY, NDT TECHNOLOGY LABORATORY, RESEARCH AND DEVELOPMENT DIVISION, LOCKHEED MISSILES AND SPACE CO.

---We have developed a new solid state x-ray imaging camera. This camera uses a new fiber-optic scintillator screen for x-ray to light conversion, fiber-optic taper coupling of screen to the electronic imaging device, and a scientific-grade CCD for electronic imaging. The camera is smaller and more robust than pre-existing real-time radiographic cameras. The camera technology is intended for use in field portable aircraft inspection systems. We describe the new camera, report the results of quantitative tests of the performance of the new camera, and show images of interesting test specimens, acquired with the new camera in a laboratory environment. This project is sponsored by the Materials Directorate, Wright Laboratory, Aeronautical Systems Division (AFSC), United States Air Force, Wright Patterson AFB, OH 45433-6533 under contract F33615-89-C-5617.

Point Spread Function Estimation of X-Ray Image Intensifier Tubes

---EDWARD R. DOERING*, JOSEPH N. GRAY**, AND JOHN P. BASART*, CENTER FOR NDE, *DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING, AND **DEPARTMENT OF MECHANICAL ENGINEERING, IOWA STATE UNIVERSITY, AMES, IA 50010

---Real-time images made with X-ray image intensifier tubes have lower resolution than their film counter parts. We are studying the causes of image degradation in these tubes in order to develop a method for improving their resolution, which is principally limited by phosphor bloom in the conversion screens. Image restoration techniques can reduce blurring if the point-spread function (PSF) is known. We have made two types of measurements to estimate the PSF of a 6-inch single-field and a 9-inch tri-field image intensifier. The first method followed the well-known optical technique for estimating the PSF by imaging a step function created by covering half of the input screen with a 8 mm thick lead plate. The PSF width was measured by fitting a Gaussian to the derivative of an intensity slice across the edge. In order to better resolve the shape of the PSF, the plate was translated relative to a single pixel using a precision stepper motor. The second method consisted of imaging a 1 mm slit between two lead plates and measuring the width directly. Circular symmetry of the PSF was confirmed using multiple orientations of the lead plate about the central axis. Additional measurements were carried out to characterize sources of error in the tubes including vignetting, veiling glare, and pincushion distortion, as well as errors in the video camera and coupling optics. This work was sponsored by the Industry/University Center for NDE at Iowa State University.

Monochromatic X-Ray Beams for NDT

---T. JENSEN, CENTER FOR NDE, ASC-II, IOWA STATE UNIVERSITY, AMES, IOWA 50011

---We describe a technique using diffraction from graphite crystals to obtain monochromatic x-ray beams for use in nondestructive testing. Using this method, beams in the energy range from 10 keV to 100 keV, and having an angular divergence of less than a degree can be produced from a conventional bremsstrahlung source. Applications include characterization and calibration of x-ray detectors, transmission studies of composite materials, and energy-specific CT reconstruction. This work was sponsored by NIST under cooperative agreement #70NANB9HO916 and was performed at the Center for NDE, Iowa State University.

Design Requirements of Step Wedge for LSF Measurements in Radiography

---AMOS NOTEA, YOSSI BUSHLIN, URI FELDMAN, QUALITY ASSURANCE AND RELIABILITY, TECHNION, HAIFA 32000, ISREAL

---Extraction of quantitative information from radiographic image involves the solution of the inverse problem using the PSF or LSF. The LSF characteristic function is usually determined from measured response for a step wedge. In this study it will be shown that the step wedge dimensions have crucial effect on the LSF. Besides the step height $\Delta h - h_1 - h_2$ also the absolute values of the heights h_1 and h_2 should be taken into consideration due to the contribution of secondary radiation. The measured LSF shape is explained on the basis of primary-secondary fluxes ratio. Experimental results show the variations in the LSF's generated by step wedges with the same Δh but different h_1 and h_2. Guidelines for the design of step wedges for quantitative radiography are discussed.

Measurement of Internal Residual Strain Gradients in Metal Matrix Composites Using Synchrotron Radiation

---TODD A KUNTZ AND DR. HYDN N. G. WADLEY, DEPARTMENT OF MATERIALS SCIENCE, UNIVERSITY OF VIRGINIA, CHARLOTTESVILLE, VA 22903; DAVID R. BLACK, NATIONAL INSTITUTE OF STANDARDS & TECHNOLOGY, BLDG. 223, ROOM A163, GAITHERSBURG, MD 20899

---Metal matrix composites will see increasing use in future high temperature aerospace applications. Under extensive investigation are titanium-based intermetallics reinforced with ceramic fibers, which show promising strength and stiffness capabilities to 1000° C. Inherent in the processing of these composite materials are residual strain gradients resulting from the different matrix and fiber thermal expansion coefficients. The feasibility of a nondestructive technique for the measurement of internal residual strain gradients has been explored. Energy dispersive diffractometry utilizing high intensity synchrotron radiation was used to measure lattice parameters near continuous fibers embedded in metal matrices. Composite samples of Ti_3Al_Nb or unalloyed Ti metal powders with SCS-6 silicon carbide or Al_2O_3 fibers were consolidated by hot isostatic pressing. Probe volumes on the order of 10^{-3} mm^3 were used, with high spatial resolution in the strain sensitive direction. Strains as small as 0.01% were measured. Radial cracking in the intermetallic matrix was observed to relieve residual strains near the fiber/matrix interface, and the grain size of the matrix was found to limit the accuracy of the measured strain values.

Quantitative Nondestructive Density Determinations of Very Light-Weight Carbon Foams

---W. E. MODDEMAN, D. P. KRAMER, D. W. FIRSICH AND P. D. TRAINER, MOUND,* EG&G MOUND APPLIED TECHNOLOGIES, MIAMISBURG, OH 45343 AND M. E. HUGHES AND R. N. YANCEY, ARACOR**, WRIGHT-PATTERSON AIR FORCE BASE, DAYTON, OH 45433

---The carbon density and its distribution in light-weight foams that are manufactured by a salt-replica process were determined by three methods, bulk property measurements, film radiography and x-ray computed tomography (CT). The first method is a destructive one that involves weight and volume measurements following several machining operations. The later two are nondestructive where foam densities are determined by x-ray attenuation of a carbon matrix. Reasonable agreement was found between all three methods, however, the high spatial resolution of CT was found to yield additional nondestructive quantitative information on a carbon density gradient. The highest and lowest densities in a foam occur at the edges and the interior, respectively. The carbon density at the edge was found to be 15 to 20 percent higher than the average foam density, and in addition, the gradient was found to follow Fick's diffusion law. A diffusion coefficient for a formaldehydephenol polymer migration in acetone at 60°C was calculated. The magnitude of this coefficient was interpreted in terms of foam manufacturing in the salt-replica process. ---*Mound is operated by EG&G Mound Applied Technologies, Inc. for the U.S. Department of Energy under Contract No. DE-AC04-88DP43495. **Supported under Air Force Contract F33615-89-C-5618.

Correlation of X-Ray CT Measurements to Shear Strength in Pultruded Composite Material

---GARY GEORGESON, RICHARD BOSSI, LARRY O'DELL, GEORGE LORSBACH AND JAMES NELSON, BOEING, P. O. BOX 3999, MS 87-60, SEATTLE, WA 98124-2499

---Pultrusion is a cost effective manufacturing method for composite structures, normally having constant cross sections. A number of variables go into the pultrusion process including the resin type, pull rate and cure temperature. X-ray computed tomography (CT) has been used in conjunction with a parametric product development experiment to optimize the material and manufacturing variables for the development of a pultrusion product. The results show that the mean and standard deviation of the nondestructive CT measurements on the pultruded product correlate to the destructive shear strength measurements for a given material and manufacturing condition. This will allow on-line, nondestructive measurement of product strength. --- This work is sponsored by the United States Air Force Contract F33615-88-C-5404 under the "Advanced Development of X-Ray Computed Tomography Applications Program", Wright Laboratories, Materials Directorate at WPAFB and by the Boeing Commercial Airplane Group.

Coherent X-Ray Imaging for Corrosion Evaluation: A Preliminary Assessment

---LARRY LAWSON, CENTER FOR QUALITY ENGINEERING AND FAILURE PREVENTION, NORTHWESTERN UNIVERSITY, ROOM 324, CATALYSIS BUILDING, 2137 N. SHERIDAN ROAD, EVANSTON, IL 60208-3020

---Coherent x-ray imaging is imaging by x-ray diffraction rather than transmission or incoherent (Compton) scattering. In principle, it has much in common with dark field imaging in transmission electron microscopy. Like dark field imaging, only those materials having the selected interplaner spacing are imaged. Imaging may be done both in transmission or in reflection. The particular applicability of this modality to corrosion detection lies in its ability to not see corrosion products. This is potentially useful because both transmission and especially Compton backscatter methods have had difficulties resolving corrosion in aircraft joints when corrosion products are entrapped. Calculations and experimental data for single-voxel coherant imaging are presented and compared for both transmission and reflection methods. These, in turn are compared with similar computations for Compton backscatter imaging. It is shown that, in principle, all points on a line cut through the material in the thickness direction may be imaged simultaneously. Techniques for obtaining quantitative measurement of metal loss are presented along with discussion of the effects of plastic strain on both images and measurements. The practicality of both transmissive and reflective coherant and incoherant techniques are examined in terms of signal-to-noise ratio given available x-ray sources.

Ultrasonic Evaluation of Elastic Properties and Damage of Sic/RBSN Ceramic Composites
---Y. C. CHU, M. HEFETZ, AND S. I. ROKHLIN, THE OHIO STATE UNIVERSITY, DEPARTMENT OF WELDING ENGINEERING, 190 WEST 19TH AVENUE, COLUMBUS, OH 43210 AND G. Y. BAAKLINI, NASA LEWIS RESEARCH CENTER, CLEVELAND, OHIO 44135

---In this paper the elastic properties of SiC/RBSN ceramic composite have been studied by both bulk ultrasonic and plate mode antiresonance methods. The ultrasonically-measured properties are analyzed by comparing with both static measurements and the predictions of microstructural theories. The effect of the pores and their morphology on the elastic properties is addressed. It is shown that impregnation of the pores by the fluid when the ultrasonic immersion technique is used should be taken into account in elastic property measurement. The effect of material damage on elastic properties is considered. Both RBSN ceramic material and SiC/RBSN composite have been studied. It is shown that ultrasonic measurements correlate with static properties measured independently, thus showing the importance of the ultrasonic method for nondestructive evaluation of ceramic composites.

A Comparison of Conventional and Advanced Ultrasonic Inspection Techniques in the Characterization of TMC Materials
---MARK R. HOLLAND, SCOTT M. HANDLEY, JAMES G. MILLER, WASHINGTON UNIVERSITY, ST. LOUIS, MO, AND MARK K. REIGHARD, MCDONNELL AIRCRAFT COMPANY, ST. LOUIS, MO

---Successful development and implementation of titanium matrix composite (TMC) materials for structural applications may require the use of advanced NDE methods to ensure structural integrity. In this paper, we present the results of a comparison between conventional ultrasonic inspection techniques and advanced ultrasonic NDE methods in the characterization of an 8-ply, quasi-isotropic ($0/\pm 45/90_S$), flat, TMC specimen. A conventional ultrasonic c-scan attenuation inspection of the TMC panel was compared with more advanced ultrasonic methods including polar backscatter, integrated backscatter, band-limited mean signal loss, and the frequency dependence of signal loss (slope of attenuation). All measurements were performed in an immersion tank using nominal 10 MHz center frequency, broadband transducers. The frequency domain analyses of the ultrasonic rf data were performed over the range of 4 to 12 MHz for polar backscatter measurements and 4 to 11 MHz for through-transmission signal loss measurements. Results of polar backscatter measurements at a polar angle of 20° show an inherent anisotropy of approximately 3 to 6 dB for the TMC panel. The consequences of this inherent anisotropy on the ultrasonic detection and localization of possible material defects are illustrated. Quantitative images of the ultrasonic signal loss and its frequency dependence are illustrated and compared with the conventional attenuation images.

Surface Wave Techniques to Characterize CMC Materials

---MANOHAR BASHYAM, GE AIRCRAFT ENGINES, M.D. Q45, OH 45215 AND JOSEPH L. ROSE, DREXEL UNIVERSITY, PA 19104

---Various traditional surface acoustic wave techniques and a novel line-focus-beam acoustic lens system are explored to measure the anisotropic characteristics of the Ceramic Matrix Composite (CMC) materials. A low frequency acoustic microscopy technique for imaging small variations in the near surface characteristics of CMC specimens is developed by measuring the local perturbation of the Rayleigh surface wave velocities. Material characterization is carried out by measuring the propagation characteristics and attenuation of the surface acoustic and leaky waves at the water sample boundary. Measurements on a variety of anisotropic CMC materials were made, where the fiber volume fraction extends from 30% - 50%. We have shown by experimental verification that the surface wave velocity changes as a function of angle with respect to the axis along the fibers of an unidirectional CMC material and also with varying fiber content. It is shown in this paper that surface waves along with bulk and sub-surface waves can provide additional insight for both practical material characterization and defect analysis in the nondestructive evaluation of composite materials. --- Work sponsored by US Air Force, under contract F33615-88-C-5433.

Ultrasonic Characterization of an Interface in a SiC Fiber Metal Matrix Composite

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---Metal Matrix Composites (M.M.C.), especially those reinforced by long fibers, are good candidate structural materials for space applications. Due to the fundamental role of the interface reinforcement-matrix in the M.M.C. behavior, nondestructive methods are required to characterize this interface. In this paper we present a method which is based on using a high frequency pulse echo technique. The experimental set up includes a C-scan system, a high frequency focused transducer (nominal frequency 50 MHz), a pulser-receiver and a digital scope which enables us to process the echoes in a computer. In the present investigation, a single fiber sample made by squeeze casting has been selected to show the potentialities of the technique: the SiC fiber is 120 μm in diameter and the matrix is of 6061 Aluminium. The heterogeneous character of the interface is clearly revealed by acoustic images obtained by focusing the beam on the interface, scanning it parallel to the fiber axis and recording the echo amplitude. The strongest acoustic amplitude heterogeneities are often associated to signal inversions: S.E.M. observations have shown that circumferential microcracks in the vicinity of the interface are responsible for this acoustic behavior. Moreover, the acoustic profile of the interface shows marked evolutions as well after thermal treatment (T6) as after plastic deformation (1%). The mechanisms linked with incompatibility and heterogeneity of deformation which could be responsible for these evolutions are briefly presented.

Ultrasonic Evaluation of Silicon-Carbide Reinforced Aluminum Metal-Matrix Composite Billet Materials

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---Ultrasonic velocities were determined on silicon-carbide particulate (SiC_p) reinforced 6013 aluminum metal-matrix composite billet materials. The composite billet was fabricated by the powder metallurgy technique. Ultrasonic velocity was found to vary with the volume percentage of SiC_p and porosity. The volume percentage of SiC_p covered a wide range, from approximately 30 to 60%, while that of porosity from 5 to 15%. Theoretical modeling was conducted to quantify the effects of SiC_p and porosity on ultrasonic velocity. The predicted ultrasonic velocities were found to be in good agreement with the experimental results.

Fatigue Crack Growth Characterization in 2024 Al and 2014 Al/20% SiC Composite Using Ultrasonic Observations

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---This paper illustrates current efforts to characterize differences in fatigue crack growth and the underlying causes for these differences in 2024 Al and a 2014 Al/20% volume SiC particulate metal matrix composite material. The growth of the fatigue cracks was interrupted by tensile overload application at similar crack lengths in each material. Ultrasonic measurements were taken at various times during the retardation period and subsequent growth and are compared with crack length measurements from mechanical means. The usefulness of the ultrasonic measurements both in monitoring crack growth and assisting in determining the underlying causes for variations between the two materials is discussed. --- Ames Laboratory is operated by Iowa State University for the U.S. Department of Energy under contract W-7405-ENG-82.

Real-Time Ultrasonic Investigation of Damage Development in Ceramic-Matrix Composite Under Longitudinal Loading

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---Damage mechanisms and development were investigated in a longitudinally loaded unidirectional ceramic matrix composite. The material was calcium aluminosilicate glass ceramic (CAS) reinforced with continuous silicon carbide fiber (SiC) with a fiber volume ratio of 0.39. Specimens were loaded in the fiber direction continuously to failure while recording load, strain, and transmitted ultrasonic waveforms. The waveforms were analyzed to obtain attenuation and wavespeed as a function of applied stress and correlated with the stress-strain behavior and independently observed damage mechanisms in the material. Both attenuation and wavespeed proved to be sensitive indicators of matrix cracking and fiber-matrix debonding.

Thermographic Characterization of Impact Damage in Carbon-Carbon Composites

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---The extent of impact damage in carbon-carbon composites is determined from the time evolution of thermographic images. A single side inspection technique is used which has potential field application. Measurements were performed on uncoated carbon-carbon composites specimens which had been subjected to low-energy level impacts. The damage was extremely difficult to defect by visual inspection. The thermographic technique was able to detect the effects of damage at the lowest energy impacts performed. An area of damage is estimated by thresholding the thermographic images. The estimated area is found to increase with impact energy, however, is less than estimates based on ultrasonic c-scans and microscopic inspection of sectioned specimens. Modeling suggest this is particularly the case for carbon-carbon composites where the in-plane diffusivity is much larger than the out of plane diffusivity.

Measurement and Processing Effects on Residual Thermomechanical Stresses in Composites
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---Residual thermomechanical stress in both a SiC reinforced ceramic composite and a glass reinforced polymer matrix composite have been directly measured. The thermomechanical stresses developed in these composites were primarily a result of thermal expansion coefficient differentials between composite constituents. Such stresses which are present in virtually all composite materials have a direct bearing on mechanical properties. Since the mechanical properties of composites are heavily influenced by the fiber/matrix interface, the residual stresses were measured near the fiber bundle/matrix interface as well as throughout the matrix. The generation of thermal stresses in composite materials can be attributed to both processing and thermal cycling while in service. The residual stresses measured in this study were made using microscopic photoelastic techniques and a CCD imaging camera. The effects of thermal expansion coefficient mismatch and processing conditions on residual stresses will be addressed.

Acoustic Emission Monitoring of a Fatigue Crack
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---Acoustic emissions from fatigue crack growth in titanium aluminide XD composite material were monitored. Digitized acoustic signals as well as event characteristics were stored. The event trends and signals have been analyzed in order to discriminate between acoustic events associated with the cracking process and those produced by benign sources. The occurrence of acoustic events is a good indicator of crack advance. The applied load and the time in the fatigue cycle at which events occur serve as means of verifying crack signals. Signal processing has also been applied to classify event categories and to distinguish cracking from noncracking events. The results provide a basis for an adaptive neural network training set.

Analysis of Guided Waves in an Asymmetric Sandwich Plate

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---Dispersion of guided waves in an Aramid-epoxy/Aluminum plate with the two outer aluminum plates having same and different thicknesses has been studied in this paper. The object of this investigation is to analyze the effect of asymmetry due to differing thicknesses of the Al plates on the changes in the dispersive wave behavior. It is shown that 10 or 20 percent differences can cause noticeable shifts in the dispersion curves as well as existence of new modes. These changes can be used to characterize the geometry and the material properties. Some experimental results will also be presented and compared with the theoretical predictions.

Ultrasonic Wave Propagation Through an Interface With a Step Discontinuity

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---The condition of liquid-solid interface through which an ultrasonic wave passes is an important factor in the ultrasonic examination of materials. In nuclear reactor components, factors such as weld overlay, claddings, grinding and diametrical shrink can give part surfaces a wavy, corrugated or abruptly stepped topography. These irregular surfaces can severely distort or redirect the ultrasonic beam, leading to false indications of size and location of defects. This paper reports progress on a study intended to model the distortion of ultrasonic beams passing through such interfaces. A hybrid model is utilized. Away from interface, propagation phenomena, within the Fresnel approximation, are included by employing the Gauss-Hermite beam model. In the immediate vicinity of the interface, ray tracing techniques are used to account for the aberrations induced on the beam in that vicinity. The case consider in this paper is that of a step discontinuity. The theoretical results obtained from the hybrid model are compared to experimental results both in the frequency and time domain. ---This work was sponsored by the Electric Power Research Institute under contract RP-2687-01 and was performed at the Ames Laboratory. Ames Laboratory is operated for the U.S. Department of Energy by Iowa State University under Contract No. W-7405-ENG-82.

Iterative Boundary Integral Solution for Curved Interface Ultrasonic Transmission
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---This paper addresses the problem of three-dimensional ultrasonic transmission through a non-planar fluid-solid interface in the short wavelength regime, where the characteristic scale is, say, the local radius of curvature of the interface geometry. For many cases of practical interest, this problem is adequately solved using simple ray theory. However, in cases involving the generation of surface waves, such as in acoustic surface wave microscopy of curved components, simple ray theory must be augmented by the geometrical theory of diffraction, resulting in an increasingly *ad hoc* solution procedure. A second method of solution is a numerical inversion of the governing boundary integral equation (BIE). However, the straightforward application of standard numerical BIE techniques can easily yield matrices far too large to manipulate on current computers. For example, a 0.5 in. dia. 10 mHz ultrasonic beam implies a ka of 531, where a is the beam diameter. A method of solution is presented which seeds the BIE with the simple ray theory solution, then performs an appropriate iteration to satisfy the governing BIE. It was observed that a pure Neumann series solution will diverge. However, numerical experimentation yielded a stable solution procedure which combines local explicit inversion with global iteration. Application of this procedure to transmission through arbitrarily curved three-dimensional component interfaces will be demonstrated. --- This work was sponsored by NIST under cooperative agreement #7ONANB9HO916 and was performed at the Center for NDE, Iowa State University.

Generalized Boundary Conditions for Imperfect Interface Between Two Solid Anisotropic Media
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---The boundary conditions for imperfect contact between two anisotropic solids are given. They are obtained as an asymptotic representation of the three dimensional solution for a thin orthotropic layer of off-axis orientation between two solids. The boundary conditions are represented by a 6 x 6 matrix which relates the six dimensional vectors formed from stresses and displacements on each side of the interface. Such boundary conditions couple the in-plane and out-of-plane stresses and displacements on the interface even for isotropic bodies. Interface imperfections are modeled by an interfacial multiphase orthotropic layer with effective elastic properties. This determines the coefficients in the boundary condition. The results are illustrated by numerical examples of reflection and transmission of ultrasonic waves from imperfect interfaces between anisotropic solids. The case of interface waves is also considered and illustrated by numerical examples.

The Interfacial Mass Detection with Lamb-Wave Sensors

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---The influence of liquid layers on the propagation of Lamb waves in a plate of finite thickness. The principle of mass detection is studied theoretically. The dispersion equations of Lamb waves in a plate bordered with layers of liquids are derived. For the lowest antisymmetrical mode of very thin plates, the numerical results calculated from the dispersion equations are compared with those derived from the bending wave acoustic impedance approach. The limitation of the latter is discussed. This work is supported by BFGoodrich Simmonds Precision Aircraft System.

Material Characterization of Composite Laminates Using Low Frequency Plate Wave Dispersion Data

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---The phase velocity of flexural waves in graphite/epoxy laminates is measured through two experimental methods in the frequency range of 10-160 kHz. The measured dispersion curves are shown to compare favorably with theoretically calculated curves based on exact and certain approximate models of the laminates. It is shown that the dispersion curves are strongly dependent on some of the stiffness constants as well as the thickness of the laminate that these constants can be accurately determined through systematic inversion of the dispersion data.

Lamb Wave Mode Selection Guidelines for Defect Detection Optimization in Thin Plates

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---More and more attention has been given to defect detection using ultrasonic guided waves. In our investigation, plate waves are used to detect defects preset in a thin plate specimen. Such an effort is of fundamental value in developing efficient NDT methods for large thin structure such as the skin on an aircraft. Proper mode selection is a key step towards successful detection of defects. Different wave modes are sensitive to different regions across the thickness of the plate. Analysis and experimental exercise are carried out to illustrate this point. Owing to the fact that the waves are usually generated with a finite source it is important to select a good frequency-angle combination so that undesired modes will be minimized. Despite the complexity of the wave phenomenon itself, our preliminary results are very encouraging. In our experiment, we were able to detect cracks running 2% through the thickness of the plate. In order for such a technique to be applicable to a real world structure like aircraft skin, more effort must be paid to consider the influence of the multilayered nature of the structure, existence of rivets, anisotropy of the materials, etc. Should this technique be implemented in practical inspection, time efficiency will be greatly improved over the existing techniques.

Analysis of Transient Lamb Waves in Metal Plates, Composite Panels, and Curved Members Via Laser and Fiber Optic Methods

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---The research described involves the integration of a laser based system for generating and detecting transient Lamb waves in a variety of materials and geometries. The work is different from other research in that the system is fiber optic based for both detecting and generating transient Lamb waves. A two channel, fiber optic interferometer is used for detecting the transient Lamb waves. Therefore, the system is non-invasive and allows the same wave to be detected at two separate locations on a variety of materials and fabrication geometries without destroying or modifying the wave's characteristics. Using analysis developed by the authors and also techniques developed by numerous other authors, phase velocity and attenuation information for the transient Lamb waves is found. A detailed study of the experimental system and the various analysis techniques is used as a basis to evaluate the uncertainties in the calculated phase velocity and attenuation curves. Also, where applicable, the results are compared with known closed form solutions. When such solutions are not available, Finite Element Methods are used to model the experimental set-up to predict the nature of the propagating Lamb wave and to identify the best signature to use for characterizing behavior of defects.

Determination of the Flexural Modulus of Thin Films from Laser-Ultrasonic Measurement of Symmetric Lamb Waves

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---A technique is presented to measure the flexural modulus of free-standing metallic films from 0.001-0.025 mm thick and < 2.5 cm diameter. Lamb waves are excited in the film with a pulsed Nd:YAG laser, and detected using heterodyne interferometry. Excitation of the waves generally occurs in the near ablative regime, and for films on the order of one micron thick, in the thermoelastic regime. Variability in waveform structure is observed as a function of film thickness and other experimental parameters, and an explanation for the variability is offered. The first arrival of the lowest order symmetric Lamb mode can be unambiguously identified over the range of observed waveform shapes, and is used to calculate the flexural modulus.

Connection Machine Simulation of Ultrasonic Wave Propagation: Two Dimensional Case

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---In a previous report we have presented a new computer simulation technique for the study of ultrasonic wave propagation in materials for the one-dimensional case. The technique is based on the use of the Connection Machine, which is a massively parallel computer. In the parallel computer, thousands of independent processor work concurrently on the solution of the same problem, leading to tremendous savings in computer time. Since each material cell is assigned to a different processor, arbitrarily complex media can be considered by simply inputting the physical properties of each "cell" as initial data. Although interesting application of our simulation techniques are possible in the one-dimensional case, more important are the two (and three) dimensional problems. In the present paper we extend this technique to two dimensions; more specifically, we consider two-dimensional strains in a three dimensional media.

On-Axis Formulas for Ultrasonic Transducer Beams in Anisotropic Media

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---The on-axis ultrasonic field pattern of a piston transducer has been investigated for the case of propagation in an anisotropic medium. The solution is formulated from an angular spectrum of plane waves approach and employs the Fresnel approximation. This approximation treats the slowness surface of the anisotropic material as quadratic about the direction of propagation and is generally valid for paraxial rays. The result is limited to propagation in a plane of material symmetry. A simple formalism is obtained which can be used as a diffraction correction for ultrasonic measurements in anisotropic materials.

Validity of the Gauss-Hermite Beam Model in an Anisotropic, Layered Medium-Comparison to the Finite Element Method

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---In certain cast stainless steels found in nuclear reactors, highly aligned grain structures can cause significant elastic anisotropy and variations of wave speed with direction. In some components there may be more than one such layer with different anisotropies and grain morphologies. Furthermore, when these components are integrated into structures by welding, additional inhomogeneities are introduced. The Gauss-Hermite model is a candidate for the study of ultrasonic wave propagation through these anisotropic, layered materials, with one of its primary advantages being the simplicity with which it treats propagation through interfaces. This approximate model has been previously validated experimentally for homogeneous, isotropic and anisotropic materials. This paper reports the investigation of the performance of the Gauss-Hermite model in predicting the beam propagation in anisotropic layered medium. To this end, we have chosen a model problem and compared the prediction of the Gauss-Hermite model and the Finite-Element method. In particular, we consider the propagation of an ultrasonic beam through an isotropic steel into a transversely isotropic steel whose preferred axis is inclined at various angles to the interface normal. Detailed comparisons are made of time domain waveforms as a function of distance from the beam axis. In addition to examining the accuracy of the Gauss-Hermite beam model, other advantages and disadvantages of both techniques are discussed. ---This work was sponsored by the Electric Power Research Institute under contract RP-2687-01 and was performed at the Ames Laboratory. Ames Laboratory is operated for the U.S. Department of Energy by Iowa State University under Contract No. W-7405-ENG-82.

Sensitivity Analysis for Elastic Property Reconstruction in Anisotropic Media

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---Recently, there has been a great deal of interest in the quantitative analysis of composite structures using modulus reconstruction from ultrasonic velocity measurements. A variety of approaches have been suggested for this purpose based on either bulk wave or guided wave (both surface and plate waves) propagation data. One of the principal questions remaining to be resolved with these techniques is sensitivity. Of particular concern in this regard is the high degree of uncertainty encountered in recovering the elastic properties in the plane of the fiber reinforcement, especially the Poisson-type terms. In this work, we investigate the effects of experimental uncertainty on the reconstructed elastic moduli in a systematic fashion. The effect of making several ultrasonic velocity measurements in excess of the minimum number required for modulus reconstruction and solving an overdetermined system of coupled, nonlinear equations is explored. This approach is implicit in some of the current approaches used where a best fit to a slowness surface section is sought using techniques such as least squares minimization. A significant improvement in the accuracy of reconstructed moduli for overdetermined systems is expected. However, the time required for the additional measurements needs to be kept to a minimum. Therefore, we seek to find an optimal solution to the problem which takes both accuracy and time concerns into account.

Three Dimensional Representational Surfaces for Anisotropic Media

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---One of the best ways to visualize directional variations in material properties is via the use of representational surfaces. With this graphical approach, the parameter of interest in a material (e.g. modulus, velocity attenuation, etc.) in a given direction is represented as a vector in that direction whose magnitude corresponds to the parameter's value. The locus of the end point of such vectors forms a three dimensional surface in space. The most commonly used representational surface for composite materials is the slowness surface where the directional dependence of the slowness (1/velocity) is presented. This surface is particularly useful for treating reflection and refraction problems at anisotropic media interfaces. While such surfaces are implicitly three dimensional in nature, one usually sees them presented as two dimensional sections. However, with the advent of computer software with extensive three dimensional plotting capabilities, this limitation can be overcome. Of particular interest in this regard are the newly emerging symbolic manipulation routines (Maple, Macsyma, Mathematica, etc.) with three dimensional plotting readily available. In this work, the uses of such capabilities are demonstrated representational surfaces for materials with a variety of symmetry properties.

Correlation Study of Nondestructive Predictions of Formability Parameters with Destructive Measurements for Aluminum and Steel Sheet

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---Last year we completed development of a prototype instrument which predicts formability parameters of steel and aluminum sheet from measurement of ultrasonic plate mode velocities. Included were preliminary results from blind tests performed at various industrial sites. The results of more recent, detailed studies, are reported in this paper. Comparisons of tensile measurements of r-bar and delta-r with ultrasonic measurements for steel sheet from a variety of sources will be presented. Also presented will be results of beverage can earing during deep-drawing from ultrasonically determined orientation distribution coefficients. ---
This work was supported by the Industry/University Center for Nondestructive Evaluation and the Center for Advanced Technology Development at Iowa State University.

Ultrasonic NDT of Fiberglass Sandwich Marine Composites

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---This paper reports experimental results of contact mode ultrasonic testing of fiberglass sandwich composite structures. Two measurement configurations were used: pulse-echo and acousto-ultrasonics: both methods affort single-side access. Typical marine structures are fabricated in the form of sandwich construction using fiberglass/polyester skin and foam or balsa wood core. The types of flaws included voids, impact damage, delamination and through-crack. Since the ultrasonic mode, chosen for the ease of practical application, was the contact mode, the following issues were addressed in this study: (1.) Reproducibility of contact mode UT measurements, (2.) Spatial variation of UT response due to material property inhomogeneity, (3.) Effects of the segmented core and its spacing, (4.) Detectability of the various flaws. Quantitative results were obtained and included in this paper. In order to evaluate flaws behind the foam core, measurements were made using a high voltage pulser and transducers with frequencies of 0.5 MHz or lower. This paper also discusses the detectability of flaws behind the foam core and presents testing results. This work was supported the Industry/University Center for NDE at Iowa State University.

Ultrasonic Reflection and Transmission Study of Aramid/Aluminum Composites

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---Ultrasonic reflection and transmission amplitudes have been measured in a laminated plate of Aramid/Aluminum composite as a function of frequency, incident angle and in-plane direction. Ultrasound from conventional piston radiators is introduced into the plate by fluid coupling. The samples are in the form of alternating bonded layers of aluminum/lithium alloy and aramid fibrous composite, each approximately 280 μm in thickness. The specimens we have studied consist of several lamina, an odd number of aluminum and even number of aramid. Experimental measurements have been compared to a theoretical model which accounts for the anisotropy of the aramid and the layering of the composite. We demonstrate that the layering of two acoustically different media changes substantially the reflectance and transmittance of the plate from those observed with either material alone or a linear combination of the two stiffnesses and densities which yields the same average plate properties. Implications for guided mode generation are also discussed.

Lamb Wave Propagation in Multi-Layered Composite Plates

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---The propagation of Lamb waves in graphite/epoxy composite laminated plates is studied both analytically and experimentally. A numerical technique is presented to solve for the wave number as a function of frequency in multi-layered orthotropic plates. The technique uses a stiffness method which allows continuity of displacements and tractions at the interfaces. Calculating the Lagrangian for the entire plate results in a standard eigenvalue problem which yields the wave numbers at a specified frequency. Theoretical wave-number dispersion curves are compared to experimental measurements of phase velocity over the frequency range 150 kHz - 2 MHz in 8 and 16 ply $(0/90)_S$ graphite/epoxy laminated plates. The experimental method employs variable-angle-wedge contact transducers operated in a pitch-catch mode. The phase velocity is evaluated from the phase spectrum of the transmitted burst. Agreement and discrepancies between theoretical and experimental results are discussed.

Acoustic Emission Investigation of Fiber Fractures in Composite Materials

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---The primary failure mechanisms in fiber composites are matrix cracking, fiber-matrix debonding, and fiber fracture. These mechanisms produce acoustic emission (AE) outputs of various amplitudes and spectra. Thus, fiber fracture produces a higher acoustic emission activity than fiber debonding, which in turn produces more measurable activity than matrix cracking. Prior investigations with acoustic emission output from fiber fractures relied on visual observations of specimens with single embedded fibers to correlate the occurrence of fiber fracture and acoustic signals. A different method is proposed here for precise correlation of a given fiber fracture and its corresponding AE signature. Polymeric specimens are prepared with three to ten embedded parallel graphite fibers which are connected in parallel to an electric circuit. Thus, fiber breaks are precisely detected by measuring the electrical resistance of this specimen. The specimens are loaded in tension to failure while monitoring the electrical resistance and AE output. Thus, a good correlation is obtained between the occurrence of fiber fractures and their AE signatures. A modified method is proposed for the detection of multiple fractures within the same fiber by using transverse crossing fibers and a multiplexing technique.

Quantitative Characterization of Thick Composite Laminates Using Oblique Insonification

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---It has been shown that the LLW reflection from thick composite plates are due to the interference of bulk waves excited in the plates because of relatively small diameters of transducers. The traveling times of the mode-converted bulk waves are shown to be sensitive to material properties of composites in some incident angles and fiber orientations by parameter study. It results in that measured time-of-flight of individual pulses are able to quantitatively characterize thick composite laminates. The results obtained by a systematic inversion scheme are in excellent agreement with experimentally measured data.

NDE of Fracture-Induced Anisotropy
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---A material is anisotropic when it has an aligned fabric with characteristic dimensions substantially smaller than the wavelengths that measures it. This fabric can result from layered composites or stress resultant oriented fractures. A layered composite whose individual elements are isotropic will appear transverse isotropy in the long wavelength limit. The elastic properties of transversely isotropic media do not vary with azimuth. Azimuthal variation is, however, frequently observed in materials that were thought to be transversely isotropic. This aximuthal anisotropy is often interpreted to result from stress induced aligned fractures. Realistic models must therefore include all the significant constituent anisotropies of the fracture systems and of the background composite in which these fracture systems are embedded. Considering the many possible combinations of constituents, a variety of anisotropies can result. This paper presents an analytic separation technique applicable to general fracture systems. Once the global elastic moduli have been estimated, this technique can be applied to separate the contributions of the fractures from those of the background. This method reveals several relationships among the measured elastic constants which contrain the complexity of the constituents' symmetry. --- One of the authors (JAH) is an NRL-National Research Council fellow.

Ultrasonic Characterization of Woven Composites
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---Woven materials possess localized variations in interface thicknesses. These variations result according to the weave profiles, tenures, and relative offset of the joined plies. Thus, woven materials possess interface zones, rather than planar interfaces. Furthermore, woven materials have a tendency to contain defects not only in their interface zones, but within the plies themselves. An ultrasonic technique known as Software Gating has been developed in our laboratory which provides the capability to discriminate between damage locations. An assessment of the effectiveness of this technique on woven materials has been performed by evaluating specimens with simulated defects implanted at various depths within the material. These implanted defects were intended to simulate porosity, delaminatins, and hairline cracks. Results of this study demonstrate the technique can be adapted to conform to the type of material being evaluated.

Application of SAFT on Composites
---M. S. HUGHES, S. R. GHORAYEB, D. K. HOLGER, L. W. ZACHARY, R. B. THOMPSON, AND D. K. HSU, CENTER FOR NDE, IOWA STATE UNIVERSITY, AMES, IA 50011

---We will present results of a comparison of reconstructed images using synthetic aperture focussing technique applied to isotropic plastic and anisotropic composite samples. Our goal is a quantitative investigation of the image artifacts introduced into the SAFT reconstruction by material anisotropy. We will compare reconstructed images of flat-bottom holes, side-drilled holes and flat-bottom slots in both plexiglas and unidirectional and [0,90] graphite/epoxy specimens. --- This work is supported by the Office of Naval Research.

A Comparative Study of Experimental and Simulated Ultrasonic Pulse-Echo Signals from Multilayered Structures
---M. N. ABEDIN*, D. R. PRABHU*, W. P. WINFREE, AND P. H. JOHNSTON, MS 231, NASA LANGLEY RESEARCH CENTER, HAMPTON, VA 23665, *Analytical Services and Materials, inc., 107 Research Drive, Hampton, VA 23666

---Ultrasonic contact pulse-echo technique is used to detect disbonds as well as thicknesses of various layers in multilayered structures, such as lap joints of aircraft. Experimental signals are acquired from a fabricated three-layered (Aluminum-Epoxy Aluminum) lap joint. The observed ultrasonic signals contain clearly distinguishable echoes from successive layers of the sample. A one-dimensional model of sound propagation in multilayered structures is used to compute the ultrasonic response. There is good agreement between the measured and the simulated signals from both bonded and disbonded locations. The effects of a single layer of paint on the lap joint are also studied. Preliminary results show that the presence of paint makes it difficult to identify individual echoes with interfaces beyond the epoxy layer. The effect of variations in the thicknesses of paint and epoxy is also investigated.

Effects of Thin Layer Adherents on Ultrasonic Testing Results

---E. C. JOHNSON AND G. F. HAWKINS, THE AEROSPACE CORPORATION, M. S. M2/248, P. O. BOX 92957, LOS ANGELES, CA 90009

--- A number of examples are cited where curious ultrasonic testing results appear to be related to the presence of a thin adherent layer (such as paint or an adhesive layer) on one of the surfaces of the component under test. Analysis if presented which suggests that in many instances, significant ultrasonic signal variations can be expected, even when the wavelength of the ultrasound is much longer than the thickness of the layer itself. Experiments were performed to test the validity of the model used for this analysis. The results of this study are applicable to inspection techniques which rely upon ultrasonic echo reflections from painted surfaces or boundaries involving thin adhesive layers. In addition, the effect of liquid films on the performance of ultrasonic liquid level sensors is discussed.

Ultrasonic NDE of Adhesively Bonded Aluminum Lap Joints

---THADD C. PATTON AND DAVID K. HSU, CENTER FOR AVIATION SYSTEMS RELIABILITY, IOWA STATE UNIVERSITY, AMES, IA 50011

---Adhesively bonded and riveted aluminum skin panels were evaluated with ultrasonic methods for disbonds. The detection sensitivity of through transmission ultrasonics (TTU), higher order pulse-echo, and Rayleigh waves were investigated. Rayleigh wave measurements were made in the contact mode on the outer skin of the panel. The frequency was chosen to give a high bond/disbond discrimination for a given skin thickness. Results obtained with different methods will be compared.
--- This work was supported by the Federal Aviation Administration.

Physically Based Feature Mapping Concepts in Bond Interface Evaluation

---D. JIAO, J. ROSE, AND N. HODIWALLA, DREXEL UNIVERSITY, MECHANICAL ENGINEERING AND MECHANICS DEPARTMENT, PHILADELPHIA, PA 19104

---Excellent progress has recently been made on a variety of adhesive bonding interface evaluation techniques. Emphasis has been focused on physical models of wave propagation across or along the interfae in treating bulk, lamb, or interface wave analysis. Now that some reasonable guidelines have been established for obtaining the required sensitivities in interface evaluation work, it is time to recall techniques in signal processing and pattern recognition to draw conclusions on implementation potential. Feature mapping techniques are explored in this paper to produce a number of physically based images of the interface state drawing upon a number of different time and frequency domain features extracted from experimentally obtained reflection factor and guided wave test data. Theoretical guidelines are summarized for the generation of optimal data collection and analysis test procedures. Key contributions focus on the image variations as a function of frequency. A variety of interesting experimental results are presented that demonstrates the signal processing utility in interface evaluation work.

Experimental Study of Interface Properties Between Layer and Substrate

---RAY T. KO, PETER B. NAGY AND LASZLO ADLER, DEPARTMENT OF WELDING ENGINEERING, THE OHIO STATE UNIVERSITY, COLUMBUS, OH 43210

---The modified Rayleigh wave has been used to study interface properties between layer and substrate. Although there have been some experimental studies of the dispersive behavior of the Rayleigh wave o a layered substrate, most of them have been confined to two extremes: ideal bond and complete misbond. In order to study experimentally the full range of the bonding qualities in a controlled way, we have developed a meshed intervening layer approach. This intervening layer is used to control the bonding conditions between layer and substrate. The dimensions of the individual mesh of the intervening layer were much smaller than the ultrasonic wavelength used. The experimental dispersion curves of the modified Rayleigh wave for both the meshed and extreme cases were obtained. The significant difference in the phase velocities in the experimental results indicated that a quantitative assessment of the interface properties between layer and substrate is feasible. --- This work is supported by the Office of Naval Research under Contract N00014-88-K0452.

An Ultrasonic Testing Technique for Measurement of the Poisson's Ratio of Thin Adhesive Layers

---E. C. JOHNSON, J. D. POLLCHIK AND J. N. SCHURR, THE AEROSPACE CORPORATION, MAILSTOP M2/248, P. O. BOX 92957, LOS ANGELES, CA 90009

---An ultrasonic technique is presented which permits accurate measurement of the Poisson's ratio for a specimen which exists as a thin (<10 mil) layer. This technique should prove especially useful in situations where a bulk specimen is either not readily available or would not properly reflect the properties of the material when configured as a thin layer. The paper includes a detailed discussion of the theory underlying the technique. As a test, three materials which could be easily formed into both a thin specimen and a thick specimen were selected. The technique was then used to determine the Poisson's ratio of the material comprising each thin specimen. These values were then contrasted to those of the bulk specimens obtained in a more conventional manner. The technique as presented, could be extended for a number of applications including the cure monitoring of adhesives.

Quantitative Nondestructive Evaluation of Adhesive Lap Joints in Sheet Molding Compound by Adaptation of a Commercial Bond Tester.

---EMMANUEL P. PAPADAKIS, CENTER FOR NDE, IOWA STATE UNIVERSITY, AMES, IOWA 50011; GILBERT B. CHAPMAN, II, MATERIALS ENGINEERING, CHRYSLER CORPORATION, MADISON HEIGHTS, MICHIGAN 48071.

---A method has been devised to obtain quantitative NDE measurements from a commercial adhesive bond tester designed for GO/NO-GO qualitative sorting. The method requires the connection of one electric meter across two points in the alarm circuit of the instrument. Further, the method requires the choice of proper referencing specimens as standards by a statistical method. The principle is that the reference specimens must be only marginally better than the barely acceptable adhesive bond. With the reference specimens and the new output, the instrument can be used to make measurements which correlate with adhesive bond strength even in the presence of bonds which fail partly by substrate delamination. With the reference specimens and the built-in alarm mode of the instrument, measurements can be made to define a probability of detection (POD) for disbonds versus disbond size. With this POD in hand, one can define a Specification for an adhesive lap joint in terms of an acceptable percentage of bonded area. This Specification is in use. The bond test instrument is in use on adhesive bonds in SMC and continues to be cost-effective according to the Deming Inspection Criterion. Use of the bond tester has permitted one automotive manufacturer to continue and expand its utilization of adhesively bonded SMC body panels. This work was supported by the Industry/University Center for NDE at Iowa State University and Chrysler Corporation.

Computer Simulation of Steel Cord Radiograph Profiles

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---Radiographic profile analysis has been investigated for the detection of corrosion in the steel cord elements of a steel/rubber composite. Although well defined by the cord specification, the twisted cord structure does not yield a "standard" profile against which those of inspected cords might be compared. While several general classes of shapes are seen, the profile details are considerably varied. In fact, the possible superpositions of the twisted strand and wire elements of the cord are infinite. In order to better understand the information content of cord profiles and to determine if features are present which can be used to detect corrosion, the authors have implemented a simulation. Computer graphics methods were used to generate profiles of cords in both random and sequential orientations. Corrosion was also modeled as wire thinning or pitting. Several schemes were considered for extraction of feature vectors from the profile data. Plans are also presented for the implementation of an artificial neural network to classify radiograph profiles.

Unfocused Source of X-rays in a Microfocus X-Ray Tube

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---The detection of differences in material density within a flat sample using X-ray images can be compromised if the source produces anomalous shadows. It has been shown that these shadows are caused by a source of X-rays outside the focal spot of the tube and can be eliminated by internal baffles. It was noted that this effect was only seen on film and not in a real time mode using an image intensifier. In this work a simple pinhole camera shows the shape of the distributed source of X-rays to be a uniform disk surrounded by a brighter ring. The image could be seen both with film and in a real time mode. While the spectral response of the image intensifier is shown to be more sensitive to the higher energy X-rays, the shape of the images on film and real time are found to be similar. The resolution of the pinhole camera is not sufficient to compare the brightness of the focused source to the distributed source, but the effect of the larger area of the distributed source can be measured. Calibrated X-ray film shows the energy in the distributed source to be about 1% of the focal spot energy and this is sufficient to account for the shadow anomaly.

Hybrid Lossless-lossy Compression of Industrial Radiographs

---AJAI NARAYAN AND TENSKAI V. RAMABADRAN, CENTER FOR NDE, DEPARTMENT OF ELECTRICAL ENGINEERING AND COMPUTER ENGINEERING, IOWA STATE UNIVERSITY, AMES, IOWA 50011

---Data compression methods are useful in reducing the storage and/or transmission bandwidth requirements of NDE images. Such methods can be lossless or lossy. Lossless methods allow exact reconstruction of the original images but have relatively low compression ratios. Lossy methods have high compression ratios but result in some amount of distortion. In this paper we consider a hybrid approach in which a lossless method is used to compress critical regions of the images and a lossy method in used to compress non critical regions. Such an approach has the advantage of high compression ratios with no loss of critical information. The paper discusses the application of a lossless method based on Walsh-Hademard transform for critical regions of the images and two different lossy methods for the non critical regions, fiz., Discrete Cosine Transform with Adaptive Quantization (DCT-AQ) and Differential Pulse Code Modulation with Vector Quantization (DPCM-VQ). Performance results obtained for typical industrial radiographs are also presented.
This work was supported by Martin Marietta Corporation under Contract No. A71445.

Radiographic Image Enhancement by Wiener Decorrelation

---Z. W. BELL, COMPUTING AND TELECOMMUNICATIONS DIVISION, AND B. W. GODFREY, DEVELOPMENT DIVISION, OAK RIDGE Y-12 PLANT, MANAGED FOR THE U.S. DEPARTMENT OF ENERGY BY MARTIN MARIETTA ENERGY SYSTEMS, INC. UNDER CONTRACT DE-AC05-840R21400, BUILDING 9103 MS 8141, P. O. BOX 2009, OAK RIDGE, TN 37831-8141

---A simple model for the radiographic imaging of thin objects is introduced and developed. It is shown that this model implies that the detected image is related to a correlation (rather than convolution) integral involving the transmission of the object under inspection, and the emittance of the x-ray source. The model is inverted via Wiener filtering to obtain an estimate of the true transmission function and some examples are shown.

Quantitative Determination of Material Compositions of Composites Using Energy Sensitive X-Ray Measurements

---J. TING, T. JENSEN, J. N. GRAY, CENTER FOR NDE, IOWA STATE UNIVERSITY, AMES, IA 50010

---We present an energy sensitive x-ray method capable of rapid, high resolution measurements of material properties for a wide range of materials. The method begins with a measurement of the attenuation coefficient of the component materials using a Bremsstruhlung source or, if appropriate, isotrope sources. The energy sensitivity is achieved with a germanium detector coupled to a multichannel analyzer and rather than by manipulating the energy of the initial X-ray beam as is done in dual energy methods. By measuring the attenuation of the initial beam at a number of selected energies, we have sufficient information to calculate the constituent materials of the part, this includes determining porosity from material composition variations. Experimental results will be presented for the determination of material properties of systems such as carbon plastic composites, metal matrix and ceramic composites. --- This work was supported by the Center for NDE at Iowa State University.

Application of an X-ray Process Model for Inspection Optimization

J. GRAY, T. JENSEN, AND R. WALLINGFORD, CENTER FOR NONDESTRUCTIVE EVALUATION, IOWA STATE UNIVERSITY, AMES, IA 50011

---We demonstrate the use of a computer model of the image formation process for an x-ray radiograph in optimizing the inspection parameters that affect flaw detection. Parameters that strongly affect the detectability include the geometry of the set up, the exposure parameters, the film used, whether image processing is used, and the flaw morphology. The choice of these parameters has a strong impact on the cost of the inspection and the resulting probability of detection (POD). The simulation code is a quantitative tool for assessing trade-offs in sensitivity and cost. We will present examples of the effect of cost constraints on the capabilities of specific inspections and the resulting optimized inspection parameters. The simulation code is compatible with a computer aided design (CAD) environment and as such has a role in incorporating NDE in the design process. Further, as with any simulation, a role as a training and qualification tool is apparent. Comparison of the modeled images with experimental data will also be presented. --- This work was sponsored by NIST under cooperative agreement #70NANB9H0916 and was performed at the Center for NDE, Iowa State University.

Rotating, Orthogonal Coil, Differential Eddy Current Probe

---M. FREDERICK DERSCH, DTRC, CODE 2815, ANNAPOLIS, MD 21403

---Commercial probes are available which employ differential excitation of orthogonal axes coils. Both axes are parallel to the specimen surface and conventional phase display instrumentation amplifies differences "seen" by the coils. Relatively large indications result from linear discontinuities (e.g. cracks) aligned with one coil axis. Little or no indication results when both coils "see" an identical change (e.g. lift-off or cracks at 45°). Additionally, in order to obtain an indication the probe must be moved which hampers identification of exact location. An apparatus for rotating a probe of this design has been fabricated and used to obtain signals from linear discontinuities. Rotating the probe provides additional features not present with a non-rotating probe. Indication amplitude is maximum when one coil axis is aligned with the discontinuity and this condition is met four times during each revolution. Bi-phasic indications are produced (e.g. positive signal when coil 1 is aligned and negative signal when coil 2 is aligned) compared with the positive or negative (but not both) indication produced by a non-rotating probe. These bi-phasic indications are continuous, without lateral translation, as a result of probe rotation and location of discontinuities can be easily identified.

Cross-Correlation of Eddy Current Images for Detection of Fatigue Crack Propagation

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---There is a need within the NDE industry to evaluate the growth of damage such as fatigue cracking and corrosion over the life of a structure. To accomplish this aim, data collected over a period of time must be compared spatially while quantitative measures must be developed to determine the extent of crack propagation in a damaged region. To facilitate automated inspection and characterization of defects in metals, the application of cross-correlation techniques and frequency mixing to sequential eddy current images of fatigued welds and fatigue cracks in compact tension specimens has been investigated. Results indicate that frequency mixing can enhance the signal-to-noise ratios of fatigue cracks in welded steel, while cross-correlation techniques can be used to align scan images to provide a history of damage development. Detection of localized damage was accomplished by segmenting the images into smaller cross-correlation regions for improved resolution. The technique may be used to examine magnetic eddy current data from ferrous welds and seams and to identify cracks or regions of cold working in transportation and energy-generation systems.

A Feedthrough Eddy-Current Transducer with Rotating Magnetic Field

---P. LEMBEYE, P. SALEMI, IRSID, 78105 ST. GERMAIN EN LAYE, FRANCE

---Feedthrough differential eddy current transducers are widely used for on-line inspections of hot long products such as wire, rods, and pipes, but their lack of sensitivity to longitudinal flaws remains an important disadvantage. Therefore, we have designed a feedthrough eddy current transducer with rotating magnetic field, whose main property is to be sensitive to any kind of flaws, including long ones, situated on cylindrical metallurgical objects. The mechanical simplicity of this transducer enables the insertion of a cooling circuit, and, as a consequence, the testing of hot products. This device differs from similar ones by the direction of the rotating magnetic field, which is here axial. The excitation windings have been designed with analytical and 3-D numerical models and realized using a multicoated circuit technology. They are powered by a purpose-built electronic device, which is connected to a standard eddy current instrument. Experimental results obtained with this kind of transducer will be presented.

Eddy Current Inspection of Weld Defects in Tubing

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---This paper describes the application of finite element analysis to the modeling of weld defects in small bore tubing. A weld model is proposed which includes conductivity variations for the weld material and the heat affected zone around the weld. Impedance plane signals are predicted for various weld configurations, materials and weld defect types, and compared whenever possible with signals from actual welded tubing.

Benchmark Problems in Eddy-Current NDE
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---We present five benchmark problems for the computation ΔZ in eddy-current NDE: 1) Rectangular slot in a thick plate (900 Hz), 2) Rectangular slot in a thick plate (7 kHz), 3) Cracks in a thin plate, 4) Cracks in a double plate system, 5) Cracks in a thin plate: tangent coil. The problems are of great value in validating eddy-current codes, and for that reason have an important role to play in the development of quantitative eddy-current NDE. A complete description of the problems, including experimental data, is available through the Applied Computational Electromagnetics Society (ACES).

Skin Depth Considerations in Eddy Current NDT
---P. STUCKY AND W. LORD, ELECTRICAL ENGINEERING DEPARTMENT, IOWA STATE UNIVERSITY, AMES, IA 50011

---The theoretical definition of skin depth $\delta = (\pi f \mu \sigma)^{-1/2}$m is most commonly derived from considerations of either a plane electromagnetic wave or an infinite alternating current sheet interacting with a conducting half-space. While such analyses may be pedagogically correct, they hold little relevance for practical eddy current NDT measurements which make use of neither plane waves nor infinite current sheets. This paper gives results of finite element simulations which compare the electromagnetic field distributions in conducting slabs and tubes relative to theoretical ideal.

Computer Simulations of Induced Surface Electromagnetics Fields Around Circular-Arc Cracks in Ferromagnetic Metals

---S. H. H. SADEGHI AND D. MIRSHEKAR-SYAHKAL, DEPARTMENT OF ELECTRONIC SYSTEMS ENGINEERING, UNIVERSITY OF ESSEX, COLCHESTER CO4 3SQ, UK

---In an earlier paper, a mathematical analysis together with its experimental verifications for the interaction of a circular-arc crack in ferrous metals with a surface field was reported. In that analysis it was assumed that the surface field is induced by two U-shaped wires carrying a high frequency ac current. This paper extends the analysis to cases where the inducer is a horizontal coil of rectangular cross-section. Modifications to the analysis technique, replacing the U-shape inducer with a horizontal rectangular coil of arbitrary orientation is presented. The limitations of the technique based on the assumptions made are reviewed. Computer simulations of the surface magnetic field distributions around arc-circular cracks for various combinations of inducers and cracks are reported. These embrace inducers with lengths larger and smaller than the crack length and with orientations parallel and inclined to the crack lip (edge). The effects of the crack depth and small variations in the inducer lift-off on the magnetic field distributions are examined. The criteria for achieving a local uniform field using a rectangular coil are investigated. Some practical applications of the results are addressed. This work was supported in part by the Science and Engineering Research Council of the U.K.

Significant Improvement of Remote Field Eddy Current Probe Performance with Modified Probe Structures

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---Some structure modifications of RFEC probe design significantly improving the probe performances, including shortening effectively longitudinal length of probes, significantly reducing excitation power and greatly enhancing the detector signal level, are introduced in this paper. Computer simulation of the new structure characteristics and finite element predictions of some critical design parameters are also provided. Experimental measurement results from a few primitive prototypes given in this paper verify the ideas of the new designs.

OSEE Responses on D6AC Steel Due to Sample Preparation

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---Optically stimulated electric emission (OSEE) measurements using parallel electric field (PEF) techniques are sensitive to surface conditions and the containment thickness variations. A contaminant instrument has been developed to contaminant sample surfaces with a certain thickness of HD-2 grease. The purpose of this study is to relate the PEF readings to contamination levels on solid rocket motor (SRM) castings. SRM samples were contaminated with a known amount of a common contaminant, and the OSEE response was measured with the PEF instrument. Varying levels of contamination were tested. The sample preparation and the experimental results will be presented.

Contact Free Outer and Inner Diameters Measurement of Cylindrical Conductive Tubes using Long Inner Coils

---B. DE LIMBURG STIRUM, J. DRIRA, TH. CARDINAEL, V. DUJARDIN, AND B. DE HALLEUX, CATHOLIC UNIVERSITY OF LOUVAIN, MECHANICAL ENGINEERING DEPARTMENT, LOUVAIN-LA-NEUVE, BELGIUM

---Eddy currents are mostly used for defects detection and characterization. For some particular geometric parts, there is an analytical solution to Maxwell's equations and therefore the eddy current distribution can be exactly calculated. For these special cases, the eddy current technique can be used to measure some of the characteristics of the part i.e. electrical parameters and geometrical dimensions. See for example the paper "Cross Section Measurement of Long Cylindrical Products Using Long Cylindrical Coils" Review of Progress in Quantitative NDE Vol. 10B, pp 2201-2208. Tubes belong to this category. Working at low frequencies with a long encircling coil on non-ferromagnetic tubes enables us to measure the wall thickness. The accuracy obtained for tubes with an outer diameter of about 40 mm and wall thicknesses between 1 and 5 mm is about 0,05 mm. Working at high frequencies with a long inner coil enables us to measure the inner diameter of non-ferromagnetic tubes, while working at low frequencies enables us to measure the outer diameter. The accuracy obtained for the inner diameter measurement is about 0,3% on diameters from 10 to 20 mm and the accuracy on the outer diameter is in most cases better than 1% on external diameters from 11 to 22 mm except in some currently unexplained cases, where the accuracy is between 5 and 10%.

A Physical Model Underlying the Maxwell Equations, Application to Electromagnetic Problems
---B. DE HALLEUX, CATHOLIC UNIVERSITY OF LOUVAIN, MECHANICAL ENGINEERING DEPARTMENT, LOUVAIN-LA-NEUVE, BELGIUM

---This study presents a possible physical model in which the charged particle's dynamics ensues from Coulomb's law and the delay in the remote action of the forces as well as the propagation of the electrical charge perturbations. Based on these physical hypotheses, we will show that it is possible to deduct the four Maxwell Equations. We will conclude by a discussion on the interest of this physical approach in treating electromagnetic problems occuring in "Quantitative Nondestructive Evaluation".

Simulation of Nondestructive Testing of Materials in Microwave Cavities
---J. S. WANG AND N. IDA, THE UNIVERSITY OF AKRON, DEPARTMENT OF EE, AKRON, OH 44325

---The numerical model reported in [1] was shown to be quite promising for characterization of materials in a microwave cavity. But the model required a relatively large mesh size if cavity walls and material interfaces are curved, since the model used quasi-linear tetrahedral elements. In this work, the model is improved by using curvilinear hexahedral elements, allowing accurate prediction of lower modes with a relatively small mesh size. The new model is used for simulation of more realistic testing situations. These situations include incorporating cavity wall losses, characterizing anisotropic materials (such as composites), rotating irregularly shaped specimens (such as corn kernels) in a cavity, and comparing solutions with available test results by cavity perturbation. --- This work was supported in part by NSF Grant #EET8714628 and in part by The Ohio Board of Regents Academic Challenge Program. Computational Resources on the Ohio Supercomputer Center CRAY Y-MP are gratefully acknowledged.

Production Parameters that Affect Practical Application of NDE Procedures.
---WARD D. RUMMEL, MARTIN MARIETTA ASTRONAUTICS, 8776 W. MOUNTAINVIEW LANE, LITTLETON, CO 80125.

---The capability and reliability of an NDE procedure may be demonstrated by repetitive measurements on a series of flaws of varying sizes to provide a statistically significant sample of procedure performance. The conditions of both data collection and procedure application may cause wide variation in results. It is therefore necessary to understand and to account for production application conditions and variations in order to relate theoretical and laboratory measurement results to the performance that might be realized under production conditions. This paper discusses some of the factors and conditions that affect NDE performance capabilities and reliability under production conditions. Discussion includes: (1) calibration methods; (2) effects of etching; (3) effects of surface roughness; (4) effects of proof loading; (5) effects of geometry; effects of part thickness; (6) effects of operator training; (7) effects of operator experience; (7) effects of NDE process control; and (8) use of EDM notches as representative cracks.

Mathematical Methods to Set Up and Justify Industrial NDE Tests
---EMMANUEL P. PAPADAKIS, CENTER FOR NDE, IOWA STATE UNIVERSITY, 1915 SCHOLL ROAD, BLDG. II, AMES, IA 50011.

---Correlations can be used to develop NDE tests for physical properties where the NDE indication yields a correlation coefficient R_{ij} with respect to the property measure. Tests of all NDE types can be analyzed by Internal Rate of Return (IRR) to justify the investment in testing facilities. The concepts of functions and correlations are explained in terms of their use in developing nondestructive tests for material properties. Particular attention is paid to the concept that the output of a manufacturing process is not just a part but also a set of measurable intrinsic variables relating the part to the process. The model used is that the process applies a physical determinant to the material which results in a desired physical property and at least two other measurable properties which are related to the desired physical property. The model further postulates that one of the alternate measurables has been accepted over time as a measure of the desired property but that the second alternate measurable has been discovered as more modern and potentially faster and better. The question of supplanting the old specification with the new measurement is addressed. The question of the continued need to do 100% NDE inspection in the context of very high process capability is addressed by the method of Internal Rate of Return (IRR). In the case of genuine data on defects in jet engine discs used us a paradigm, the inspection method is ultrasonic pulse-echo in immersion. The IRR method is applied to the cash flow data concerning the inspection. This financial analysis method indicates that 100% inspection is advantageous. The most striking calculation resulted in an IRR of 105% for the investment in NDE equipment despite the process capability level of nearly five sigma (5 σ). Specifically, the proportion defective over several years and production of over 25,000 parts averaged 0.00135, while the 5σ level is around 0.001 and the 4σ level is about 0.010. Thus, NDE can make a profit for a firm even in the regime of very high manufacturing process capability. This work was sponsored by the Industry/University Center for NDE and by NIST under cooperative agreement #70NANB9HO916 and was performed at the Center for NDE, Iowa State University.

Fifty Years of Improved Safety and Reliability Through NDT American Society for Nondestructive Testing

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---1991 marks the 50th anniversary of the American Society for Nondestructive Testing (ASNT). From its humble beginnings in 1941, as the American Industrial Radium & X-ray Society, today's organization is constituted by over 10,000 members of 91 sections in both the United States of America and several foreign countries. NDT technology is now embedded and essential to modern industry in the life-cycle management of most products. This paper reviews and shares a celebration of the development and growth of both NDT technology and ASNT. Origins, key developments, critical applications and distinguished contributors to the founding, development and growth of the technology are reviewed. Invitation is extended to the world NDT community to join in a recognition and celebration of contributions of NDT pioneers, peer contributors and in the promises of a bright and rewarding NDT future.

IDA: An Architecture for an Intelligent Design Assistant for Assessing the Inspectability of Structures From a Description of Their Geometry

---STEPHEN M. NUGEN, CENTER FOR NONDESTRUCTIVE EVALUATION; LESTER W. SCHMERR, JR., CENTER FOR NONDESTRUCTIVE EVALUATION AND AEROSPACE ENGINEERING AND ENGINEERING MECHANICS; BABAK FOROURAGHI, CENTER FOR NONDESTRUCTIVE EVALUATION AND COMPUTER SCIENCE DEPARTMENT, IOWA STATE UNIVERSITY, AMES, IA 50010

---The program in integrated design, NDE, and the manufacturing sciences at the Center for Nondestructive Evaluation is developing a system that assesses the inspectability and reliability of mechanical structures from a description of their geometry. Part of this effort involves using techniques of artificial intelligence (AI) to integrate the various components together. An Intelligent Design Assistant (IDA) will couple a design team to the inspectability models and will provide expert advice on how to improve the probability of detecting flaws in the manufactured part. An important feature of IDA is that rather than being limited to a single AI technique, it has an architecture that allows us to take advantage of advances in rule-based expert systems, neural networks, Taguchi-type analysis and case-based reasoning. We do this by deploying a family of distributed AI modules, each of which uses a single technique to criticize a given design from a narrow perspective. For example, one module uses a Taguchi-type analysis to make recommendations about how to improve the eddy current inspectability of a structure while another module uses a neural network to test assertions about how to improve ultrasonic inspectability of the same design and so forth. These modules live as opportunistic, autonomous agents on a network of UNIX workstations running in parallel whenever possible.
--- This work was supported by the Center for NDE at Iowa State University.

Graphite Epoxy Defect Classification of Ultrasonic Signatures Using Statistical and Neural Network Methods

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---The performance of classical statistical techniques and a neural network learning algorithm was compared for the classification of defects in graphite epoxy composite laminates. A 3/8-in. thick plate, 60 layers at $(0/90)_{30}$, containing simulated voids, inclusions, and delaminations was fabricated with the defects located at various depths. Ultrasonic signatures were collected using a 5 MHz transducer at a 30 MHz sampling rate from 10 unique locations for each defect type. Three features were selected from the power spectrum of each waveform for input to the four classifiers. Specifically, the four classification techniques were: a linear discriminate rule, a Guassian classifier, a K-means nearest neighbor classifier, and a three layer, feed forward, back propagation neural network using the modified delta learning rule. A set of 56 randomly selected signals, eight from each of seven defect types, was used to train the classifiers. A test set consisting of 14 signals, unique from the training set, was used to evaluate the performance of each classifier. Results and comparisons of the four classification techniques are presented.

New Training Algorithms for Neural Networks
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---Neural networks are finding increasing use as trainable signal classifiers in a variety of applications including NDE for interpreting ultrasonic and eddy current signals. Traditional training algorithms such as the backward error propagation algorithm are based on minimization of an error function using gradient techniques. Such techniques, however, are highly susceptible to convergence to a local minima. This paper presents the application of a new method involving the use of the homotopy continuation method for obtaining globally minimum error during the training phase. Results comparing the performance of the proposed method with that of the more conventional backward error propagation method will be presented.

Time Delay Neural Networks for the Classification of Ultrasonic NDT Signals
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---Neural networks are playing an increasingly important role in the classification of ultrasonic NDT signals. A major advantage associated with neural networks lies in the fact that the method does not require any apriori statistical information. One of the challenges encountered in ultrasonic signal classification lies in rendering the classification immune to temporal shifts in the signal. This is necessary since we are interested in establishing the nature of the defect irrespective of its location in the test specimen. Consequently, it becomes necessary to preprocess the signal to extract features which are independent of temporal shifts. Additional translation invariance can be achieved using Time Delay Neural Networks (TDNN). The TDNN employs a network of time delays within the structure to identify features and their temporal relationships. Details of the network as well as the training procedure will be provided and results showing the classification performance of the network will be presented.

Neural Network for Crack-Depth Determination from Ultrasonic Backscattering Data

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---A neural network approach is developed to determine the depth of surface breaking cracks from ultrasonic backscattering data for a steel plate. The network is trained by the use of a feed-forward three-layered network together with a back-propagation algorithms for error corrections. Both experimental and synthetic data are employed for network training. The signal used for crack insonification is a mode converted 45 degree transverse wave. The plate with a surface breaking crack is immersed in water and the crack is insonified from the opposite side of the plate. A numerical analysis based on elastic wave theory is carried out by the use of the boundary element method, and the numerical data are calibrated by comparison with the experimental data. The numerical analysis provides synthetic data for the training of the network. These data are calculated for cracks with specified increments of the depth. The performance of the network has been tested on experimental data which are different from the training data. A network system with two stages of detection, namely, a rough classification stage and a more precise evaluation stage, is also discussed.

Acoustic Emission Applications on the NASA Space Station

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---Acoustic emission is being investigated as a way to continuously monitor the space station *Freedom* for damage caused by space debris and seal failure. Acoustic emission experiments run to date focused on detecting and locating simulated and real impacts and leakage. These experiments were performed both in the laboratory on a section of material similar to a proposed space station shell panel design, and also on the full-scale common module prototype at Boeing's Huntsville facility. A neural network analysis approach supplemented standard acoustic emission detection and analysis techniques. These experiments demonstrated that acoustic emission monitoring could provide the means to successfully locate and assess damage to the space station shell.

The Application of Phase Quadrature Information to the Automated Detection and Classification of Defects in the Presence of Deterministic Noise of Similar Characteristics

---DONALD L. BIRX AND STEPHEN J. PIPENBERG, SYSTEMS RESEARCH LABORATORIES, DAYTON, OHIO 45440

---Recently we presented preliminary results from the initial application of neural networks to eddy current defect detection and classification in IN00 and Titanium. More specifically, we developed a network that performs a complex mapping, allowing classification on phase as well as amplitude and frequency characteristics. This network utilizes phase quadrature information by essentially embedding the impedance plane representation in a network structure. This paper focuses on the implementation of the network in an automated inspection environment (RFC/NDE) for detection and classification of defects boundaries, machining grooves, and geometric discontinuities. The essential issues of network operation, reliability, and applicability of results when confronted with variations in probe characteristics and different types of inspections are discussed as well as the issue of network design and training for different inspection requirements. It is the authors' belief that the topics initiated in our last session have been brought to a useful conclusion in this paper.

Detection of Deep Flaw Inside a Conductor Using a SQUID Magnetometer

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---SQUID magnetometers are sensitive devices to measure weak magnetic fields and allow mapping of the distribution of DC or low frequency AC magnetic fields. For NDE applications, SQUIDs can be used to detect the DC magnetic signal produced by a non-surface-breaking flaw in a conductor. We have detected a 3/8" diameter flaw located 1/4" below the surface of a brass bar which is 6" long, 3.5" wide and 1" thick. By injecting a 80 mA DC current through the brass bar and mapping the DC field distribution at 3 mm above the top surface, a 12 nT peak to peak perturbation field due to the flaw was produced. We also measured the field map by injecting AC current at several frequencies between 10 Hz and 320 Hz. At a frequency of 320 Hz, the disturbing field produced by the flaw disappeared. The experimental results will be presented, and the frequency dependence of the disturbing field due to the deep flaw will be discussed. --- Supported by the Air Force Office of Scientific Research.

A Nondestructive Crack/Imperfection Detection System on a Silicon Chip

---H. T. HENDERSON, K. P. KARTALIA, AND J. D. DURY, CENTER FOR MICROELECTRONIC SENSORS AND MICROSTRUCTURES, UNIVERSITY OF CINCINNATI, CINCINNATI, OH 45221

---Conventional eddy current probes are beset with two major problems: (1) no detailed information can be obtained about cracks or crack arrays that are smaller than the physical size of the probe and (2) for applications such as quality assurance, a vast amount of time must be taken must be taken to scan a complete surface, even if robotic methods are used for a physical scan of the surface. Eddy current arrays offer a possible way to circumvent these problems. Laboratory efforts have been made to fabricate linear arrays of single turn probes in a thick film format on a ceramic substrate (hybrid technology) as well as in a flexible cable format, however such efforts inherently suffer from relatively large size requirements as well as sensitivity issues. This paper describes PRELIMINARY efforts to extend eddy current probing from a point or single dimensional level, fully to a two-dimensional micro-eddy current format on a silicon chip which might overcome all of the above problems. Moreover, using a serial readout of rows and columns one might be able to achieve eddy current imaging. Thus the scanning (within the area of the chip) would be electronic rather than physical, resulting in an essentially instantaneous scan when compared to the physical scan method. Moreover, although the demonstration vehicle herein described is only a 10 x 10 array on a silicon chip of the order of 0.25 to 0.5 in^2, the ultimate chip could consist of an array covering a complete wafer of pizza size (4-8 inches in diameter). Also, insufficiently thin silicon materials, the surface can conform to non-planar topographies. If successful, the pixel size (based upon integrated eddy current coil size) might approach 0.001 in. or smaller, although in our test coil the spacing is on the order of 0.005-0.015 in. This opens the possibility of resolution within the typical width of a crack, thus allowing identification of much smaller cracks, early onset of material fatigue from microcracks, classification of cracks and even imaging.

A Linear Eddy-Current Array Driven by a Whip Excitation

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---In eddy-current inspection, it is often desirable to use an array of sensors, as opposed to a single sensor. An array can alleviate problems such as scanning time and sensor positioning. We describe a "whip" excitation source (an approximation of a single linear wire carrying current) that is used to excite a workpiece for an eight-sensor array of air-core, inductive, pancake coils. The array has been exercised on various samples in the laboratory, and results are presented. Some difficulties exist when using an array; for example, it often becomes necessary to adjust the data for phase, gain, noise, and drift differences in the sensors, as well as nonuniformity in the exciting field. We describe the characteristics of the whip excitation in terms of frequency response and field uniformity, and we present our methods for dealing with the sensor variations mentioned above. Applications are numerous; for example using the eight-sensor array in our laboratory setup increased our effective scanning speed by approximately a factor of eight.

Eddy Current Arrays for Defect Detection

---D. C. HURLEY, K. H. HEDENGREN, AND J. D. YOUNG, GE CORPORATE RESEARCH & DEVELOPMENT, P. O. BOX 8, SCHENECTADY, NY 12301

---We have developed a new type of eddy current array for high-resolution detection of small defects in industrial alloys. In this presentation, we will describe general characteristics of the array and its accompanying acquisition system. Experimental images of both EDM notches and man-made fatigue cracks obtained with a single array element will be presented. The images will be used to discuss such array parameters as flaw signature, signal-to-noise ratio, and sensitivity to defects. Scans created by a single sweep of the entire array will be shown to address collective performance issues such as element-to-element uniformity.

Surface Coverage Issues when Using Eddy Current Arrays

---K. H. HEDENGREN, AND P. J. HOWARD, GE CORPORATE RESEARCH & DEVELOPMENT, P.O. BOX 8, SCHENECTADY, NY 12301

---The array approach to eddy current sensing shows promise for enhancing the productivity of inspections for small defects in industrial alloys. Traditionally, a single probe is used to scan a surface with small incremental steps in two dimensions, creating an image of the surface. This is a time consuming process. Image resolution is determined by the spatial step size which, typically, is much smaller than the diameter of the probe and the resulting image is greatly oversampled. When using an array probe, however, data is inherently acquired in one dimension while scanning takes place in the second dimension. Thus, if the array covers the inspection area without loss of detection capability, data acquisition time is greatly reduced. However, as only one sample is acquired for each array element, the spatial width of the array element, rather than a spatial scanning step, determines horizontal resolution. In this presentation, we will address some new issues associated with array scanning. In particular, experimental images will be used to discuss complete surface coverage, necessary for detection of defects in arbitrary locations.

Eddy Current Arrays and Data Imaging

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---In many eddy current inspection situations, the results can be improved if an image is generated. The image is a two-dimensional map of data that is taken over the surface of the part that is inspected. When properly used, the array/imaging approach can provide (1.) improved flaw detection sensitivity, (2.) tolerance to variations in geometry and material, and (3.) rapid data review. In order to fully take advantage of this approach without unduly lengthening the inspection time, it will be necessary to use probes that consist of arrays of eddy current coils. In this paper, we report on results of taking such two-dimensional data, and using it to generate images for the purposes described above in several cases, including fastener hole flaws in the second layer of aircraft structure.

Ultrasonic Measurement of Stress in Rolled Sheets
---WEI-YANG LU & CHI-SING MAN, UNIVERSITY OF KENTUCKY, LEXINGTON, KY 40506

---A rolled metal sheet exhibits a preferred orientation, or texture. The properties of the sheet are dependent on the orientation. In this paper, the rolled thin sheet with stress is modelled s a homogeneous weakly anisotropic prestressed planar membrane. The application in stress evaluation of horizontally polarized quasishear waves (which correspond to the SH_0 mode in a plate theory) is studied. In principle, the theory would be valid irrespective of the origin of the prestress and the thermomechanical history of the specimen. A series of experiments was performed to examine the validity of this theory for thin aluminum sheets that had undergone plastic deformations. By using a probe that consisted of three electromagnetic acoustic transducers, velocities of horizontally polarized quasishear waves were measured for various directions of propagation at various places of each sample sheet. Although the plastic deformations of the sheets were found to be nonhomogeneous, there were indications that the present theory and measurement system delivered at each place a good estimate of the local principal surface-stress directions and difference in principal surface stresses. Work is in progress to compare the ultrasonic results with other stress measurement techniques and to extended the theory to nonhomogeneous stress cases. Preliminary results of this further work will also be reported.

An EMAT System for Railroad Wheel Residual Stress Inspection
---R. E. SCHRAMM, A. V. CLARK, JR., D. MITRAKOVIC* AND S. R. SCHAPS, NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY MATERIALS RELIABILITY DIVISION 325 BROADWAY, BOULDER, CO 80303, *NIST GUEST RESEARCHER: ON LEAVE FROM UNIVERSITY OF BELGRADE

---EMATs are ideal for ultrasonic nondestructive evaluation in field operations where couplants are undesirable and specimen preparation must be minimal. Railroad wheels experience stress and tread wear which may develop surface cracks and lead to tensile residual stresses in the outer rim that are sufficient to cause failure. Currently, inspection for residual stress is largely visual and not totally reliable. To address this problem, an instrument incorporating EMATs is now undergoing field tests for the Federal Railroad Administration. A shear wave EMAT measures birefringence in the rim to determine the residual stress state. Special electronic circuits allow the high precision timing necessary to measure very small velocity changes. The major challenge is to separate the effects of stress and metallurgical texture. Initial tests indicate that the latter may be sufficiently constant to permit quantitative evaluation of the stress. We have delivered a first-generation prototype to the Association of American Railroads, Transportation Test Center. The intent is to bring the device to a level where it can be licensed for commercial development and production.

Experience with Two Ultrasonic-Based Measurement Techniques for Residual Stress Determination in Railroad Rails

---DAVID UTRATA, ASSOCIATION OF AMERICAN RAILROADS, 3140 S. FEDERAL STREET, CHICAGO, IL 60616

---Two nondestructive stress measurement ultrasonic-based techniques were evaluated for application to the measurement of residual stresses in railroad rails. This entailed use of a device known as the Debro-30, developed by the Polish Academy of Sciences, and a prototype EMAT-based system, manufactured by MagnaSonics of Albuquerque, New Mexico. These techniques were employed to evaluate the quantitative effects of steel mill straightening procedures on residual stress distributions in rails. Such stresses are believed to contribute to service performance of such rails, specifically with respect to the phenomenon of rapid web cracking. Results show that the Debro-30 does indeed provide a viable measurement of the stresses in rails, one that can be corroborated by previous research in this field. The EMAT technique, while providing qualitative information about such stresses, appears to be affected by sample surface conditions. The origin of such effects is currently unclear.

Overview of the LCR Technique for Ultrasonic Stress Measurement

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---The Lcr ultrasonic stress measurement technique used the ultrasonic wave which is most sensitive to stress and least sensitive to texture in metals. With these characteristics the technique has seen significant success in both field and laboratory applications. A review will be given of early work on railroad rail where field experiments showed that the technique could measure stress changes over a daily period. More recent applications have shown that the technique can distinguish between stress relieved and non-stress relieved welds and between several heat treatments for ductile cast iron specimens. Additional examples will be described where the technique has been used on gas and steam turbine components.

Effect of Surface Condition on SH Wave Stress Measurements

---RON B. ALERS, CALIFORNIA POLYTECHNIC STATE UNIVERSITY, DEPT. OF MATERIALS ENGINEERING, SAN LUIS OBISPO, CA 93407

---In order to measure the stress level in a metal by interchanging the polarization and propagation directions of an ultrasonic wave, a shear horizontal wave moving parallel to the surface must be used. This wave may be a Lamb wave in a thin sheet or a surface skimming SH wave in a thick plate. In the latter case, it is assumed that the wave samples the properties of the material to a depth of about one wave length and hence may be subject to errors introduced by surface layers that are less than a wave length in thickness. By using EMATs that couple via a magnetostrictive mechanism, shear horizontal waves at 2 MHz (wave length - 1.5mm) were launched and detected in thick plates of low carbon steel in which a known stress had been imposed by a mechanical testing machine. The relationship between the applied stress and the stress deduced from the angular dependence of the propagation direction of the surface skimming SH waves was explored by using samples with a wide variety of surface conditions. The surface conditions investigated included the rust and scale found on steel exposed to the environment or left behind by the fabrication process, the cold worked surfaces characterized by machining processes as well as the gradient of the stress induced by bending loads.

Magnetic Characterization of a Steel Sheet as a Function of the Degree of Recrystallization

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---As an initial exploratory study on the possibility of developing a "recrystallization sensor" to monitor the degree of recrystallization after continuous annealing of steel sheets, the magnetic coercivity, H_C, and amplitude of Barkhausen noise (BN) were measured for a cold rolled carbon steel sheet at different stages of recrystallization. The volume fraction of recrystallized material (VFR) was varied between 0 and 100% in a carbon steel sheet by heat treatment and measured by metallography. The coercivity, obtained by analyzing the time response of the surface magnetic field produced by a small C-magnet placed on the surface of the sheet, was found to decrease monotonically with the degree of recrystallization. The variation was found to be greater in the early stages of recrystallization and to vary slowly between 80 and 100% VFR. Barkhausen noise was studied as a function of magnetic field amplitude and orientation with respect to rolling direction. The BN amplitude increases rapidly for field amplitudes slighty greater than the coercivity, H_C, and saturates for amplitudes of the order if ~8 H_C. The degree of anisotropy of BN depends on the amplitude of the magnetic field and is correlated with a small anisotropy in H_C. As is the case for H_C, the BN level changes more rapidly in the early stages of recrystallization and more slowly beyond ~50% VFR.

Magnetoacoustic Residual Stress Measurements in Railroad Wheels - Experience with Field Modeling and Component Testing

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---Efforts to apply the magnetoacoustic measurement technique, developed by NASA, to determine residual stress states in railroad wheels have been hampered by dealing with complex geometries and ill-defined stress gradients. The use of finite element magnetic field modeling has recently been employed to assist in the analysis of test data. Specifically, through the use of such modeling, one of the two electromagnet configurations used in testing has been shown to provide effective bulk magnetization of the wheel rim. The second configuration used for surface stress measurement, however, has been demonstrated as inducing inadequate magnetization required for a viable magnetoacoustic stress response. These results are discussed, with a particular emphasis on the implications for railroad wheel stress determination. A tentative stress analysis algorithm based on this information will be evaluated in light of recent results obtained on various test wheels.

Globus Model in Analysis of Hysteresis in Textured Materials

---J. ZSARGO AND J. A. SZPUNAR, MCGILL UNIVERSITY, DEPARTMENT OF METALLURGICAL ENGINEERING, 3450 UNIVERSITY STREET, MONTREAL, PQ, CANADA, H3A 2A7

---Globus model which describes the magnetization processes in a spherical grain with two antiparallel domains was used to calculate hysteresis loops in textured Fe-Si steels. Known textures were used to obtain magnetic hysteresis curves for different directions on the specimen. Also the analysis of the grain size influence on hysteresis behavior was proposed to illustrate the observed changes in the coercive force and the remanence. It was demonstrated that the predictions of the model are in qualitative agreement with experiments, however the model is too simple to be used to obtain fully quantitative results.

Magnetic NDE Techniques for Detecting Mechanical Changes in Materials

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---The magnetic properties of ferromagnetic materials change in response to mechanical influences, such as applied stress, fatigue and creep. The magnetic parameters of materials in service can monitored for damage due to the above mentioned sources by measuring the magnetic properties. Measurements have been performed using a portable magnetic measuring instrument, the Magnescope. A number of magnetic parameters, notably the maximum differential permeability and coercivity have been shown to be sensitive to applied stress. The surface condition of the materials affects the measurements but provided the surface condition remains constant over the region of measurement, the magnetic technique can be used with confidence. Creep damage has been shown to affect the magnetic parameters. The above investigations indicate the desirability of developing simple magnetic sensing devices for detection of incipient failure of materials in service. --- This work was supported by the Electric Power Research Institute, Palo Alto, CA 94303 under the Exploratory Research Program and by the Center for NDE, Iowa State University, Ames, Ia. 50010.

Effects of Irradiation and Prestraining on the Magnetic Properties of ASTM A533 and Other Steels

---M. K. DEVINE, J. APOSTAL AND D. C. JILES, CENTER FOR NDE, AMES, IA 50011, P. K. LIAW, WESTINGHOUSE SCIENCE AND TECHNOLOGY CENTER, PITTSBURGH, PA 15235

---The effects of irradiation and annealing on the magnetic hysteresis parameters of ASTM A533 steels have been studied. Magnetic measurements were taken on three groups materials, unirradiated, irradiated and irradiated & annealed. The magnetic properties of the irradiated groups were significantly different from the unirradiated. In the irradiated and annealed group, some of the parameters were seen to return to the unirradicated levels. In another experiment, the effect of prestraining on the magnetic properties of 4340 steel was analyzed. A number of samples were prestrained, some monotonically, some cyclincally. The hysteresis loss and the coercivity were seen to increase with prestraining. The remanence and maximum differential permeability were seen to decrease with prestraining. It was apparent from the results that it is possible to distinguish between irradiated and unirradiated specimens on the basis of magnetic property measurements. --- This work was supported by Westinghouse Electric Corporation Science & Technology Center, 1310 Beulah Rd., Pittsburgh, PA 15235.

Effects of Uniaxial Compressive Stress on Magnetic Field-Induced Motion of Active 90-Degree Domain Walls

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---Three major factors associated with the state of 90° domain walls determine the characteristics of magnetoacoustic emission (MAE) spectra in an iron-like ferromagnet. These are the total area of 90° domain walls available for MAE generation, their mobility and the magnitude of their interaction with lattice defects. Of particular interest are the following experimental observations. First, the MAE generation is most active and the asymmetry in the MAE burst is most pronounced in HY80 steel samples at -75 MPa. Second, only the sharp peaks located at the leading edge of the MAE burst are noticeably affected by a further increase in compressive stress level and a change in AC magnetic field amplitude. The former is most likely due to an optimized combination of the above mentioned three factors at this particular compressive stress level. The latter clearly indicates the existence of active 90° domain walls directly participating in the MAE generation. This paper presents the most recent experimental results of MAE and linear magnetostriction measurements in HY80 steel samples under uniaxial compression. In addition, a detailed analysis is made to interpret the results based on a simple model describing the motion of 90° domain walls under various conditions.

Parameterization of Asymmetry in Magnetoacoustic Emission by Numerical Processes

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---Embrittlement in HY80 steel causes an asymmetric magnetoacoustic (MAE) burst. The asymmetry as a function of applied AC magnetic field is considered the best parameter for quantitatively assessing the embrittlement state since it is insensitive to artifacts caused by geometrical variations. This functional relation can only be obtained by numerically processing the MAE data. A technique was developed to obtain the envelope function for each MAE burst. The degree of asymmetry was obtained from the location of the centroid, and the ratio between the highest and lowest amplitudes of the envelope function. The relationship between the asymmetry and AC field intensity, when plotted for samples with different levels of embrittlement, shows that it is feasible to detect embrittlement in HY80 steel components without necessitating a complicated correlation database.

Micromagnetic Surface Studies of Materials for NDE

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---There is a strong need for non-invasive methods of determining the mechanical properties of materials. In steels this can be achieved by magnetic measurements. Previous research has shown that it is possible to correlate changes in bulk properties of materials with the measurement the surface properties. In this investigation, the Barkhausen effect has been employed and a new device has been devised to evaluate of surface condition of steels. This has been used mainly for determining the mechanical conditions of constructional steel components. Barkhausen emissions show strong dependence on microstructure. This has been used to probe the material to different depths by changing the frequency of the applied field and relying upon the skin effect. Measurements are made by superimposing on a quasi dc field an ac field of appropriate frequency (30Hz-300Hz) for the depth of interest. The change of coercivity with depth can be observed from the shift in the location of maximum count rate with frequency. This micromagnetic technique is being used to investigate surface stress states such as tensile and compressive stress, and residual stress.

Wednesday

Wednesday, July 31, 1991

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8:30 AM	Session XVIII	Signal Processing - UT **S. Neal**, Chairperson Smith Auditorium Pages 87-91
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1:30 PM	Session XXII	DEFECT SIZING **A. Mal**, Chairperson Cleaveland Hall Pages 106-110
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Measurement and Calculation of Transient Eddy Currents in Layered Structures

---J. R. BOWLER, DEPT. OF PHYSICS, UNIVERSITY OF SURREY, GUILDFORD SURREY G72 5XH, UK AND D. J. HARRISON, MOD (PE) ROYAL AEROSPACE EST., MATERIALS & STRUCTURES DEPT., X32 BUILDING, FARNBOROUGH, HANTS. GU14 6TD, UK

---Transient eddy current signals excited by an air core coil have been measured using a hall probe on the coil axis above a pair of parallel aluminum plates. The measurements are compared with theoretical predictions of the magnetic field and show good agreement. The behavior of the transients is discussed in terms of the physical properties of the structure in order to assess the potential of pulsed eddy current testing for the measurement of corrosion in aircraft skins.

Through-Transmission Impedance Measurements on Moving Metallic Sheets

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---Eddy current measurements on metallic sheets are sensitive to travel of the test material through the sensor coil system. This effect is significant in the use of eddy current sensing for monitoring the resistivity and thus the temperature of extruded or rolled metallic products. The effect of the translational in-plane motion of the conductive sheet is to induce an ac electric field $E' = v \times B$ in the metal, which modifies the eddy current distribution induced by the coil system. We have solved the electromagnetic problem for the case of a moving sheet for which the thickness is much less than the skin depth, a condition which is usually met in through-transmission measurements. The model predicts a modified impedance plane curve in which the low frequency limit of the normalized (comma) curve is increasingly depressed below 1.0j as the velocity is increased. An experimental test of the through-transmission was performed, in which we used a circular disk of lithium-aluminum alloy rotating at speeds corresponding to tangential velocities up to 6000 ft/min; satisfactory agreement was obtained between the analysis and the observations. We also report results on low speed effects observed on aluminum I-beams during extrusion processing.

Numerical Modeling of Probe Velocity Effects for Electromagnetic NDE Methods

---Y. K. SHIN AND W. LORD, ELECTRICAL ENGINEERING DEPARTMENT, IOWA STATE UNIVERSITY, AMES, IA 50011

---Most numerical modeling of electromagnetic NDE phenomena has been based on the assumption that the probe is stationary. In real testing situations, however, the output signals are often generated by a moving probe, so that they are affected by the resulting motionally induced currents. This may result in a false interpretation of the output signals. For this reason, it is necessary to include such velocity effects in the field/defect interaction models. In this paper an upwinding technique is applied to the axisymmetric magnetic flux leakage inspection model. Results obtained by linearly superposing main and motional fields at a particular speed are compared with the magnetic field distributions resulting from repeated application of the finite element algorithm for incremental step changes in probe velocity. Other results of probe velocity effects on the output signal are also presented.

Theory of Eddy Currents in Metal Matrix Composites

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---In the inspection of a metal matrix composite by the eddy current method, the response of the probe is determined by the interaction of induced currents with the reinforcing fibers or particles. If this interaction can be understood in detail, then an eddy current inspection may be useful for characterizing the material in terms of reinforcement volume fraction and other microstructural properties. As was previously demonstrated, probe response can be calculated if the composite is modeled as a homogeneous anisotropic conductor. It is now shown how the effective conductivity tensor is related to the microstructure and to localized variations in microstructure. Calculations of the conductivity tensor are presented for continuous fiber composites as a function of volume fraction and localized fluctuations in volume fraction corresponding to regions of abnormally high and low fiber density. The study is extended to probe impedance calculations, with calculated conductivity tensors as input data, thus establishing a link between composite microstructure and eddy current data. Preliminary results are also reported on the design of special-purpose probes for metal matrix composite inspection.

A Study of Eddy Current Corner Crack Inspection
---N. NAKAGAWA, S. MITRA, AND J. C. MOULDER, CENTER FOR NDE, IOWA STATE UNIVERSITY, AMES, IA 50011

---A quantitative study of eddy-current corner-crack inspection is presented. Measurements were made with air-core coil probes over an aluminum bolt-hole specimen, which contained a fatigue crack at the corner of the bolt hole. An automated EC scanning station was used to obtain high-precision impedance data. A numerical model has also been developed to predict both edge and flaw signals for the system of a tight crack at a straight corner. A comparison between experiment and theory will be shown to demonstrate the level of accuracy of the present approach. ---This work is supported by the Center for NDE at Iowa State University.

Probability of Detection Models for Eddy Current NDE Methods
---S. N. RAJESH, L. UDPA, S. S. UDPA, AND N. NAKAGAWA, FAA, CENTER FOR AVIATION SYSTEMS RELIABILITY, IOWA STATE UNIVERSITY, AMES, IA 50011

---A considerable amount of attention has been focused in recent years towards the development of Probability of Detection (POD) models for a variety of Nondestructive Evaluation (NDE) Methods. Interest in these models is motivated by a desire to quantify the variability introduced during the process of testing. As an example, sources of variability involved in eddy current methods of NDE include those caused by variations in liftoff, material properties, probe canting angle, scan format, surface roughness and measurement noise. This paper presents a comprehensive model incorporating most of the sources of variability for predicting the POD with respect to eddy current methods of NDE. The model treats these variations as having a multivariate Gaussian distribution and employs the finite element approach to predict the resulting signal and its distribution. The POD model has been incorporated into a CAD framework. This allows the incorporation of a fracture mechanics model for predicting critical flaw sizes which can be coupled with the finite element model to predict the POD for various regions in the component under test. The model also employs the Method of Mixtures to estimate optimal threshold values. Results showing the viability of the approach are presented.

Real Time Gauging and Conductivity Measurement of Cylindrical Structures Using Inverted Multifrequency Eddy Current

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---This paper takes up the practical use of inverse processing of multifrequency data for measuring exterior cylindrical dimensions and mean conductivities of conductors from 6E7 to 7E3 Mhos/M on the Datamac System. Also the application of inverse processing to map radial conductivity profiles over the same range of conductivities will be presented. In particular the procedure used in establishing the initial conditions of both inverse procedures will be discussed along with convergence rates, accuracies and test times in industrial application. Particular emphasis will be given to high temperature materials processing for detection of temperature through conductivity measurements and alloy phase stability.

Thickness and Conductivity of Layers on Metals from Eddy Current Measurements

EROL UZAL, JOHN C. MOULDER AND JAMES H. ROSE, CENTER FOR NDE, IOWA STATE UNIVERSITY, AMES, IA 50011

---The conductivity and thickness of surface layers are often of critical importance in the performance of parts. Claddings, surface coatings, conducting paints and case hardened surfaces are examples of such critical surface modifications. In this paper we show that, up to a certain accuracy, the thickness and the conductivity of such surface layers can be inferred from the frequency dependence of the impedance of an air-core eddy-current probe. Experimental measurements of the frequency dependent impedance are reported for a variety of conducting layers on various base materials. These measurements are compared with the theory of Dodd and Deeds for air-core coils above a layered halfspace. Finally, the theoretical results are fit to the data using a least squares norm. This yields estimates of the thickness as well as the conductivity of the layer. The strengths and weaknesses of the proposed method will be discussed.

Eddy Current and Four-Probe DC Methods for Conductivity Measurements in Thin Sheets of Low-Conductivity Materials.
---M. GVISHI, VISITING SCIENTIST, ISRAEL MINISTRY OF DEFENSE, P. O. 2250, HAIFA 31021, ISRAEL, A. H. KAHN, NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY, GAITHERSBURG, MD 20899, M. L. MESTER, BABCOCK AND WILCOX, CLEVELAND, OHIO 44685-0190.

---In preparation for the measurement of the electrical conductivity of carbon-carbon composites during high temperature pyrolytic processing, we have constructed apparatus for performing *in situ* eddy current measurements of conductivity. For verification, we have constructed a four-probe dc system suitable for room temperature measurements on carbon-carbon samples and for elevated temperature measurements on metallic sheets. The eddy current measurement used a commercial gain-phase network analyzer to obtain the real and imaginary parts of the transfer impedance of a two-coil sensor with the test material placed between the coils. Frequencies were scanned to find the frequency of maximum real part of the impedance, which was used to obtain the conductivity-thickness product. The four-probe measurement for obtaining the conductivity used the van der Pauw method; measurements were made concurrently with the eddy current method. The measurements were carried out on a 304 stainless steel sheet of thickness 0.0375" at temperatures up to 800°C. Room temperature measurements by both methods were made on 302 and 304 stainless steel sheets, and also on a pre-pyrolyzed carbon-carbon sheet of thickness 0.20". For the carbon-carbon sample the two methods gave results agreeing to within 1.5%. Room temperature simulations of the carbon-carbon were made with a sheet of 302 stainless steel of thickness 0.005", and also with three sheets of the same material of thickness 0.002" separated by paper sheets. The products of thickness and conductivity for the simulations were approximately the same as that of the carbon-carbon.

Eddy Current Crack Signals
---S. ROSS AND W. LORD, ELECTRICAL ENGINEERING DEPARTMENT, IOWA STATE UNIVERSITY, AMES, IA 50011

---EDM notches are often used to simulate cracks for the purpose of eddy current equipment calibration, as a replica for laboratory studies and to verify theoretical simulation data. This paper gives eddy current impedance plane trajectories obtained from EDM notches and fatigue cracks in small bore tubing and compares them with corresponding finite element simulations.

A Combined Theoretical and Experimental Ultrasonic NDE Investigation of Adhesively Bonded Metal-to-Metal Materials

---R. LUDWIG, J. M. SULLIVAN, WORCESTER POLYTECHNIC INSTITUTE, WORCESTER, MA 01609 AND R. ANASTASI, U.S. ARMY MATERIALS TECHNOLOGY LABORATORY, WATERTOWN, MA 02172

---The use of adhesively bonded materials experiences widespread applications in a variety of industrial and military materials. Concommitant with the ever increasing utilization of bonded structures comes the NDE need of assessing the inherent strength of the bond. Within the context of a multiple attack strategy encompassing analytical, numerical and experimental techniques, a unified approach has been developed to test metal-to-metal bonds employing pulse-echo contact transducers in the range of 5 to 20 MHz. Generic laboratory samples were prepared with a controlled interfacial layer representing the adhesive. Time and frequency domain experimental data is processed and compared with a transient elastodynamic numerical approach. Typical simulations involve approximately 300,000 degrees of freedom and 5,000 time steps. The ability to simulate arbitrary geometric shapes as well as material inhomogeneities makes the numerical approach a highly successful tool for the theoretical study of bondline inspection. In particular, the tracing of the pulsed elastic wave in the substrate/bond interface provides important insight into the underlying physics of the interaction processes. It will be shown that the numerical predictions of the ultrasonic energy, its refection and transmission behavior in the sandwiched substrate exhibit excellent agreement with experimental data processing. As a consequence these theoretical studies can be utilized as part of an artificial intelligence strategy to analyze realistic field data. --- This project is supported by the U.S. Army under grant DAAL 04-90-C-0024.

Application of Guided Acoustic Waves to Delamination Detection

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---It is well known in waveguide theory that certain modes of sound waves are capable of propagating a relatively long distance in a material of plate configuuration, and that their propagation properties are determined by the product of sound frequency and plate thickness. Recently, it was found that, with this thickness dependence, some of these plate waves provided a different approach to probe the integrity of materials of laminate structure, and showed their potential application for large area inspections. Low-order modes of plate waves (Lamb waves) were excited and propagated in an aluminum plate or a plate assembly, which was composed of two plates bonded by epoxy. By changing the boundary condition of plate surface between transducers, the resultant amplitude variation of the received signals can be examined to locate the unbonded areas between the plate and the epoxy layer, and/or between the plates. In the measurements, an unbounded area of less than 1 mm width has been detected. Experimental results and possible model which includes out-of-plate particle displacement and mode conversions of this technique will be discussed. This work is supported by NASA Langley Research Center.

Ultrasonic Evaluation of Environmentally Degraded Adhesive Joints

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---This work addresses the experimental and theoretical study of ultrasonic evaluation of environmentally-degraded adhesive joints. The samples were degraded in salt water at different temperatures under static strain. Ultrasonic measurements have been made using the angle-beam ultrasonic reflection technique from the adhesive-joint interface. Both the frequency shifts and the widths of the ultrasonic frequency minima have been found to be indicators of joint degradation. The changes of the ultrasonic signal have been related to the joint strength as determined by static measurements of the joint. It has been found that degraded samples failed predominantly in the interfacial mode and had lower strength. The ultrasonic experimental data have been interpreted using a multilayer adhesive joint model which includes anisotropic Al_2O_3 and weak boundary layers. --- This work was sponsored by the Center for Advanced Nondestructive Evaluation, operated by the Ames Laboratory, USDOE, for the Air Force Wright Aeronautical Laboratories/Materials Laboratory under Contract No. W-7405-ENG-82 with Iowa State University.

The Detection of a Weak Adhesive/Adherend Interface in Bonded Joints by Ultrasonic Reflection Measurements

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---The detection of a weak interlayer between the adhesive and the adherends(s) in an adhesive joint is one of the major current challenges in NDE. Inspection of the interlayer is difficult because it is frequently only of the order of 1μm thick, compared with an adhesive layer thickness of the order of 100μm. One of the most promising techniques for the inspection of the adhesive/adherend interface is the measurement of the ultrasonic reflection coefficients from the interface. This paper describes a combination of analytical work and experiments which have shown that at practical inspection frequencies of up to 100 MHz, a degraded interlayer of the order of 1μm thick between the adhesive and adherend in a joint will only be detected if the shear velocity in the layer is reduced from over 1000 m/sec to below around 300 m/sec, implying that the material forming the interlayer is behaving like a viscous fluid. The degradation would also be detectable if it resulted in a significant increase in the thickness of the layer, or if it resulted in a change in the properties of the bulk adhesive. Changes of this type may occur during environmental degradation and the technique can also be used to detect the presence of mould release at the interface provided that it forms a layer several microns thick. More subtle changes at the interface due to, for example, the use of different standard surface preparations are unlikely to be detectable.

Frequency-Domain Ultrasonic NDE of Adhesively-Bonded Joints

---VIKRAM K. KINRA AND SUSAN HANNEMAN, DEPARTMENT OF AEROSPACE ENGINEERING, TEXAS A&M UNIVERSITY, COLLEGE STATION, TX 77843-3141.

---The UNDE problem is posed as follows: From the measured reflected and transmitted displacement fields, deduce the wavespeed (c), the thickness (h), the attenuation (α) of the adhesive in an adhesively-bonded joint. We examine the problem of steady-state, time-harmonic waves in two aluminum plates bonded by a thin layer of an adhesive and immersed in water. We will present an exact solution for the reflected and transmitted fields, as well as for the fields inside the joint. We will show that it is possible to determine a priori the ranges of frequency over which a unique inverse does not exist; a UNDE experiment over this frequency range can yield a very precise but a ludicrously inaccurate result. Conversely one can determine a priori the ranges of frequency over which the INVERSE SCHEME is quite robust: to this end a detailed sensitivity analysis has been carried out. Finally, we will present a comparison between theory and experiment. To understand the physics of the problem, we have introduced the concept of a COMPLEX MODE SHAPE. It will be shown that a thorough understanding of the complex mode shapes is a prerequisite to a successful implementation of a UNDE INVERSION SCHEME.

An Ultrasonic Scanning Technique for the Quantitative Determination of the Cohesive Properties of Adhesive Joints

---PAUL N. DEWEN AND PETER CAWLEY, DEPARTMENT OF MECHANICAL ENGINEERING, IMPERIAL COLLEGE, LONDON SW7 2BX, U.K.

---A nondestructive technique for the determination of the cohesive properties of adhesively bonded joints has been developed. The cohesive properties evaluated are the thickness of the adhesive layer and the velocity of the longitudinal bulk wave through the adhesive material as previous work has shown that these parameters have a profound effect on the cohesive strength of the joint. The bulk wave velocity is calculated from the reflection coefficient at normal incidence between the substrate and the adhesive. The thickness of the adhesive layer may then be deduced from knowledge of the longitudinal bulk wave velocity and the transit time of an ultrasonic pulse through the bondline. The technique has been developed as a scanning procedure, using a single immersion-coupled transducer. A microcomputer is used to drive the stepper motors of the scanning system and to perform analysis on the received data. Using this system, it is possible to produce 'maps' of the cohesive properties over a user-defined portion of the joint. Results are presented to illustrate the application of the technique to a variety of adhesive/substrate combinations. The accuracy of the technique is discussed with reference to that achievable with other techniques developed previously.

Quantitative Evaluation of Adhesive Interface Layer Properties Using Ultrasonic Dispersion Techniques

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---The interface quality evaluation in adhesive joints is of serious concern due to a tremendous growth in their application potential due to improved load bearing as well as environmental resistant characteristics when compared to traditional mechanical joints. Several recent breakthroughs have improved the NDE technology for evaluating bonds, especially the adhesive quality. Usually this amounts only to distinguishing between a 'good' and a 'weak' adhesive interface. However, in practice there is a vital need for evaluating adhesive bonds which are neither 'good' nor 'weak', but in between. Any such quantitative evaluation technique of the interface quality could significantly improve performance prediction capabilities. In this research program, an effort has been made to determine the material properties of the interface layer, from which the quantitative evaluation of the adhesive bond quality could then be obtained. A theoretical model for multi-layered structures with definable interface conditions was used in this study. The reflection factor of ultrasonic waves reflecting from the interface is analyzed for dispersion characteristics. The frequency dispersion characteristics of the reflection factor is sensitive to the material properties of the adhesive interface layer. The experimental approach involved a broad banded ultrasonic pulse, which provides data over a large range of frequencies, at the same time keeping all of the external parameters the same. Individual narrow band frequency filters in the Fourier domain is used to derive the reflection factors vs. frequency plots. A wide range of interface quality was simulated by controlling the surface preparation procedure as well as by using contaminants at the adhesive interface. Both longitudinal and shear waves were considered.

The Examination of Adhesive Bonds Using Optically-Generated Periodic Surface Acoustic Waves

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---We present a new application for surface acoustic waves which have been generated by a periodic optical source. When the pulsed output from a Q-switched Nd:YAG laser is split into two beams, separated by a narrow angle, which are recombined at a sample surface, the resultant spot consists of a series of lines due to interference. This periodic source generates surface waves with a preferred Rayleigh wave frequency. The spacing of the lines in the interference pattern is proportional to the (small) angle between the beams, and also to the cosine of the angle that the beams make with the normal to the sample. By changing this second angle, it is possible to generate Rayleigh waves with frequencies of the order of 10 MHz (at normal incidence) down to 900 kHz (at about 80° from the normal. We demonstrate that these surface waves may be detected by a homodyne laser interferometer. For such a source and detector, sited on opposite sides of a region on the surface to which a smaller block has been adhesively bonded, surface waves with frequencies greater than 3 MHz are completely attenuated for all lengths of bonded region studied. The amplitudes of lower frequency waves decrease with increasing lengths of bonded surface. This effect, however, is less marked for those bonds in which deliberate adhesion defects were incorporated, appearing to offer a means of distinguishing between well or poorly adhered joints.

Assessment of Aircraft Structural Integrity by Detecting Disbonds Through Ultrasonic Scanning
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---The presence of disbonds in the lap joints and doubler joints of aging aircraft has triggered the development of several techniques to detect disbonds nondestructively for the assessment of airframe structural integrity. In the present study, the Ultrasonic Contact Scanning technique is used to detect disbonds in aircraft lap joints and doubler joints. In this technique, an inspection probe is held in contact with the external surface of the aircraft, with a thin film of water acting as the coupling medium. A high-frequency ultrasonic pulse is launched by the transducer into the structure and the reflected pulses are received by the same transducer, which acts as both the transmitter and the receiver. The reflected pulses are used to characterize the inspected location as being bonded or disbonded. Two methods are used to classify the reflected signals. The first is an amplitude-based method, and the second one makes use of an artificial neural network. A second ultrasonic inspection technique called "Immersion Scanning" is used to verify results obtained using the contact scanning technique. A good agreement is seen between results obtained using the two techniques. Results from scanning both fabricated panels as well as aircraft panels will be presented.

Assessing the Integrity of Structural Adhesive Bonds by the Measurement of Acoustic Properties
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---Changes in the acoustic properties at the interface of adhesively bonded steel/rubber joints have been evaluated using ultrasonic techniques. The application of known magnitudes of shear stress at the bond interface, are correlated with the quality of the bond. During the loading process surface stresses are initiated in the surfaces of the adherend and adhesive. The distribution and the type of stresses are dependent on the relative rigidity of the bond. Such surface stresses can also be induced by changes in the sample material temperature. The present work attempts to correlate the quality of the adhesive bond with the changes in the acoustic properties of test samples as the samples are loaded or are subjected to temperature changes.

Adaptive Array Processing for Real-Time Medical Ultrasound Imaging

---M. O'DONNELL, DEPARTMENT OF ELECTRICAL ENGINEERING AND COMPUTER SCIENCE, UNIVERSITY OF MICHIGAN, ANN ARBOR, MI 48109-2122

---Over the last decade, ultrasonic phased arrays have been used routinely for real-time medical imaging. Because of the inhomogeneous nature of tissue, however, the size of arrays employed in these systems has been limited. In particular, very small numerical apertures are commonly used because of the inability in maintaining phase coherence over large apertures. Recently, phase aberration correction methods have been explored for medical phased arrays permitting diffraction limited resolution from large apertures. In this talk, the principles of imaging with a sampled aperture will be reviewed. Following this review, the use of adaptive signal processing methods for removal of phase aberration problems will be explored. In addition, a practical array system constructed to test the principles of real-time phase aberration correction will be presented. The talk will conclude with a discussion of the application of this type of system to problems in ultrasonic NDE, particularly quantitative measurements from objects with rough, nonplanar surfaces.

Wavelets and Their Application to Digital Signal Processing in Ultrasonic NDE

---B. DEFACIO, C. R. THOMPSON, DEPARTMENT OF PHYSICS AND ASTRONOMY; AND S. P. NEAL, DEPARTMENT OF MECHANICAL AND AEROSPACE ENGINEERING, UNIVERSITY OF MISSOURI-COLUMBIA, COLUMBIA, MO 65211

---Digital signal processing will play a prominent role in ultrasonic NDE as the application of digital data acquisition and processing systems becomes more prevalent. Current digital signal processing approaches utilize classical Fourier transform techniques with extensions to the Cepstral domain and the time-frequency domain. This presentation will introduce a relatively new signal processing idea involving wavelets. Basic concepts, mathematical origins, and potential advantages of wavelets over Fourier transform based techniques will be covered. The potential application of wavelet based signal processing approaches to NDE will be discussed by reconstructing simple scatterers. An example of the application of wavelets to ultrasonic NDE will be given by showing results of a wavelet based flaw signal deconvolution.

Split Spectrum Technique as a Preprocessor for Ultrasonic Nondestructive Evaluation

---PRASANNA KARPUR, RESEARCH INSTITUTE, UNIVERSITY OF DAYTON, 300 COLLEGE PARK AVENUE, DAYTON, OH 45469-0127

---Split Spectrum Processing (SSP) has been in use for a little over a decade for the processing of ultrasonic signals to reduce coherent material noise content of the signal. Although SSP is very effective in signal-to-noise ratio (SNR), enhancement, the technique is being used only to improve detectability and not to improve characterization and sizing of anomalies. This paper is to demonstrate the effective use of the SSP technique as a preprocessor wherein the signals are SNR enhanced before being processed for defect characterization and/or sizing using techniques such as neural networks and deconvolutions. The paper includes results of appications involving detection, location, sizing and characterization of anomalies in various samples such as aluminum, centrifugally cast stainless steel and carbon epoxy composites. This work was supported by Air Force contract F33615-89-C-5612.

Split Spectrum Processing with Computationally Efficient Sinusoidal FIR Filters

---ORLANDO J. CANELONES, PRASANNA KARPUR, RESEARCH INSTITUTE, UNIVERSITY OF DAYTON, 300 COLLEGE PARK AVENUE, DAYTON, OH 45469-0127

---Split Spectrum Processing (SSP) is efficient in the enhancement of signal-to-noise ratio (SNR) of ultrasonic signals in nondestructive evaluation applications. However, the process is very time consuming when implemented in frequency domain which requires many Fourier transformations thereby precluding "real time" implementation. As a result, industrial applications which require fast data acquisition and processing cannot benefit from SSP technique implemented in the Fourier domain. Hence, there is a need for an implementation which uses time domain filter synthesis and computationally efficient convolutions. This paper presents computationally efficient sinusoidal finite impulse response (FIR) filters implemented in time domain and designed based on a two-branch structure of cascaded subfilters of lower complexity which can reduce the processing time by up to 75%. Results of parametric studies and comparisons with the Fourier technique will be presented. This work was supported by Air Force contract F33615-89-C-5612.

Rank Determination of Order Statistic Fibers for Ultrasonic Flaw Detection

---XING LI, JIAN-QIANG XIN, KEVIN DONOHUE AND NIHAT M. BILGUTAY, ELECTRICAL & COMPUTER ENGINEERING DEPARTMENT, DREXEL UNIVERSITY, PHILADELPHIA, PA 19104

---Frequency diverse order statistic fibering applies the order statistic operation over an ensemble of frequency diverse narrowband time signals. In the past, this technique has been successfully used to improve flaw detection in large grained materials. However, the determination of the rank for the order statistic operation requires *a priori* knowledge of the distribution functions of the flaw signal and the grain noise. The this paper, the spectral histogram method is utilized to determine the rank of the order statistic operation. The rank is determined based on the histogram of the narrowband time signals selected by the different rank operations. Analysis and experimental results for ultrasonic nondestructive testing show that a strong correlation exists between the spectral histogram pattern and the usable rank of the order statistic operation. Therefore, frequency diverse order statistic filtering can be utilized without the *a priori* knowledge of the distribution functions to achieve flaw-to-grain echo ratio enhancement. Although this technique yields a robust range of ranks, further refinements may also permit the determination of the optimal rank.

Coherent Flaw Reflectivity Estimation in Nonstationary Noise

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---This paper presents a signal model for RF broadband ultrasonic A-scans obtained from large-grained materials. The model incorporates both the RF phase and magnitude differences between the grain and coherent flaw echo spectra. An implementation of an adaptive maximum-likelihood estimator (MLE) is presented for estimating the reflectivity of a coherent scatterer (which represents the flaw). The structure of the estimator is shown to be equivalent to other popular signal processing techniques, such as matched filtering and deconvolution, under certain restrictive assumptions on the statistics of the A-scan. The importance of using both RF phase and magnitude over the spectrum of the illuminating signal is illustrated. In addition, this paper demonstrates how the covariance matrix of the signal model characterizes the nonstationary behavior of the signal due to scattering and absorption of the propagating pulse. The MLE performance is compared in cases where the grain noise spectrum is assumed statistically stationary, and where it is not assumed stationary. Experimental and simulated A-scans are examined to indicate cases when the MLE for nonstationary grain noise should be used for improved performance. --- This material is based on work supported in part by the National Science Foundation under Grant No. MIP-8920602, and the National Cancer Institute and National Institutes of Health Grant No. CA52823. The Government has certain rights in this material.

Characterization of Materials Using Grain Backscattered Ultrasonic Signals

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---In the nondestructive testing and evaluation of materials, ultrasonic techniques are widely used. In this paper, we investigate the usefulness of grain backscattered ultrasonic signals in the characterization of materials. The backscattered signal is first processed by means of a Kalman filter based deconvolution algorithm in order to remove the effect of the measurement system response. The spectrum of the deconvolved signal is then obtained and fitted with zeroth and first order polynomials within the bandwidth of the measurement system. The coefficients of these polynomials are related to the average scattered energy and its rate of change with frequency. Testing of several material samples reveals that these polynomial coefficients can be used as suitable features for characterizing materials in certain applications. --- This work was supported by the Center for Nondestructive Evaluation at Iowa State University.

On the Use of Wigner Distributions and Wavelet Transforms in Ultrasonic NDE.

---C. H. CHEN AND JIANN-CHING GUEY, SOUTHEASTERN MASSACHUSETTS UNIVERSITY, ELECTRICAL/COMPUTER ENGINEERING DEPT., N. DARTMOUTH, MA 02747.

---Although there has been much progress in using time domain analysis and frequency domain analysis for ultrasonic NDE signals, neither analysis domain has been able to provide us enough information especially on complex defect problems. A high resolution time-frequency analysis is much needed to meet the increasing demands in NDE. The capability of short-time Fourier analysis is severely limited by the window length used. The Wigner distribution, if properly implemented, can provide the desired time-frequency analysis. Wigner distribution, for example, can be useful to identify and extract the signal component corresponding to the defect. The wavelet transform though mathematically very different, has similar capability of time-frequency analysis that, for example, can identify signal components due to defect from frequency instabilities. In this paper, efficient implementation of both Wigner distribution and Wavelet transform is considered. Several examples based on the real and simulated NDE signals are given to illustrate the capabilities of both in time-frequency analysis of ultrasonic NDE.

Ultrasonic Signal Processing of Adhesive Bonding Data Employing Chirp-Z Transform and Adaptive Filtering Techniques

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---Adhesively bonded structures have found widespread utilization in a variety of industrial and military applications. Unfortunately, the nondestructive determination of the inherent bond strength of such structures has not been satisfactorily solved. In this paper experimental signals from contact L-wave transducers with center frequencies in the range of 5 to 20 MHz are employed to assess metal-to-metal bonding parameters. In particular, the recorded A-scan signals are transformed into the frequency domain by means of the Chirp-Z transform in an effort to analyze and precisely locate frequency resonance phenomena in the received transducer spectrum. Furthermore, to isolate the bond layer response in the time domain a recursive least square adaptive filter approach is applied. The adaptive filter employes 256 tap weights and is trained by the signal response from an unbonded sample. The resulting signals in the time and frequency domains are compared and correlated with bondline parameters. --- This project is supported by the U.S. Army under contract DAAL 04-90-C-0024.

Characterization of West Virginia Hardwood Using Acoustic Emission and Vibration Methods
---H. L. CHEN, H. W. ZHOU, H. GANGARAO, DEPARTMENT OF CIVIL ENGINEERING, WEST VIRGINIA UNIVERSITY, MORGANTOWN, WV 26506.

---A total of 80 hardwood (Red Oak) specimens, each with dimension of 1.5" x 3.5" x 60", were randomly selected from 900 samples and tested under a four-point bending test set-up. Acoustic Emission (AE) signals were monitored by a two channel AE system, AET 5500. The variables in our specimens are: Grade No. 3 and Select Structural, two moisture contents (6% and 15%), and two kinds of treatment - preservative and controlled. An average longitudinal wave speed of about 5900 m/s was observed. A statistical approach was used to predict the modulus of rupture (MOR) from the modulus of elasticity (MOE). Vibration frequency was measured and an equation to calculate the initial MOE of the specimens from the free vibration tests was developed. The vibration method was shown to be simple and reliable in determining the MOE of the hardwood specimens. Analysis of the AE signals shows that the specimens with higher moisture contents have higher magnitude of b-value which implies those specimens are more ductile. The b-value is determined from the distribution of event by peak amplitude curve in the logarithmic scale. The ductile behavior was confirmed from the load-deflection curves. The other AE characteristics, such as cumulative events and energy, were examined at different levels of load and deflection.

Electromagnetic Properties of Large-Grain Materials Measured with Large Coaxial Sensors.
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---This paper describes the measurement of the electromagnetic properties of large-grain inhomogeneous materials with coaxial sensors. Large coaxial sensors have an advantage in that the fluctuations in the electromagnetic properties of a material caused by the heterogeneities inherent in its composite structure are averaged over a large sample volume. Recently, two large sensors have been designed, calibrated, and tested over a frequency range of 1 MHz-3 GHz. A coaxial transmission line cell yields the most accurate results in a laboratory setting and has the largest available bandwidth. An alternative sensor, the open-ended coaxial probe, is the best geometry for *in-situ* measurements. Various concretes were measured over a wide frequency range and over long periods of time. It is shown that the electromagnetic properties of concretes depend upon the water/cement (w/c) and sand/cement ratios (s/c). The frequency dependence of the electromagnetic properties also indicates the ongoing electrochemistry of the concretes. Hence, the *in-situ* measurement of concrete properties can be potentially useful for the quality control of the concretes.

Preliminary Results of Using Microwaves for Detecting Steel Bar Preferred Orientation in Concrete Slabs and Detection of Breakage in These Bars.

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---Polarization properties of microwave signals have been used to detect the preferred orientation of steel bars in concrete slabs. This technique involves a transmitting horn antenna with linear polarization that irradiates the concrete slab. Another horn with linear polarization is used as the receiving antenna. Rotation of the receiving horn about its axis determines the preferred orientation of the steel bar inside the concrete slab. This is due to the fact that the signal reflected by the steel bar is also linearly polarized. When the polarization of the reflected signal and that of the receiving horn are parallel, maximum signal is detected by the receiver. A reflection/transmission technique is also used to detect any breakage in these steel bars. Description of the technique and some preliminary results are discussed.

The Feasibility of CT and DR Characterization of Cement Solidified Low Level Nuclear Waste.

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--- This application paper will discuss the feasibility of using digital radiography (DR) and computed tomography (CT) to obtain density and volume quantification for the purpose of screening filled waste containers. The presentation will include 2 M_eV image analysis of a realistic phantom scanned on ACTIS. The timely topic of environmental clean-up includes the safe disposition of low level nuclear waste. The final form, transportation, and storage of this waste are subjects that have quantifiable requirements. The processes of cement, glass, and polymer solidification can provide safe forms for transportation and permanent storage of low level nuclear waste with typical radiation levels between 0.01 to 0.1 R/Hr. DOT and EPA transportation and storage safety requirements for this waste include elimination of process polluting by-products including liquids and sludge at 0. to 1.0% of volume. Container volume utilization for solids can typically be 90%. There are numerous types of storage containers including common 55 gallon round steel drums (the phantom) and denser packing polygon shapes weighing in excess of 400 kg when filled. This paper will demonstrate that the wide dynamic range and contrast sensitivity of DR and CT allows for the non-intrusive identification and density discrimination of water, sludge, polymers, and cement. For this application study, specific gravity variability was between 0 and 2.7. In addition, the three dimensional aspects of CT provides dimensional and volume analysis of the waste form. The currently used alternatives to DR and CT include conventional projection real-time radiography of free moving surface water with limited contrast resolution, destructive coring analysis, and intrusive surface contact testing for compressive strength.

Study of Discontinuities Evolution in Metallic Structures Under Dynamic Stress by Ultrasonic Examination

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---The behavior of internal discontinuities extant in metallic structures under dynamic stress-as bridges, buildings, ships-represents a complex phenomenon with important implications concerning the structures safety. This paper illustrates interesting results of the research in this field carried on in INCERTRANS. The investigations consisted of periodical ultrasonic examinations of two elements (road-stringers) pulled out from the metallic structure of a highway and railway bridge and also of three test - bodies made from stell plates, all containing internal discontinuities like inclusions or porosity. Two of the test - bodies have been strengthened by plates and high tension bolts and the third remained for control. All pieces have been tested under dynamic compression or bending during over 65×10^6 cycles. Each million cycles the test-pieces have examined by ultrasonic methods and the evolution of discontinuities has been recorded. These investigations have been completed by metallographic examinations, extensometric and deflection measurements. These data colligate the extension rate of discontinuities and the number of stress cycles and pointed out the influence of discontinuities position and strengthening solution. The conclusions led to a surveying program for metallic bridges but also applicable fo other types of metallic structures.

Defect Imaging Using Long-Distance Ultrasonic Testing

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---Ultrasonic testing of large-scale civil engineering structures is applied in the short-range, inspecting localized areas. Often, connections and critical nodes are not easily accessible to within the range required by present ultrasonic testing techniques. Further, small inspection areas result in a time-consuming inspection operation for a large structure. This work investigates the possibility of increasing the range of ultrasonic testing to a distance of 0.5-1.0 meter in order to facilitate inspection of nodes that are difficult to access and to increase the size of the inspection area. Examination of long-distance wave propagation behavior on 40 mm thick steel plates indicates that neither multiple reflections from plate surfaces nor long wave paths cause serious attenuation in the ultrasonic signal. Because of the low attenuation, signals received from long-distance ultrasonic testing can be used in defect detection. By focusing data obtained from scanning, regions anywhere within the propagation paths can be imaged, thus increasing the inspection area. Using image reconstruction from long-distance ultrasonic data, a fabricated, embedded crack with area 150 mm^2 is detected from distances greater than 0.5 meter. Long-distance ultrasonic testing is not suitable for detailed characterization of this type of defect. However, the method has proven very effective in the long-distance detection of defects.

The State-of-the-Art of Nondestructive Evaluation of Military Runways.

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---Nondestructive evaluation (NDE) of military runways is an integral part of our national defense strategy. Nondestructive military runway evaluations include conventional evaluations geared toward runway maintenance planning, as well as wartime evaluations for the definition of a minimum operating strip (MOD) or to locate unexploded ordinances (UXOs). This state-of-the-art paper describes nondestructive devices and methods currently used for military runway evaluation, as well as emerging nondestructive evaluation techniques and systems. The author is the Principal Investigator for the Air Force research program on advanced techniques for the nondestructive evaluation of runways, at the Air Force Engineering and Services Center, Tyndall Air Force Base, Florida. The paper includes a discussion on current Air Force research for the development of advanced nondestructive evaluation technologies for runways, such as impulse radar, spectral analysis of surface waves, laser profilometry, and laser-controlled load-deflection testing. Also, related Air Force research on the use of scanning electron microscopy and computerized tomography is discussed. Many of the nondestructive methods used by runaway evaluators have a great deal of similarity to quantitative nondestructive evaluation (QNDE) methods currently used by industry. This paper provides a state-of-the-art review, of general interest to the QNDE community, of a research and development area which could provide applications for many emerging QNDE technologies.

A Visual Inspection System for Evaluating the Interior Surface of Valve Flanges on Hazardous Material Storage Container Tops

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---A nondestructive inspection for evaluating the interior surface of small-diameter valve flanges on hazardous material storage container tops was mandated. The design specifications require the interior surface of the valve flange to have a surface finish of #16 or better. Conventional instruments which utilize mechanical "stylus-type" (surface analyzing) equipment do not easily extend into deep narrow holes as found on the hazardous material container's valve flange. When equipment is located that can extend into deep narrow orifices, it generally does not provide adequate measurement accuracy. A visual inspection system which exploits the capabilities of a high resolution fiberoptic borescope was designed and assembled. The design and inspection features of the aforementioned system will be discussed along with several illustrations of inspection results and a possible image processing method for data analysis.

Nondestructive Evaluation of the Granite Veneer at the Bronx Museum of the Arts

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---Approximately 3200 square feet of wall area of the Bronx Museum of the Arts building is covered with granite panels. The 2 ft. by 2 ft. by 1/2 inch thick granite veneer panels are attached with a thin-set latex-modified mortar. The panels were initially installed in 1988 and since then several panels have fallen off the building. An investigation was carried out in the fall of 1990 to determine the extent and cause of delamination of the granite panels. The investigation involved review of documentation (stone shop drawings, specifications, architectural drawings, etc.), nondestructive testing and laboratory testing and analysis of samples. The nondestructive testing included visual examination, hand sounding and impulse response testing. This paper will describe each phase of the investigation focusing on the procedures used for the nondestructive testing. The test results and conclusions will be presented to illustrate the use and limitations of each testing technique.

Pulsed Lasers for Quantitative Ultrasonic NDE
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---Recent advances in the use of pulsed lasers for ultrasonic generation will be described. The use of an EMAT detector will be shown to lead to a flexible non-contact ultrasonic system, with a wide bandwidth. The system can be used in both through-transmission studies, and in pulse-echo measurements. Results will be presented for use in the testing of bonded joints, and in thickness testing of thin metal sheet. It will also be demonstrated that the system may be used for the imaging of defects, using fast imaging methods and SAFT processing. Tomographic imaging applications will also be presented, where a pulsed laser source and EMAT detector have been used to collect data across the surface of metallic solids. This has led to the reconstruction of Rayleigh wave images on the surface of a thick sample, and Lamb wave images in thin aluminum samples. Two other NDE applications will be described. The first uses the laser to excite resonances in miniature tuning forks, where the excited vibrations are monitored as a function of temperature using a capacitance detector. In the second application, the laser is used to test fiber-reinforced polymer composites.

Inspection of Components having Complex Geometries using Laser-Based Ultrasound
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---Laser-based ultrasound (LBU) offers the potential for rapidly inspecting large-area composite structures having complex geometries. Since the material being inspected acts as the transducer for converting light to sound, knowledge of its transduction characteristics are crucial to the design of such a system. Key material properties that significantly impact the system design are the maximum allowable generating beam energy, maximum allowable probe laser energy and the angular reflectivity of the structure surface. The maximum laser power that can be used ultimately determines the signal-to-noise ration (SNR) that can be achieved with a LBU system. We will report on the results of investigations of the laser damage thresholds in various composite materials using a 1064 nm Q-switched Nd:YAG laser for generation and a 514.5 nm CW argon-ion laser for detection. We will also report the results of angular reflectivity measurements made on a variety of surface textures. These results determine the variation in SNR during angular scanning of the probe laser beam. Materials having both painted and "as received" surface finishes have been examined. In those that did not have any type of coating applied to the surface, the reflected light was found to have a large specular component. From these reflectivity studies, we infer that a reduction in SNR as large as 33 dB will occur as the detection laser beam is swept over an angular sector from 0 to 45 degrees. In contrast, those materials which had a painted layer exhibited a larger diffuse component, indicating that a reduction in SNR of typically less than 3 dB would occur. This work was sponsored in part by the Center for Advanced Nondestructive Evaluation, operated by the Ames Laboratory, USDOE for the Air Force Wright Aeronautical Laboratories/Material Laboratory under contract No. W-7405-ENG-82 with Iowa State University.

Elastic Constants for Unidirectional Boron-epoxy Composites.

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---Unidirectional boron fiber-epoxy composites are used for crack repair and for reinforcement of highly stressed regions in aircraft. Critical nondestructive evaluation problems related to such repair include ensuring the bond integrity between the composite and the substrate and measuring the depth of any cracks underneath the reinforcement. Among possible ultrasonic techniques, the use of leaky interface waves may solve both these problems. However, it is first necessary to determine elastic constants, c_{ij}, for the composite, in order to assess whether leaky interface waves occur for a particular composite/substrate combination. Based on laser ultrasonics, procedures have been proposed previously to measure c_{ij} values for composite overlays (Doyle and Scala, 1990 Review). These procedures exploit bulk waves along principal and off-axis directions as well as Rayleigh and pseudo-pressure waves on the composite surface. Experimental results using these procedures for c_{ij} measurement in a specimen of unidirectional boron-epoxy composite will be presented. The results show that this specimen must be regarded as having orthotropic rather than transversely isotropic symmetry. The existence of interface waves between this boron-epoxy composite and various metallic substrates will also be discussed.

Long Cavity Laser Excitation and Digital Filtering of Narrowband Ultrasound for Enhanced Signal-to-Noise Ratio

---J. B. DEATON, JR. J. W. WAGNER, AND J. B. SPICER, CENTER FOR NONDESTRUCTIVE EVALUATION, THE JOHNS HOPKINS UNIVERSITY, BALTIMORE, MD 21218

---A long-cavity mode-locked Nd:YAG laser has been developed to study the non-contact generation of multiple-pulse ultrasound at pulse repetition frequencies between 2.5 MHz and 13 MHz. In the frequency domain the energy in a multiple-pulse acoustic signal is concentrated in narrow frequency bands located at the fundamental and successive harmonics of the pulse repetition rate of the laser. Such a signal therefore exhibits a considerably narrower spectral content than that of a single acoustic pulse typically generated by a Q-switched laser. Variation of the pulse repetition frequency permits tuning of the ultrasonic frequency, yet still retains the outstanding temporal resolution of the single pulse techniques. For applications in nondestructive evaluation, tailoring the frequency response of an interferometer to match the spectral content of the multiple-pulse ultrasound permits remote detection with enhanced sensitivity. This has been accomplished with digital Wiener filtering, which produces a 10 dB reduction in the noise power in digitally recorded ultrasonic waveforms. Such improvement is not possible with single pulse techniques. This work is supported by a Research Award for Graduate Study from the Newport Corporation.

Analysis of Laser Ultrasonic Measurements of Surface Waves on Elastic Spheres

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---The noncontacting and point source/detection characteristics of laser ulrasonics offer the potential for investigating the properties of materials cast into nonplanar complicated geometries. Surface waves are the most easily generated and detected by this method, and they readily travel around curves surfaces. This paper investigates the elastodynamic wave modes in spheres and identifies the surface wave contributions. Analysis shows that these wave modes arise from certain spheroidal oscillations of the sphere and are dispersive in a manner similar to that seen for surface waves traveling around a cylinder. Measurements on spherical ceramic and metal spheres are presented and compared to the theoretical results. Supported by the Department of Interior's Bureau of Mines and the Department of Energy.

Effects of Laser Source Parameters on the Generation of Narrow Band and Directed Laser Ultrasound

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---It has been established that the proper implementation of laser arrays for generating ultrasonic signals in solid materials can result in an overall improvement of detection sensitivity for laser ultrasonic systems. The degree to which sensitivity may be enhanced, however, is a strong function of the temporal and spatial nature of the laser array source as well as the acoustic mode one wishes to excite. For example, variations in the dimension of each element in the array, array spacing, and laser source rise time all may affect dramatically the degree to which one is able to generate narrow band signals for high sensitivity detection. Ultrasonic directivity issues are also somewhat more complicated than they are represented in much of the current literature. In fact, the degree to which the ultrasonic energy may be directed by laser array sources of any type if a strong function of the wave shape generated by each element in the array. Consequently, individual features such as pulse height or pulse repetition, which may be derived by superposition of the signals from elements in an array, may be directed over a range of angles in a solid material while total far field energy directivity may remain unchanged. This work was supported in part by General Electric.

Ultrasonic Characterization of Laser Ablation
---J. A. SMITH AND K. L. TELSCHOW, IDAHO NATIONAL ENGINEERING LABORATORY, EG&G IDAHO, INC., IDAHO FALLS, ID 83415-2209

---Ablation of small amounts of material from the surface by a pulsed laser forms an effective source for compressional and surface elastic waves. Much work has been performed to understand these waves and measure the properties of materials from their propagation characteristics. In contrast, this paper discusses measuring elastic waveforms to gain information about the laser ablation mechanism at the material surface. An impulsive normal point force has been shown to simulate the waveform generated from laser ablation. Therefore, this waveform can be used as a direct probe of the impulse absorbed by the material during the laser ablation process. Direct measurements of the surface damage caused by this process and the effects of material properties are presented. Supported by the Department of Energy.

Generation of Dispersive Acoustic Waves by the Phase Velocity Scanning of a Laser Beam
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---A new method for non-contact generation of dispersive surface acoustic waves (SAW) and Lamb waves suitable for QNDE is proposed by using rapid scanning of a laser beam. The driving force for the generation is a heat pulse with duration of d/V, where d is the beam width and V is the scanning velocity. The strain caused by this heat pulse propagates as SAW, and this is coherently amplified if V is equal to its phase velocity. This phenomenon brings high amplitude unidirectional SAW with negligible irradiation damage. The temperature increase of the surface was less than 1 degree while generating 3 MHz Rayleigh wave on aluminum with 1 nm amplitude. If the dispersion of the SAW is large, the generated SAW take a form of tone burst. Its center frequency is determined by the phase velocity dispersion curve as far as it is consistent with the bandwidth V/d of the heat pulse. It has been shown that the duration of the tone burst is $T[1-v_p/v_G]$ where T, v_p and v_G are scanning period, phase velocity and group velocity and [] denotes absolute value. Using this new type of dispersive waves, measurement of plate thickness and anisotropy are demonstrated.

Measurement of the Center-of-Gravity Using X-Ray Computed Tomography

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---The quantitative capability of CT to measure the relative x-ray linear attenuation coefficient and position of small volume elements in a component also offers the potential to perform center-of-gravity (CG) measurements for rotating systems. Currently, the practice of engine vibration reduction is one of disassembly, iteratively checking balance and grinding off mass until the amount of imbalance is acceptable. This process is labor intensive. Experiments from a test phantom show that it is technically feasible to use CT data for calculation of the CG. The method as demonstrated with a ring test phantom is accurate to within 0.8 g-cm for homogeneous materials. Preliminary analysis indicates that for nonhomogeneous materials the accuracy is reduced but is valid with constraints. It should be noted that this technique is not limited to circular or high degree of symmetry parts but is readily applicable to parts with complex geometry. Positional accuracy of the CG can be determined very accurately (less than 0.1 mm) due to the large number of elements that are used in the calculation (approximately 60,000 for the test phantom). This work is sponsored by the United States Air Force Contract F33615-88-C-5404 under the "Advanced Development of X-Ray Computed Tomography Applications Program", Wright Laboratories, Materials Directorate at WPAFB.

Detection Sensitivity of X-Ray CT Imaging for NDE of Green-State Ceramics

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---Improved ceramic processing methods using pressure slip-casting are being developed at Norton Advanced Ceramics to produce reliable structural ceramics for advanced heat engine applications. Nondestructive evaluation of ceramic parts at different stages of ceramic processing, namely, green, debinderized, and fully densified states, can provide useful diagnostic information to improve ceramic processing. This paper evaluates detection sensitivities of three-dimensional X-ray computed tomography for determination of density gradients, inclusions, and voids in green-state pressure-cast Si_3N_4 ceramics. Density calibration phantoms and net-shape-formed tensile rods with seeded defects were used to determine the detection limits. The experimental results will be compared with theoretical limits based on detector resolution of the X-ray CT system. --- Work supported by U.S. Department of Energy, Office of Transportation Systems, as part of the Ceramic Technology for Advanced Heat Engines Project of the Advanced Materials Development Program, under Contract W-31-109-Eng-38.

Computed Tomography Imaging for Nondestructive Evaluation

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---Computed Tomography (CT) is a relatively new Nondestructive Evaluation (NDE) technique in industry. CT is an X-Ray inspection method that digitally images the internal structure of an object on a plane perpendicular to the vertical axis of the object. Traditional Radiography or Digital Radiography is a data acquisition technique where the full volume information is superimposed in an overlapping fashion on a two-dimensional image. In contrast, CT gathers full volume data at a specified plane in the object and, in software, 'reconstructs' the cross-sectional image of the object, removing all superpositioning of overlapping information. CT is being proven as an invaluable technique in the inspection and evaluation of objects from complex geometry structures such as multi-layer parts, to closed systems that heretofore have been uninspectable. Application areas for CT cover a broad spectrum of objects, for both the Air Force and industry. Process development, subcomponents and full assemblies can be examined by CT for evaluation of part integrity. This paper will present examples of CT imaging as an NDE tool in some aerospace and industrial application areas. It will also show some research efforts that insert CT into inprocess evaluation of new materials, and some experimental work to evaluate the optimum performance of the CT machine.

Development of an Advanced 3D Cone Beam Tomographic System

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---LETI and INTERCONTROLE develop within the context of a CEE BRITE project, an advanced 3D cone beam tomograph designed for the control of technical ceramics. The acquisition part of the system consists of a microfocus X-ray generator, an image intensifier and a CCD camera associated with a real time imaging hardware. A PC-AT local computer manages the system. A scientific computer, via a local area network, executes the calibration and reconstruction processing. The mechanical part of the system is featured by a precise and original mechanical design, allowing the rotation and the tilt of the object in the space. A suitable tilt motion is combined with the object rotation in order to provide complete data set. The reconstruction phasis is performed with the RADON software developed by the LETI. This software computes the reconstruction algorithm via the first derivative of the 3D RADON transform/GRANGEAT 1987/. The power of this method is its capability to deal with large apertures and complex trajectories to ensure complete data acquisition. The aim of this paper is to present this project. We will describe the general design of this system and show such real data.

Dynamic Thermal Tomography: New NDE Technique to Reconstruct Inner Solids Structure by Using the Multiple IR Image Processing

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---Discovery and quick introduction of the X-ray tomography into industry and medicine lead to a *revolution* in radiography. Ultrasonic, UHF and nuclear magnetic resonance tomography is now under quick development. As a result of recent investigations in the field of thermal characterization and NDE of solids, a new infrared thermography procedure called "dynamic thermal tomography" (DTT) has been proposed at Tomsk Polytechnical Institute in 1986. This DTT algorithm allows to *slice* the specimen into single layers since in one-side IR thermography procedure the front surface signals from deeper defects occur at longer time delay after heating had stopped. The algorithm includes the storage of multiple IR images of a specimen recorded during the heating-cooling process, the synthesis of the so-called *time images* and finally the presentation of the inner structure of a specimen in a time-converted form. This DTT algorithm was first experimentally implemented at Wayne State University in 1990. It allowed to slice a plastic specimen with artificial air holes in up to 8 depth layers. A modified version has been investigated at Universite Laval in 1991 and allowed to increase the number of separated depth layers. In the paper, this newer algorithm will be presented along with thermographic tomography theory and experimental results.

Scattering of Acoustic and Elastic Waves by Cracklike Objects: The Role of Hypersingular Integrals

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---Cracks in NDE are often modeled as slender-shaped voids with little enclosed volume, or as cracks with asperities, or as thin slits cut into the surface of a solid, or as touching surfaces with zero enclosed volume, i.e. a "mathematical" crack. Any of these models, among others, may be employed depending on a variety of factors. Although the models with nonzero enclosed volume usually represent reality better, the "mathematical" model is used very often because of its simplicity and utility, despite certain analytical and numerical difficulties associated with the zero volume aspect. Nevertheless, the more realistic models present difficulties because of the thinness of the shapes enclosed by the crack surfaces. When such models are used in computations, difficulties with at least the following two features arise: (1.) poor conditioning of the final system of equations and (2.) numerical inaccuracy. Both features are due to the proximity of the crack surfaces to each other. This paper demonstrates how a combination of conventional and hypersingular boundary integral equations provides a formulation for scattering of waves from thin-body shapes which is free of the difficulties (1.) and (2.). The methodology should be valuable in solving the rough crack and partially-closed crack, as well as the incompletely bonded crack or thin-body inclusion problem. Numerical results are given in this paper for scattering from certain thin cracklike shapes and data are compared in the near and far-field with data from a mathematical crack model. Finally, a scheme is outlined for solving the "inverse problem" of unknown crack shape and unknown orientation, based on ideas of shape optimization in conjunction with the boundary element method of solution of the integral equations.

A Discretized Green's Function for a 3-D Fluid Loaded Elastic Halfspace with a Surface Breaking Crack

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---We consider the scattering system consisting of a crack which breaks the surface of an otherwise homogeneous three dimensional isotropic elastic halfspace, which itself is coupled to a fluidic halfspace. The general scattering problem is solved by numerically constructing, for a given crack configuration and at a given frequency, a discretized Green's function (DGF) for the entire scattering system. The construction is achieved essentially by performing discrete quadratures of the continuous Green's function for a fluid loaded halfspace. The final product is a function which gives the crack-opening displacement, at each discrete point on the crack surface, due to a point force of unit magnitude applied at any one of the discrete points. In this talk we highlight the two most important features of this DGF: (1) Having it is equivalent to solving the scattering problem for any incident field; and (2) symmetry checks such as scattering reciprocity can be applied directly to it, without the need for two explicit incident fields. Numerical results which demonstrate these two points will be presented. Regarding the former point, this model is currently being integrated into an overall beam model for the calculation of transducer response. ---This work is supported by NIST under cooperative agreement #70NANB9H0916 and was performed at the Center for NDE, Iowa State University.

Transient Scattering of Rayleigh-Lamb Waves by Surface-Breaking and Buried Cracks in a Plate

---S.-W. LIU AND S. K. DATTA, DEPARTMENT OF MECHANICAL ENGINEERING, AND CIRES, UNIVERSITY OF COLORADO, BOULDER, CO 80309-0427, AND A. H. SHAH, DEPARTMENT OF CIVIL ENGINEERING, UNIVERSITY OF MANITOBA, WINNIPEG, CANADA R3T 2N2

---Transient waves generated by a ball impact on a glass plate and scattering of these waves by normal surface-breaking and buried cracks have been studied using a hybrid method that combines the finite element representation of the near field around the cracks and the Green's function integral representation of the far-field. Model results are compared with experiments using both a capacitive transducer and a PVDF sensor. It is shown that the source characteristics can be extracted quite well. Scattering of the waves generated by this ball impact by cracks is then investigated and transient waves received by an array sensor are then modeled. Comparison of model and experimental results shows excellent agreement.

Diffraction of Rayleigh Waves by "Kinked" Surface Cracks

---I. C. TSIRONIS, DEPT. OF MECHANICAL ENGINEERING, NDE CENTRE, UNIVERSITY COLLEGE LONDON, TORRINGTON PLACE, LONDON WCIE 7JE, UNITED KINGDOM AND L. J. BOND, ON LEAVE FROM UNIVERSITY COLLEGE LONDON, NOW AT NIST, BOULDER AND UNIVERSITY OF COLORADO AT BOULDER

---In fretting fatigue problems, such as those encountered in aircraft structures, complex surface breaking cracks are found. The main problem in these situations is that the cracks usually start at an angle to the surface and after they have grown to some depth, they turn to grow normally to the surface. It would therefore be desirable to know from NDI results in which stage the crack growth is, so that the suitable measures can be taken. In this work, the far field reflection coefficients for a kinked crack with initial angle of 45° to the surface were found. Three regions of interest were considered: $d/\lambda \leq 1$, $d/\lambda = 1$ and $d/\lambda \geq 1$ and the reflection coefficients were normalized with that for a quarter space. Ultrasonic spectroscopy was employed throughout and particular attention was focussed on the area when $\lambda/d \leq 1$, as this is the case for small cracks and widely used transducers (1-5 MHz). The experimental results were reproducible and agreed well with available analytical and numerical solutions. An inversion scheme has been developed which allows the crack to be characterized in terms of its length and orientation.

Rayleigh Wave Scattering from Three-Dimensional Hemispherical Depressions and Surface Slots

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---Rayleigh wave based NDE methods have been hampered by the lack of a theory to describe the scattering process. In previous meetings we discussed numerical schemes which model the two dimensional problem of plane Rayleigh waves scattering from plane defects, and recently we presented details of a simple three-dimensional model for Rayleigh wave scattering from surface slots. We have now developed a general mixed finite-element finite difference model for Rayleigh wave scattering from arbitrary localized surface defects in three dimensions. An irregular which accommodates the surface geometry is blended into a regular grid of finite elements. An explicit finite difference scheme is used to advance the solution in the regular grid region and an unconditionally stable implicit scheme is used in the irregular grid region. The computational requirements of the three dimensional models are large but can efficiently exploit distributed memory parallel processor systems such as the iPSC/860. We will present details of our new general model and preliminary results for pulsed Rayleigh waves interacting with a hemispherical depression and a cubic slot.

Phase Shift Determination of Scattered Far-Fields and Its Application to an Inverse Problem

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---The phase of the scattered far-field from flaws is focused and the phase shift analysis is carried out to quantify the scattered waveforms. The basic tool of the phase shift analysis is the integral representation of the scattered wave field. The scattering amplitude of the scattered far-field is first defined. The phase shift of the scattered far-field is then introduced by expanding the scattered far-field into partial waves with spherical wave components and taking into account the form of an energy relation. The phase shift introduced here means the shift of the constant phase in the scattered wave from the phase in an incident wave. The far-field integral representation for the scattered field is utilized to derive the explicit expression of the phase shift and the integral representation of the phase shift is obtained as a surface integral over the flaw. This integral representation is true for arbitrary flaw shape and it relates to the flaw geometry and the boundary conditions on the flaw surface. The boundary element method is advantageously adopted for the determination of boundary quantities on the flaw surface. As an application of the phase shifts in the scattered far-field, a flaw shape is reconstructed from the information of the phase shifts.

Ultrasonic Flaw Classification Using A Quasi-Pulse-Echo Technique

---CHIEN-PING CHIOU AND LESTER W. SCHMERR, CENTER FOR NONDESTRUCTIVE EVALUATION AND DEPARTMENT OF AEROSPACE ENGINEERING AND ENGINEERING MECHANICS, IOWA STATE UNIVERSITY, AMES, IOWA 50011

---One of the important flaw characterization tasks in the field of ultrasonic nondestructive evaluation is to provide flaw type information by analyzing the flaw responses acquired during an inspection. Here, we present a new quasi-pulse-echo ultrasonic classification technique that utilizes the time separation and amplitude difference of mode-converted diffracted signals to distinguish between smooth versus shape-edged flaw geometries. Experiments with cylindrical cavities, surface-breaking fatigue cracks and slag inclusions have been used to test the practicality of this approach. All results of these tests show good consistency in the separation of smooth versus sharp-edged flaws provided that the signal-to-noise ratio is sufficient. Furthermore, the scattering feature used for classification in this method is also verified by detailed elastodynamic scattering calculations.

Flaw Characterization and Sizing Using Sensitivity Analysis and the Boundary Element Method

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---The scattered field from an arbitrarily shaped flaw due to a known incident field can be obtained numerically using the boundary element method. In this so-called forward problem the flaw shape, it's location, the incident field and the properties of the material are always known apriori. However, in nondestructive evaluation information regarding the flaw shape is not known apriori. Instead, a finite number of scattered field measurements are available for a known incident field from which the flaw shape is to be determined. Problems of this type are referred to as inverse problems. Here we solve the inverse problem by combining numerical optimization, boundary element method and sensitivity analysis. In this approach the forward problem for an assumed flaw shape is solved first. Then for the assumed shape the sensitivity of the scattered field with respect to the different parameters that describe the flaw is computed. The solution to the forward problem, the sensitivity of the scattered field and the experimental measurement of the scattered field are then used as the driving mechanism for the optimization. The optimization involves minimizing the error between the computed and experimentally measured scattered field by appropriately redefining the shape parameters. In this paper this solution strategy for the inverse problem is exemplified for identifying the shape and size of a single crack. Here the forward problem and the integral equations for evaluating the sensitivities are formulated as hypersingular integral equations and solved using the boundary element method.

Ultrasonic Measurements and Modelling of Cracks Ligaments Using Corner Effect

---P. CALMON, CEA, 91191 GIF SUR YVETTE CEDEX, FRANCE, AND O. ROY, INTERCONTROLE, SILIC 433, 94583 RUNGIS, FRANCE

---Some results are presented about focused ultrasonic examination of blocks containing cracks close to the outer surface. The ultrasonic response is mainly due to the existence of a corner effect which is currently used during the detection stage. The echodynamic curves produced by this echoe can be used in order to characterize the ligament between the outer surface and the bottom of the crack and also the height of the defect. The two peaks shape of the echodynamic curves is explained and can be predicted with a simplified model using the focused beam properties. An inverse method based on this model for sizing the cracks and the ligaments is also proposed and discussed.

Errors in Determining the Flaw Centroid by Using Area Functions

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---The area function formulated from the Born approximation, a weak scattering approximation, has been widely used to determine the centroid of the flaw to assist implementation of ultrasonic inversion schemes, such as the 1-D Born Inversion. However, because the formulation is based on a weak scattering approximation, model-based errors occur when the area function is applied to a strong scatterer to determine the position of the flaw centroid, even with perfect scattering data. In this paper, we report an investigation of errors in flaw centroid determination with area functions using numerical and experimental scattering data from voids and strong scattering inclusions. The effects of scattering strength and finite bandwidth on the errors are shown. In addition, we present a simple method which extracts the flaw size directly from the shape of the area function, without requiring the determination of the position of the flaw centroid. The numerical and experimental results for estimating the sizes of a number of volumetric scatterers directly from the area functions are presented. The results show very good agreement between the true sizes and the estimated sizes.

Ultrasonic Flaw Sizing-Some New Approaches

---SUNG-JIN SONG AND LESTER W. SCHMERR, JR., CENTER FOR NDE AND THE DEPARTMENT OF AEROSPACE ENGINEERING AND ENGINEERING MECHANICS, IOWA STATE UNIVERSITY, AMES, IA 50011

---One of the challenging tasks in the field of ultrasonic NDE is to obtain quantitative flaw size, shape and orientation information. Recently, we have developed a simple time-of-flight equivalent flaw sizing method that can size relatively large flaws in terms of an equivalent best-fit ellipsoidal shape without extensive and time-consuming scanning. In this technique, the only information required for sizing is the path length between the "entry" point of the incident wave into the material and the front surface of the flaw, and the entry point location itself. Typically, this information is available once time-of-flight, wavespeed, and geometrical/positional measurements are taken. Here we will describe the elements of this new sizing method and its implementation in several different experimental configurations. For small flaws, where the method fails due to measurement errors, we will also describe a new amplitude-based equivalent flaw sizing method and describe its performance in some initial numerical tests.

Application of High Resolution Inversion of Ultrasonic Data to the Imaging of Multi-Layered Composite Structures

---K. I. MCRAE, DEFENCE RESEARCH ESTABLISHMENT PACIFIC, FMO, CFB ESQUIMALT, VICTORIA, B.C., CANADA

---The overall process of forming a structural model using ultrasonic data is called inversion. Inversion methods are designed to estimate the acoustic impedance profiles (or, equivalently, the reflection coefficients of each interface) from ultrasonic A-scans. The development of appropriate inversion procedures would improve the interpretation of ultrasonic data by improving the resolution and removing multiple reflections. Recently, a rapid, stable, high-resolution inversion technique has been developed which combines a L2 norm deconvolution with a "macro" layer-stripping approach to the inversion problem. This method may be further combined with an optimization-based procedure, provided there exists adequate prior knowledge concerning the structure. These techniques are illustrated using ultrasonic A-scan data obtained from multi-layered structures, such as composite materials, followed by the formation of two-dimensional B- and C-scan images. The implementation of the former inversion algorithm on a high-speed ultrasonic signal processing system, based on a TMS320C30 processor, is also described.

Automation of Disbond Detection in Aircraft Adhesive Joints Through Thermal Image Processing

---D. R. PRABHU, ANALYTICAL SERVICES AND MATERIALS, INC. AND W. P. WINFREE, NONDESTRUCTIVE EVALUATION SCIENCES BRANCH, MS 231, NASA LANGLEY RESEARCH CENTER, HAMPTON, VA 23665

---The presence of disbonds in aircraft lap joints and doubler adhesive joints is a major concern today, due to the increasing average age of aircraft. Thermal NDE for the inspection of disbonds is proving to be a fast and effective method to scan large areas of aircraft fuselage. Manipulation and interpretation of thermal images obtained from such an inspection technique is a monotonous time-consuming operation, especially in the presence of noise, uneven heating, and small-sized disbonds. A computer-aided image analysis procedure for automating disbond detection making the process fast and efficient is required, which can be used on-line in conjunction with thermal NDE imaging. In this paper, an algorithm is presented that uses search techniques for "template matching", followed by optimal local thresholding. The algorithm operates on thermal images, and highlights only those regions of the images that correspond to disbonds. Results using simulation data are presented for lap joints with various disbond sizes. Disbonds detected in the simulated thermal images agree well with inputs to the simulations. Results using thermal images of sample aircraft panels are also presented, and these are in good agreement with an ultrasonic characterization of the panels. --- This research was supported by NASA's Office of Aerospace, Exploration and Technology under Contract NAS1-18599

Real-Time Eddy Current Monitoring of Fatigue Crack Growth

---T. E. CAPOBIANCO, ELECTROMAGNETIC TECHNOLOGY DIVISION, NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY, 325 BROADWAY, BOULDER, CO.

---We describe the use of a differential eddy current probe to monitor the growth of a fatigue crack from a starter notch in real time. The cracks for this study were grown in aluminum flat plate specimens using a variety of starter notches including small drilled holes and electrical-discharge-machined (EDM) notches. The specimens were fatigued in four point bending. The probe consists of a circular outer drive coil containing a pair of inner pickup coils connected in series opposing and is glued on top of the starter notch. The data show that the probe is sensitive not only to the actual macroscopic fatigue crack growth but also to microscopic events leading to the formation of the crack.

Experimental Investigation of the Interaction of Elastic Longitudinal and Shear Waves with a Solid-Solid Interface for Different Contacts

---M. DE BILLY AND F. LEOMY, GROUPE DE PHYSIQUE DES SOLIDES, UNIVERSITE PARIS 7, TOUR 23, 2 PLACE JUSSIEU, 75251 PARIS CEDEX 05 FRANCE

---The interface between two solids is very difficult to simulate theoretically. The objective of this experimental study is to analyze the influence of the nature of the bonding between two limited or semi-infinite solids on the reflectivity measurements. The results are compared with theory based on Murty and Pilarski theoretical approaches. Welded interfaces and glued interfaces are studied. The influences of the parameters such as the thickness of the intermediate layer, the frequency and the viscosity are also investigated. The reflection coefficients are plotted versus the incident angle for longitudinal and shear polarizations of the incident bounded beams. Different samples have been investigated such as semi-infinite medium bounded with a plate or a substrate; a plate glued or welded with another plate of same or of a different material. For these samples the dispersion curves of the "elastic system" are plotted and analyzed. The frequency domain ranges between 1 and 4 MHz. Two different experimental methods were developed for this investigation according to the nature of the sample, a frequency analysis and an angular analysis. The agreement between the theory and the experimental data is reasonably good. The possibility of using the experimental curves as a way to solve the inverse problem of interface properties evaluation is discussed.

Ultrasonic Determination of Dissimilar Interface Strength in Diffusion Bonds

---G. C. OJARD, M. S. HUGHES, D. K. REHBEIN AND O. BUCK, CENTER FOR NONDESTRUCTIVE EVALUATION, IOWA STATE UNIVERSITY, AMES, IOWA 50011

---Diffusion bonding is a well known metallurgical joining technique which allows similar and dissimilar materials to be bonded together in near net shape. Diffusion bonding of dissimilar materials is of unique interest as the amount of interdiffusion between the two materials controls the strength of the resulting bond and can change during its service life. The resulting thickness and uniformity of the interface can be correlated with the mechanical properties. The challenge at the present time is to find ultrasonic techniques that are sensitive enough to detect small changes in the interface. Present work indicates that a total energy measurement can differentiate various qualities of Cu-Ni diffusion bonds. This measurement is based on Parseval's theorem which states that the energy in the time domain is equal to the energy in the frequency domain. The total energy technique will be compared to other techniques. Cu and Ni were chosen for the present study due to a lack of formation of a second phase. --- This work was sponsored by the Center for Nondestructive Evaluation at Iowa State University and was performed at the Ames Laboratory. Ames Laboratory is operated for the U.S. Department of Energy by Iowa State University under Contract No. W-7405-ENG-82.

Assessment of Bond Quality Between Metal Components

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---Experimental results supported by theoretical modeling aimed at the determination of the quality of bonds in metal components are presented. Attempts are carried out to differentiate between "good" and "bad" bonds in such models. Here good bond is simulated mathematically by invoking rigid bonding conditions at the interface which require continuity of displacement and stresses. Bad bond, on the other hand, is simulated by a smooth interface where all interfacial shear stresses vanish. The experiments are carried out on steel-steel and aluminum-aluminum samples. Although good agreement between the experiments and the theory is observed for must situations, appreciable differences are detected between good and bad bonds at only isolated regions of angles of incidence and frequencies. We have also demonstrated strong dependence of the dispersion characteristics on the thickness of the bonding glue. For relatively thin bonds, we demonstrate strong coupling between the metal components as is evidenced by the presence of two modes as compared with only one for a single plate. As the thickness of the glue increases, the two modes coalesce, indicating the disappearance of the coupling. --- Work supported by Regie Nationale des Unises Renault under grant V16965 and by Nato International Scientific Exchange Program CRG 900318.

Reflection of Ultrasonic Waves From Imperfect Diffusion Bonds

---I. YALDA-MOOSHABAD, F. J. MARGETAN, T. A. GRAY, AND R. B. THOMPSON, CENTER FOR NONDESTRUCTIVE EVALUATION, IOWA STATE UNIVERSITY, AMES, IA 50010

---In one category of weak diffusion bonds, the bond plane contains a distribution of microscopic defects (e.g. cracks or contaminants). The quasi-static models can predict reflection coefficients for normal and oblique ultrasonic inspections of such bonds for certain defects geometry. These reflection coefficients can be used to access the detectability of imperfect bonds and to optimize bond inspections. We present a general numerical technique for obtaining interface reflection coefficients for imperfect bonds between similar materials. A numerical boundary element method is utilized to find the far field scattering amplitude of a single defect for a normally or obliquely incident plane wave. The normal or oblique incidence reflection co-efficient for a planar distribution of such defects is then obtained from an independent scatterer model. This approach can be used for inspections of imperfect bonds with different defects geometries at the interface and at all frequencies provided that the defects do not interact with each other. --- This work was sponsored by the United Technologies Pratt & Whitney under P. O. #F452635 and was performed at the Center for NDE, Iowa State University.

Coherent and Incoherent Scattering of Ultrasonic Waves from a Rough Solid-Solid Interface

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---A solid state joint between two dissimilar materials is modeled by a random interface profile. A theoretical study of the interaction of ultrasonic waves with the rough solid-solid interface is presented. The reflection and transmission coefficients for longitudinal and shear incident waves are calculated as a function of the angle of incidence within the framework of a second order perturbation theory. The effects of the various material combinations, as well as the statistical interface parameters, are investigated. These results are used to determine the roughness induced attenuation of the coherent fields as a function of the above parameters. In addition, the relation between the incoherent part of the scattering cross sections with interface roughness is examined. --- This work was supported by the Office of Naval Research under Contract N000 14-88-K0452.

Photoinductive Imaging Studies of Cu-Ni Diffusion Bonds

---S. MITRA, G. C. OJARD, N. NAKAGAWA AND J. C. MOULDER, CENTER FOR NDE, IOWA STATE UNIVERSITY, AMES, IA 50011

---The photoinductive (PI) imaging technique has been used in preliminary experiments to characterize Cu-Ni diffusion bonds. Photoinductive imaging is a photothermal technique that uses an eddy current sensor to detect the temperature fluctuations caused by laser generated thermal waves. The series of bonds under investigation were prepared under varying experimental conditions (e.g. bonding temperatures and bonding times) to give rise to different bond strengths and interdiffusion layers. Eddy current methods are seen to be insensitive to the strength and nature of these diffusion bonds and only show the change in conductivity of the sample as a scan in made across it. We demonstrate in this study that thermal wave techniques coupled to eddy current methods are more sensitive to bond characteristics.

Ultrasonic Inspection of Brazed Titanium Samples with Complex Shape

---JOACHIM BAMBERG, MTV DAUTSCHE AEROSPACE, DAUCHAUER STRAPE 665, 8000 MUNCHEN 50, GERMANY

---Titanium is a very important basic material for aero-engines. One possibility to make strong joints of this material is brazing. In this way, complex, hollow component parts can be produced. The ultrasonic inspection is a powerful method to test the completeness of the brazed junctions. In order to assist the process development of brazing of complex shaped titanium parts, we have carried through such measurements in transmission technique. The equipment used and the results of the measurements are presented. It will be demonstrated, how the lateral resolution can be increased by axicon-lenses. For ultrasonic inspection of samples with additional non flat surfaces special dies were prepared. They reduce the complex geometry into a simple square-building block, which can be inspected by two-dimensional scanners. The limits of this method concerning the resolution and the sample dimensions will be discussed.

Application of Laser Shearography Technique to Characterization of Weld Integrity of Aerospace Pressure Vessels

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---The laser shearography technique is a powerful tool in measuring out of plane deformation gradients through optical fringe patterns. The density of fringes in a region is proportional to the amplitudes of the local strain fields. The fringe patterns are produced by doubly exposing the object, i.e. before and after deformation, to the image plane. Any strain field anomaly due to the presence of flaws will cause a distortion in the fringe patterns. For experimental verification, flat plates were deformed by applying point-loads perpendicular to the plane at different locations. The resultant strain fields were modeled by finite element methods and compared to the experimentally obtained fringe patterns with and without artificially-created flaws in the plates. Good agreement between the two results was obtained. An initial feasibility study was performed to detect flaws in the weld regions of a thin-walled pressure vessel containing artificial flaws. The fringe patterns obtained were indicative of the presence of flaws. This paper presents the basis of the laser shearography technique, numerical and experimental results, and detailed analysis that leads to further development.

Ultrasonic Inspection of Thin Metal Butt Welds

---DANIEL P. MAZZONE, SYSTEMS RESEARCH LABORATORIES, INC., NDE DIVISION, 2800 INDIAN RIPPLE ROAD, DAYTON, OHIO 45440

---Inspection of a perforated metal tube used in drivers side air bag equipped automobiles is investigated. These tubes are made from perforated sheet metal with the ends butt welded and are representative of metal items containing safety-critical butt welds. Presently a combination of visual inspection and destructive testing is used. An ultrasonic technique would be more thorough, more reliable, and less costly, but offers a challenge because of the small non-perforated area around the weld and the small thickness of the metal. Automated inspection techniques were developed and samples were tested including unflawed, flawed, and one sample with drilled simulated flaws. A shear-wave, C-scan technique was used which generated repeatable results and in all cases, detected all known flaws present. In one sample case the tube was visually inspected as being good and ultrasonically inspected as flawed. Upon closer examination an inconsistency in the weld could be seen from the inside of the tube corresponding to the ultrasonic data, not readily detected by the visual inspection.

• FHWA: Research and Development Program

---ROBERT L. NICKERSON, CHIEF, STRUCTURES DIVISION, OFFICE OF OPERATION & RESEARCH DEVELOPMENT, FEDERAL HIGHWAY ADMINISTRATION, HNR-10, 6300 GEORGETOWN PIKE, MCLEAN, VA 22170

---The purpose of this presentation is to give an overview of the FHWA structures research division, and the future structures research program with emphasis on Nondestructive Evaluation (NDE). There is a lot of activity started in NDE, much of which will be of interest to those involved in NDE of large structures. The 1991 appropriations bill, Senate Report, "directs that the FHWA study and report...on the need for a university/industry center in the area of improving the effectiveness and reliability of highway systems, especially bridges, through the use of nondestructive evaluation techniques." The material in this presentation will cover the High Priority National Program Areas (HPNPA), goals of NDE in R&D, bridge management, including inspection and the latest developments in inspection technology. Special interest will be directed to the development of bridge sensing systems to alert bridge owners as to the "health" of their bridges that they may rest assured that their bridges are safe for crossing by the traveling public. In support of the High Priority National Program Area, FHWA in 1992 plans to sponsor a National Conference on NDE in Bridge Inspection. The goal is to convene and conduct a major conference of knowledgeable researchers, users and manufacturers of NDE systems to plan a research program for NDE as a part of bridge inspection and monitoring.

Thursday

Thursday, August 1, 1991

8:30 AM	Session XXIV	IMAGE and SIGNAL PROCESSING **W. Friedman**, Chairperson Smith Auditorium Pages 117-121
8:30 AM	Session XXV	THERMAL TECHNIQUES and APPLICATIONS **R. Thomas**, Chairperson Cleaveland Hall Pages 122-126
8:30 AM	Session XXVI	MATERIAL PROPERTIES (PLASTICS, CERAMICS, and OTHERS) **S. Datta**, Chairperson Kresge Auditorium Pages 127-131
8:30 AM	Session XXVII	UT SCATTERING - II **K. Langenberg**, Chairperson Lancaster Lounge/Moulton Union Pages 132-136
1:30 PM	Session XXVIII	POSTERS - MATERIALS PROPERTIES, ACOUSTIC and ULTRASONIC TECHNIQUES and SYSTEMS, OPTICAL and LASER TECHNIQUES, THERMAL TECHNIQUES, IMAGING, SIGNAL PROCESSING, TOMOGRAPHY Pages 137-158
3:30 PM	Session XXIX	NDE for THICK COMPOSITES **C. Fortunko**, Chairperson Kresge Auditorium Pages 159-162
3:30 PM	Session XXX	NEW TECHNIQUES **F. Iddings**, Chairperson Smith Auditorium Pages 162-165
3:30 PM	Session XXXI	OPTICAL TECHNIQUES **J. Wagner**, Chairperson Lancaster Lounge/Moulton Union Pages 166-169
3:30 PM	Session XXXII	ELECTROMAGNETIC TECHNIQUES (MOSTLY MICROWAVE) **W. Lord**, Chairperson Cleaveland Hall Pages 170-173

Limited Data Tomography Using a Minimal Support Constraint

---R. A. ROBERTS, CENTER FOR NDE, IOWA STATE UNIVERSITY, AMES, IA 50010

---This paper addresses the incorporation of *a priori* component geometry and composition information in computed tomography image construction in cases where insufficient measured data is available for a unique reconstruction from the data alone. A variational algorithm was developed which fits synthetic projection data, calculated from the *a priori* component information, to the measured projection data subject to a "minimal support" constraint in the image space. Two sets of variables are simultaneously optimized, corresponding to i) *a priori* data registration, and ii) missing data in the measurement (i.e. projection) space. The key to the success of the algorithm is a constraint which seeks to minimize the support of the difference between the experimental and synthetic data reconstructions in the image space. The algorithm is most effective in reconstructing compact, high-contrast flaws, such as cracks and inclusions, and in estimating dimensional anomalies. Examples of application to experimental data will be presented. --- This work was sponsored by the Center for Advanced Nondestructive Evaluation, operated by the Ames Laboratory, USDOE, for the Air Force Wright Aeronautical Laboratories/Materials Laboratory under Contract No. W-7405-ENG-82 with Iowa State University.

Application of Two-Dimensional Matched Filters to X-Ray Radiographic Flaw Detection and Enhancement

---R. M. WALLINGFORD, E. M. SIWEK AND J. N. GRAY, CENTER FOR NDE, IOWA STATE UNIVERSITY, AMES, IA 50011

---Matched filters have traditionally been used in radar and communication systems for detecting known signals in high noise fields. A template containing the known signal is correlated with the received signal and a thresholding detector is used to identify the presence of the signal in the correlator output. In this paper, we apply two-dimensional matched filters to detect and enhance flaws in x-ray radiographic images. The output of the matched filter can be displayed as a 2-D image showing bright areas where flaws have been detected. With suitable thresholding, the detector map can be superimposed on the original image yielding and enhanced version. Significant enhancement is realized even when the flaw signal is not exactly known a priori, as templates can be chosen to approximate the expected flaw shape in a sufficiently local area. Templates are also chosen based on predicted signals generated from the x-ray simulation software developed at Iowa State University. Results of matched filtering of several weld images and simulated images are presented for a wide variety of matching templates. In addition, a preliminary study of the signal distortion in the enhanced images is presented.

Study of Microstructural Characteristics Using Mathematical Morphology

---MATHEW S. CHACKALACKAL AND JOHN P. BASART, CENTER FOR NDE AND DEPT. OF ELEC. AND COMPUTER ENG., IOWA STATE UNIVERSITY, AMES, IA 50011

---In secondary electron images of silicon carbide reinforced aluminum metal matrix composites, many of the silicon particles appear connected. To determine the material characteristics, it becomes necessary to separate the particles in the image. Three morphological techniques have been developed to break the connectivity, which involve generating a seed for each individual particle in the image. Each seed is then regrown to approximate the parent particle onto an expanded image to prevent the seeds from reconnecting. The first technique, not fully automated, involves erosion by a large structuring element to break the connectivity followed by image expansion and regrowth. The second technique, which is fully automated, involves cluster fast segmentation and image expansion. Neither technique is very successful in faithfully reproducing the original shape of the particles even though each one successfully separated the particles. A third technique, a modified cluster fast segmentation algorithm, has been developed that is robust and is fairly successful in preserving the size and the shape of the original particles. From the first technique to the third technique the execution time increases by a factor of four while the error is reduced by a factor of two. Error was calculated with reference to a manual particle separation method.

A True Wiener Filter Implementation for Improving Signal to Noise and Resolution in Acoustic Images

---KENNETH W. MITCHELL, ROBERT S. GILMORE, GENERAL ELECTRIC CORPORATE RESEARCH & DEVELOPMENT CENTER, SCHENECTADY, NY

---Several authors have reported on the use of Wiener filters to improve the spatial resolution of flaws in ultrasonic c-scan images. However, most of these implementations have involved the use of a frequency independent constant to approximate the ratio of the power spectra of the signal and noise. The frequency independent approach works well in cases where the limiting noise is thermal amplifier noise (or white noise) and the flaw signals, which result from the interrogating ultrasonic pulse, have a relatively narrow bandwidth. Such a case is demonstrated using 50 MHz images of a 1951USAF resolution target produced in single crystal sapphire by ion beam lithography and diffusion bonding. The [001] cut single crystal sapphire scatters the incident pulse only at accidental flaw locations or at the ion beam etched target patterns. The limiting noise is amplifier noise not material noise. When both the flaw signals, and the noise, result from (scattering) the incident ultrasonic pulse, then the signals and noise have similar power spectra. In this case the resolving capabilities of the filter can be improved by using estimates of the noise spectral density. This is important because in many ultrasonic images the noise in a test piece is due to scattering at grain boundaries and therefore, like the flaw signals, can be measured directly. In our paper we examine the performance of a Wiener filter implemented using estimates of both the noise and signal spectra and compare it with one implemented using a frequency independent constant.

Influence of Filtering Techniques on Holographic Images in Non-Destructive Testing

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---Broadband holography has become a powerful tool in computerized non-destructive testing. Interpretation of images, however, is difficult due to the fact that perfect imaging of flaw sizes up to now is impossible. Wave mode conversion, multiple scattering, and inhomogeneities in the material give rise to artifacts in the image. Signal and data processing at different levels of the signal flow path (generally referred to as filtering techniques) may help improve the situation. We discuss the influence of the following filters on the resulting image. 1) The well known ALOC i, k-filter. This a nonlinear filter mainly used for data reduction purposes during the inspection of large scale components. 2) Inverse and matched filters. They improve echo shape and duration, which in turn influences lateral and axial resolutions of the image. Since inverse filtering is an ill-posed problem we apply a standard Tychonoff regularization which turns out to be equivalent to Wiener filtering in its simplest form. 3) Image processing. This might be a tool to gain more insight into the relationship between the holographic image and the flaw size and geometry under test. A flexible holography system has been developed which allows for continuous real-time image reconstruction. Data have been generated in field and on mockups using standard transducers as well as transducer array.

Ultrasonic Application of Wavelet Decomposition Coherent Grain Noise Suppression and Flaw Detection.

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---Ultrasonic reflections from small, closely spaced, and randomly distributed grains are often difficult to distinguish from the desired flaw target signal. It is well known that while the grain noise is coherent in temporal domain in that it demonstrates no amplitude variation with time, it does depend strongly on transducer position and frequency. Thus most conventional techniques are not capable to effectively suppress the grain noise. On the contrary, new processing methods utilizing the frequency diversity and spatial diversity of ultrasonic grain noise have been shown to be able to suppress the grain noise and at the same time affect the flaw echoes to a much lesser extent when the flaw size is significantly larger than the grains. Split-spectrum processing (SSP) originally developed by V. L. Newhouse is a very successful diversity technique in which a broadband signal is transmitted and the received signal spectrum is divided into a number of different frequency bands using Gaussian shaped spectral windows to obtain a set of frequency diverse decomposition signals. It was recently shown that SSP using Gaussian shaped narrow band filter bank is closely related to the Gabor decomposition time-frequency analysis. And a more computationally efficient frequency diversity technique based on time-frequency wavelet decomposition and non-linear processing of the wavelet decomposition was introduced by analogy to the SSP method. In this paper, we introduce a wide sense Gabor and wavelet decomposition SSP with different basic wavelets corresponding to Gaussian shaped and non-Gaussian, zero phase and non-zero differential phase SSP narrow band filter banks. Analysis and extensive comparison among the proposed wavelets and previously used wavelets on different experimental data are presented.

Temporal Leakage and Its Effects on Resolution in Deconvolution of Ultrasonic Signals
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---Digital resolution enhancement of ultrasonic signals has become widely used in many NDE applications. Of growing interest are high-resolution deconvolution techniques aimed at extracting "spiky" responses from ultrasonic NDE data. In any realistic situation, though, sharp impulse response features will not temporally lie on digitizing points. Any deconvolution technique can only attempt to represent such features with the available set of digitizing locations prescribed by the signal digitization. In the context of circular deconvolution this is very reminiscent of the spectrum estimation problem and, in fact, we find that the energy of the response series analogously leaks out to neighboring digitizing points - a phenomenon we have termed "temporal leakage". Obvious questions arise regarding what effects this can have on a (high-resolution) deconvolution and what can be done to combat these effects. In this study we look at the behavior of a number of deconvolution methods with respect to this problem. We suggest possible schemes for improving upon these deconvolution methods by specifically addressing the issue of temporal leakage.

Cycle Stacking of EMAT Signals.
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---The powerful signal averaging technique for improving the signal to noise ratio is inapplicable in many real-time signal processing applications. Individual EMAT signals which usually consist of many cycles of data can be subjected to a different type of averaging procedure. In this procedure, several cycles of the same EMAT signal are suitably stacked to produce one super cycle. The signal to noise ratio of the super cycle EMAT signal is significantly larger than that of the raw EMAT signal. Because the bandwidth of the signal is increased, cycle stacking also improves the dynamic range of defect detection capability. The results of application of cycle stacking on dynamically acquired EMAT data are presented.

Fast Pattern Recognition Method for Eddy Current Testing

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---Goals in qualitative and quantitative characterization of eddy current (EC) signals include the increase of defect detection sensitivity, the reduction of the amount of pseudo-defects, the discrimination between signals from defects and from complex part geometries, and the classification of defects. A signal analysis method that is to be used in automated testing, e.g. during the production of semifinished products such as bars, tubes and wires, must meet the demands of high throughput and reliability even in the presence of low signal-to-noise ratios. We present a method which, using image processing techniques, separates regions possessing significant signal structures from a two dimensional EC image. Further analysis of these regions, by determining specific geometric features and characteristic signal behavior, leads to an identification and classification of defects. The complexity of this secondary analysis can be adapted to specific test situations. Using stepwise data reduction and modern microprocessor systems this method allows a processing rate in excess of 100 kb/sec and makes it suitable for high throughput automated testing. For applications that require less speed, such as in maintenance testing of aircraft, the secondary analysis and associated software can be expanded to permit evaluation of more complex test problems and provide direct interaction with the test personnel.

Signal/Noise Analysis for Quantification NDE Capabilities in Complex Geometries.

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---The capability and reliability of an NDE procedure may be qualified by repetitive measurements on a series of flaws of varying sizes to provide a statistically significant sample of procedure performance. A probability of detection (POD) for fatigue cracks in flat plate specimens may be obtained using established methods. Signal/noise analysis from fatigue cracks and corresponding electrodischarge machined (EDM) notches in flat plate may be used to quantify relative response relationships. A signal response transfer coefficient may then be obtained by measurement of the respective signal response distributions from EDM notches of equal size in flat plate and in production components of complex geometry. Prediction of the crack signal response in the complex geometry may then be obtained by reference to the comparative responses of the EDM notches on flat plate and in the complex geometry. Predicted NDE capability in the complex part may then be obtained by analysis of the predicted crack signal response with respect to the component noise response distributions. This paper describes the measurements and methodologies necessary to predict the performance capability of an NDE procedure by comparison of crack and EDM notches response distributions.

Analytic Calculations and Numerical Simulations of Box-Car Thermal Wave Images of Planar Subsurface Scatterers.

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---We present an analytical Green's Function technique for calculating thermal wave images of planar subsurface scatterers, following pulsed surface heating. Numerical simulations based on these calculations will be compared with experimental boxcar thermal wave images. --- This work was sponsored by Army Research Office, under Contract No. DAAL 03-88-K-0089 and the Institute for Manufacturing Research, Wayne State University.

Numerical Solutions for Heat Flow in Adhesive Lap Joints

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---A technique for numerical modelling of adhesively bonded lap joints is presented. A typical geometry for a structure with an adhesively bonded lap joint is two relatively thin plates with a region of bonded overlap. To reduce the errors associated with the large aspect ratio of the lateral to the through-the-thickness dimensions, a grid with a large number of nodes is necessary for standard finite element models. Computational time is thus increased significantly and is prohibitive for three dimensional analyses. A formulation of the problem is presented where the heat flow through the thickness of the plates is approximated as quasi-static. This reduces the dimensionality of the problem by one and removes the difficulty due to the large aspect ratio of standard formulations. The resulting partial differential equation is solved using finite element analysis. The solutions are found to be in good agreement with analytical solutions.

Theoretical Calculations and Experimental Results of Thermal Diffusivity Measurement of Polymer Foils Using Low-Frequency Thermal Wave Method With IR Detection

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---We have measured thermal diffusivities of polymer foil samples using low-frequency thermal wave technique with IR temperature detection. The thicknesses of the samples were 10 - 100 μm. Theoretical calculations of the behavior of the thermal wave propagating in the low-diffusivity sample will be presented and the results of the calculations will be compared with the measurement results. Especially the effect of the interaction between the thermal waves propagating in the sample and in the surrounding air will be discussed. This is an important factor when thin and low-diffusivity samples are measured.

IR Thermal Wave Tomographic Studies of Structural Composites.

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---We report a real-time thermal wave tomographic technique. The surface is first flash-heated. We obtain a reference temperature/time curve, corresponding to a surface region beneath which there are no subsurface scatterers, and subtract it in real time from the time-dependent signal for every pixel of the image as it is generated. A pixel-by-pixel determination of the peak times of these subtracted curves is stored as a 512 x 480 tomogram. We will present applications of this new thermal wave tomography to NDE of structural composites. ---This work was sponsored by the Center for Advanced Nondestructive Evaluation, operated by the Ames Laboratory, USDOE, for the Air Force Wright Aeronautical Laboratories under Contract No. W-7405-ENG-82 with Iowa State University and by the Institute for Manufacturing Research, Wayne State University.

Thermal Wave Characterization of IC Metal Lines.
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---The difficulty of understanding and monitoring present-day failure modes in submicron IC Al lines is due in large part to the existence of complex interactions between individual surface and subsurface defects. The efforts and logistics involved in characterizing these defects with conventional technologies severely limit the frequency of such studies and since these methods are generally destructive they cannot be used for in-line monitoring. In this paper I describe how a thermal wave technique can be used for in-line monitoring of product wafers to detect potential failure modes of IC metal lines. This technique simultaneously combines surface topography imaging, performed with laser microscopy, with subsurface defect imaging, using thermal wave modulated reflectance [1]. From these images, we can detect, characterize and quantify the principal metal defects such as subsurface voids, precipitates, edge notches and hillocks [2,3]. The dominant defect types can thus be revealed and the degree of spatial correlation between defects determined. Since this technique is totally nondestructive, the device wafer may be repeatedly subjected to temperature and current stresses and re-imaged in order to determine the growth rates and interactions of the various defect types. This rapid imaging technique has been used to characterize metal films and to predict electromigration failure of metalizations from an early detection of defects and their growth progression in stressed IC lines. This thermal wave method results in a 20- to 100-fold reduction in test times compared to conventional electrical testing procedures.

Bonds NDE Using Stimulated IR Thermography
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---Bond failure in structure using soldered, brazed, riveted or stuck joints may lead to dramatic failure. For this reason, detection of disbonds is of prime importance. The stimulated IR thermography technique previously applied to delamination in carbon/epoxy and carbon-carbon composite may be used for this detection. The front face temperature of the structure, monitored by the IR camera after the heating by a heat pulse delivered by an extended IR source, is used for data reduction. An analytical model and feasability experiments were performed on composite-composite and metal-composite sticked lap joints samples a lack of stick being willingly created in the bond, and in metal-metal samples partially brazed. For two stacked lap joints samples, a lack of bonding as thin as 60 μm is detected in the case of two 1.8 mm thick carbon-epoxy samples, of a 1.8 mm thick carbon-epoxy sample bonded with a 1 mm thick aluminum sample, and of two bonded aluminum samples, 1 or 2 mm thick. The case of brazed brass samples was also studied.

Time-Resolved Infrared Radiometry (TRIR) for Characterization of Impact Damage in Composite Materials

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---A quantitative thermographic NDE technique for the characterization of impact damage in composite materials is under development along with supporting theoretical analysis. We have previously shown that the technique of time-resolved infrared radiometry (TRIR) is an effective method for quantitatively detecting coating thickness variations and for characterizing the degree of coating disbonding in terms of equivalent air gaps. The TRIR technique differs from other pulsed thermography techniques in that the surface temperature of the specimen is monitored as a function of time during the application of a step heating pulse to the sample. Full-field images with temporal resolution faster than video frame rates are acquired by disabling the vertical galvanometer in the infrared camera and scanning the heating source across the sample. The temperature-time response as a function of position on the sample is analyzed to provide thermal transit times indicating the depth of defects and the shape of the curve indicating the thermal resistance of the defect. We extend this technique to the study of composite systems by applying the results of a multilayer analytical model. Experimental results in both simple and hybrid composite systems will be discussed. The depth and lateral extent of interlaminar separation in composites subjected to impact loading will be presented. The use of lateral heat flow techniques to image vertical defect structures will also be examined. --- This work was sponsored by the Center for Advanced Nondestructive Evaluation operated by the Ames Laboratory, USDOE, for the Air Force Wright Aeronautical Laboratories/Materials Laboratory under Contract No. W-7405-ENG-82 with Iowa State University.

Fast Photothermal Inspection of Plasma-Sprayed Coatings of Primary Circulation Seal Rings of a Nuclear Reactor

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---An obvious need for NDE of sufficiently thin plasma-sprayed coatings has arisen in the industry lately. Traditional methods like ultrasonics and x-rays usually can not be used because of the high attenuation and the heterogeneity of the coating. Instead, photothermal techniques have been successfully applied. Thus, nuclear industry ordered a photothermal inspection of the plasma-sprayed coatings of two seal rings. The rings are 30 cm by diameter and they are used in the main pump of the primary circulation of the PWR-type nuclear power plant. In this paper we describe the whole measurement process: computer simulations to estimate the detectivity of faults and to optimize the experimental parameters, the design of the fast infrared scanning measurement system based on laser heating, the measurement, and the results of the project.

Comparison of Heating Protocols for Detection of Disbonds in Lap Joints

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---Thermographic imaging of bonded lap joints has been shown to be an effective technique for disbond detection. This paper investigates the effectiveness of three different heating protocols: single long pulse, a short burst and periodic radiant heating. Measurements are performed on lap joint samples with disbonds of varying shapes and sizes. Infrared images of the surface as a function of time are acquired. After processing, these images are analyzed to determine the contrast between the bonded and unbonded regions of the lap joint. The contrast is calculated from the moments of the regional histograms from the portions of the images corresponding to the unbonded and bonded regions of the sample. This measure of contrast enables optimization and comparison of the three different heating protocols. The results are compared to the results of numerical simulations of the thermographic technique

Line-Focus Acoustic Microscopy to Measure SAW Dispersion and Anisotropy in Thin-Film Coated Materials

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---Propagation characteristics of surface acoustic waves on thin-film coated elastic materials have been investigated by the acoustic microscope using a line-focus beam. Experiments were performed on the (001) plane of cubic crystals as well as on isotropic materials, both coated with crystalline films of various thicknesses. The phase velocities measured for various angles of orientation from a crystal axis display the anisotropy, and confirm the advantage of directional measurement by the line-focus acoustic microscope. The dispersion curves of surface waves propagating along a crystal axis were obtained for various thicknesses of the film. A comparison of experimental results with theoretical predictions showed good agreement.

SAW Dispersion in Diamond Films on Silicon by Acoustic Microscopy.

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---SAW dispersion measurements were applied to the characterization of diamond-like films (DLF) synthetically grown on a single-crystal silicon substrate. DLF-layered structures show great promise in industry as hard, protective coatings and where high heat-transfer is crucial. Recent advances in this field will be reported. Several specimens of DLF-coated <100> Silicon (Si) substrates with a film thickness range between 0.7 and 9 μm were investigated using both spherical and cylindrical acoustic lens systems in the frequency range between 200 and 600 MHz. The SAW velocities were obtained from the acoustic material signatures (AMS) at each frequency. The DLF/Si layered specimen yielded positive dispersion in a relatively narrow SAW velocity range. Substantial differences in the AMS traces and consequently in the SAW dispersion were obtained with point-focus beam (spherical lens) and line-focus beam (cylindrical lens) geometries. The major results may be summarized as follows: AMS curves were obtained on all DLF/Si specimens in spite of substantial surface roughness as large as 5 μm or 0.2 wavelengths in the thickest layers. The measured AMS differences are due primarily to the two different lens geometries. The variation in SAW dispersion arises from the polarization of the acoustic beam excitation that produces isotropic as well as anisotropic velocity results with point-focus and line-focus beams, respectively. The SAW velocity range in these positive dispersion curves is consistent with the known anisotropy in the cubic face (100) of the silicon substrate.

Ultrasonic Assessment of Thermal Damage in Ceramics

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---Structural ceramics are susceptible to microcracking damage due to thermal shock. Usually the damage starts at some critical thermal shock temperature and becomes more significant with increase of shock temperature. In this work the applicability of an ultrasonic method for the determination of the critical temperature and of the accumulated damage is demonstrated in aluminum oxide. The information is obtained via velocity and attenuation measurements using surface and obliquely-incident bulk ultrasonic waves. The anisotropic effect due to preferred orientation of the cracks has been estimated. It is found that the critical temperature for aluminum oxide is about 200°C. The damage increased steeply from 200° to 400°C and grew significantly above 400°C. The ultrasonic data are supported by microstructural studies of the damage.

Acoustoelastic Technique for Structural Plastics

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---Plastics like acrylics and polycarbonates are important structural materials for transparent enclosures in high performance aircraft. The ultrasonic nondestructive techniques widely used for metals should also be effective for these plastics. There are, however, two major problems encountered in dealing with plastics. First, because acoustic velocities are lower in plastics, it is difficult to launch Rayleigh and Lamb waves with standard wedges and immersion transducers. Second, the viscoelastic nature of plastics makes acoustic evaluation of stresses in them more difficult. The research we have conducted in this area has addressed the above issues. The problem of launching guided waves was solved by producing transducer wedges made of Silicone Rubber (RTV). Both Rayleigh and L-Cr wave transducers were developed and used for acoustoelasticity and flaw detection. Acoustoelastic measurements were made in both stress relaxation and creep tests. It was found that the acoustic velocity was linearly proportional to stress but was independent of strain during creep.

Ultrasonic Monitoring of Phase Transformations During Processing of $YBa_2Cu_3O_z$

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---In-situ measurements of ultrasonic (8-10 MHz) velocity and attenuation as a function of time and temperature from 20° C to 900° C were carried out. These results were compared with the phase diagram calculated for Y-Ba-Cu-0 from first principles using an asymmetric next nearest neighbor Ising model and applying Monte Carlo and CVM (Cluster Variation Method) techniques. The ultrasonic data support the theory of D. De Fontaine and explains the velocity and attenuation changes due to oxygen ordering in the basal Cu-0 plane in Y-Ba-Cu-0 polycrystalline samples. The ordering occurs during annealing at temperature predicted by phase diagram for the phase transformation from tetragonal; disordered, non-superconducting to orthorhombic; ordered, superconducting structure. The superconducting properties as a function of processing conditions were checked by magnetic susceptibility measurements. Increased stiffness was always observed when ordering took place; for the case of $YBa_2Cu_3O_z$, the superconducting transition temperature increases with increasing elastic modulus. The spatially averaged elastic modulus of a polycrystalline tetragaonal (non-superconducting) phase is 0.85 the modulus of the 91K phase and is 0.95 superconducting of the 60K superconducting phase. The particular sequences of phases which develop during heating are readily determined by this technique. It was observed that the 90K phase cannot be obtained if a peak temperature of 635° C is exceeded during processing. The processing routine for obtaining the 91K superconducting phase will be experimentally demonstrated and discussed based on the phase diagram predictions.

Thermal Diffusivity Measurement of Diamond Materials

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---We report the results of thermal wave measurements of diffusivities for two types of diamond: 1) Synthetic single crystals of varying isotopic content (from 99.93% C12 to 99% C13); and 2) Polycrystalline films produced by chemical vapor deposition. An in-solid mirage method is used for the single crystals. The temperature dependences of thermal diffusivities of both materials are also reported. --- This work was sponsored by Army Research Office, under Contract No. DAAL 03-88-K-0089 and the Institute for Manufacturing Research, Wayne State University.

Critical Current Measurements of High Tc Superconductors in a Scanning Low Temperature Cryostat

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---Attaining high critical currents in the new superconductor materials cast into the forms of wires and strips is still a difficult process. A noninvasive local critical current measurement technique would be valuable for determining the performance limitations due to processing or fabrication parameters. This paper presents measurements of local critical currents in these materials made using induced currents from a scanning probe. A special vacuum cryostat has been constructed that allows simulataneous cooling of samples to about 20K and scanning of AC electromagnetic induction generation and pickup coils over the sample surface. By using the "critical state" model for flux trapping in superconductors, the local full penetration field value and critical current can be determined as a function of position over the sample surface. Results are presented for materials in slab and coating forms. Supported by the Department of Energy.

A Study of Dislocation Starting Stresses in Alkali-Halides Using a New Ultrasonic Method.

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---The results of the first systematic investigations of the dislocation starting stresses in alkali-halide crystals having NaCl-type and CsCl-type structure obtained with the aid of a new nondestructive method [1] are present. It was found that the dislocation starting stress value in easy glide systems {110} <110> (NaCL-type) and {110} <100> (CsCl-type) is several times smaller than the static value of yield point for these crystals and practically doesn't depend on temperature. The positive correlation between the dislocation starting stress and the dislocation density also can be marked.

On the Characterization of Torsional Creep Properties of Viscoelastic Materials

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---The mechanical properties of viscoelastic materials are significantly changing with time, temperature, moisture content and the stress-strain state itself. To characterize the stress-strain state of the material the nonlinearly viscoelastic model was formulated in terms of the free volume concept. For the numerical evaluation of the constitutive stress-strain relations the time dependent material functions are needed. In this article an apparatus for characterization of the shear creep compliance function is presented. The apparatus was constructed mainly for determination of the creep compliance function as well as to study the limits of linear viscoelastic theory. To minimize the frictional forces all moving parts are embedded in air bearings. The lowest torque applied to the specimen and the smallest measurable angle of deformation are respectively $3,2\,10^{-5}\,Nm$ and $5\,10^{-6}$ rad. The apparatus is equipped with the environmental chamber constructed for temperatures from -100 C to 250 C. The characterization of the torsional creep behavior or dry and wet poly (vinyl acetate) will be presented.

Detection and Characterization of Fatigue Cracks in Thin Metal Plates by Low Frequency Resonant Modal Analysis

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---A novel technique is being investigated to detect fatigue cracks in thin plates. This technique combines the capabilities of resonant modal analysis and acoustic emission (AE). The resonance frequency of the plate modes generated by a noncontact, sinusoidal mechanical driving force varies due to the size and geometry of cracks. In addition, critical crack information can be obtained from the amplitude and phase of the AE burst with respect to that of the external driving force. Along with an experimental investigation, finite element modeling has been performed to simulate the resonant plate modes under given geometry and crack conditions. This paper presents the detailed results of experiments and numerical simulations.

Scattering of Waves from Multilayered Anisotropic Piezoelectric Cylinders

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---Exact analytical treatments supported by numerical illustrations are presented for the scattering of shear waves from multilayered concentric anisotropic cylinders with piezoelectric coupling effects. Piezoelectric "smart" materials are now being investigated for possible applications in the detection and control of dynamical parameters. The matrix transfer method is utilized to execute the final results in simple, compact form. According to this method, formal solutions are obtained for the individual cylindrical component which relates its displacements, stresses and electric field potential of one surface to the other. By satisfying appropriate interface conditions, results are obtained for the total system via the matrix transfer from one component to the other. Applications of this analysis are directly used for the assessment of interfacial conditions of the layered cylinders fiber-matrix interfaces in composite materials. Supported by AFOSR.

Wave Reflection and Refraction at a Slightly Undulating Interface

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---Currently, most of the ultrasonic techniques for the nondestructive evaluation of composite materials are based on the assumption that the interfaces between the plies are perfectly flat. In reality, interfaces between the plies in composite laminates are slightly undulated because of non-uniform resin thickness and fiber spacing, or because of interfacial defects such as interface cracks and delaminations. It is believed that many of the existing discrepancies between the theoretical predictions and experimental observations are, to some degree, due to this over-idealized assumption. The purpose of this paper is to study wave reflection and refraction at a slightly undulating interface between two solids. Asymptotic solutions to the coefficients of reflection and refraction are derived as functions of the incident wave angle, the incident wave frequency and the characteristics of the undulating interface. The method of asymptotic expansion is used in conjunction with the Fourier transforms. Critical angles for the incident wave are investigated and the conditions for the existence of the Stoneley waves are identified. Possibilities of using the critical angles and Stoneley waves in non-destructive testing to characterize interfacial strength and delamination are discussed.

BIE Analysis of Elastic Wave Scattering by a Nonlinear Interface

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---The ultrasonic scattering technique is one of the most prospective method to evaluate the quality of material interfaces, which is of great importance in predicting the failure process of composite materials and bonded materials. The outstanding mechanical property of an interface between two different materials is nonlinear behavior including separation, contact and large plastic deformation. In this paper, scattering problems of elastic waves by a partially damaged interface are solved by a time-domain boundary integral equation method. A nonlinear property at the damaged interface is modeled by a distribution of nonlinear springs. Nonlinear dynamic behavior at the interface and its effect on far-field scattering are numerically obtained by a step-by-step time marching analysis of the boundary integral equation. Results can be useful for ultrasonic techniques to measure bond-parameters and to evaluate defects and damages of material interfaces.

Ultrasonic Scattering from Anisotropic Shells

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---Scattering of ultrasound from an anisotropic shell is investigated theoretically. The shell is assumed to be embedded in an isotropic elastic medium, and the material surrounded by the shell is also assumed to be isotropic. We consider the shell to have an anisotropy which is the spherical analog of a transversely isotropic material in Cartesian coordinates. Field equations for this material are derived, and these equations are shown to be separable. In the special case of a fully isotropic material, the radial equations reduce to the spherical Bessel equations used by Ying and Truell (1956). For an incident plane longitudinal wave, the radial equations are coupled second-order ordinary differential equations with boundary conditions expressed in terms of stresses and displacements at both shell boundaries. Since solutions in both the isotropic host and core materials are known to within coefficients of the longitudinal and transverse wave potentials, matching stresses and displacements at the shell boundaries becomes a problem of using the anisotropic field equations to relate the inner and outer solutions. Both numeric and asymptotic methods are explored for solving the field equations in the shell. Results are shown to agree with the Ying and Truell solution as shell thickness goes to zero, and with previous results for isotropic shells of finite thickness. The effect of shell anisotropy on farfield scattering amplitude is then explored, to provide guidance in the experimental determination of shell properties.

Ultrasonic Backscatter From Microstructure
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---A rigorous theory has been developed previously for the early time asymptotics of backscattering from the microstructure of weakly scattering solids. This theory has a simply computable limit if the width of incident pulse is much larger than the grain size. This is the typical situation for the fine grained materials used in the manufacture of jet engines. We present simple closed form formulae for the scattering efficiency of hexagonal and cubic materials. These formulae roughly predict the power backscattered from a stainless steel and an alpha-titanium sample. Similar formulae are presented for mixed phase materials such as titanium α/β alloys. Finally, it is shown that the present rigorous results can be easily related to the independent scattering approximation (which approximates the power at the transducer as being proportional to the sum of the power backscattered from each grain). --- This work was sponsored by the Center for Advanced Nondestructive Evaluation, operated by the Ames Laboratory, USDOE, for the Air Force Wright Aeronautical Laboratories/Materials Laboratory under Contract No. W-7405-ENG-82 with Iowa State University.

Effects of Surface Roughness on Ultrasonic Flaw Signals
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---The ultrasonic detection of flaws in structural materials depends not only on the coherently reflected signal, but also on the noise that is generated by scattering from the microstructure. Surface roughness reduces the coherent signal reflected from the flaw. The material noise is altered much less for immersion probes. As a result the signal-to-noise ratio may be decreased substantially, with a consequent degradation of the probability of detection. In this talk, we describe the effects of surface roughness on coherently reflected flaw signals. It is assumed that the rms roughness is much less than the surface correlation length. In particular, the effects of surface roughness on the coherent signal are primarily accounted for by introducing frequency dependent reflection and transmission coefficients. The transmission coefficients are normalized by the normal reflection coefficient, and are approximated, in the ranges of interest in typical inspection problems, by a nearly universal function that depends only on the angle of incidence. Experimental and theoretical results are presented to show that the transmission coefficient is much less reduced (from its smooth surface value) than the reflection coefficient. The difference is roughly a factor of ten. The transmission coefficients are only weakly dependent on angle. The experimental results presented are for samples with roughness ranging from 5 to 50 microns, and for frequencies ranging from 2 to 20 MHz. --- Supported in part by NSF Tie Grant No. EC0-9008272.

Effects of Surface Roughness on Ultrasonic Backscatter

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---The ultrasonic detection of flaws in structural materials depends on the noise that is generated by scattering from the microstructure, as well as the signal generated by the defect. Surface roughness tends to randomize the phase of the incident pulse. Signals that depend on phase coherent detection are thus substantially affected, while signals that depend only on the magnitude of the field are much less sensitive. Consequently, surface roughness alters the material noise much less than the coherent signal reflected from the flaw (for immersion inspections). As a result, the signal-to-noise ratio may be decreased substantially, with a consequent degradation of the probability of detection. In this talk, we describe the effects of surface roughness on the incoherent backscatter generated by the microstructure using a simple model. Experimental results confirm the simple model, and are presented for samples with roughness from 5 to 50 microns, and for frequencies ranging from 2 to 20 MHz. Implications of the results are discussed for materials characterization as well as flaw detection. --- Supported in part by NSF Tie Grant No. EC0-9008272.

Relationship of Microstructure to Backscattered Ultrasonic Noise

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---An independent scattering model, recently proposed and experimentally validated, quantitatively predicts the relationship between the backscattered ultrasonic noise and a material figure-of-merit (FOM). For single-phased microstructures, the FOM has been found to be equal to $n^{1/2} |\overline{A}|$, where n is the number of grains/unit volume and $|\overline{A}|$ is the rms scattering amplitude of a grain in an effective medium. In this paper, we examine the accuracy of this relationship and consider its generalization to more complex microstructures. Studies are first described in which the noise is measured and compared to theory for nominally single-phased, stainless steel and commercially titanium pure samples. Noise measurements in T_1-6-2-4-6 and T_i-6-4 alloys are then described. These alloys have more complex microstructures and sometimes exhibit highly anisotropic noise which is not simply correlated with the features visible in an optical micrograph. Results of studies aimed at elucidating the underlying mechanisms of the noise anisotropy in terms of the FOM are reported. --- This work was sponsored by the Center for Advanced Nondestructive Evaluation, operated by the Ames Laboratory, USDOE, for the Air Force Wright Aeronautical Laboratories/Materials Laboratory under Contract No. W-7405-ENG-82 with Iowa State University.

Theoretical Predictions and Experimental Measurements of Echo Responses From Angled Targets

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---A recently-developed model allows the prediction of echo-responses from targets of various geometry and acoustic impedance. The model combines the retarded potential formula for the scattering problem, with the impulse-response method for the transducer diffraction effects. Stated assumptions and approximations allow both a generalization of the reciprocity principle from its already-known form for point targets, and the formulation to be explicit. Although the model is truly 3-dimensional, it is very economical in computer-time, since the computation involves integration of analytical results only over the insonified area of the target. In this paper, we use the model to predict echo-responses for cone-shaped and angled planar targets. The results are compared with experimental measurements. The implications for quantitative nondestructive evaluation are discussed. Particular attention is given to the physical interpretation of the results in term of scattering of the geometrical and edge waves components of the incident transient field.

Calculated and Measured Ultrasonic Response of an Elastic Cylinder Embedded in an Elastic Medium

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---The response of an embedded elastic cylinder to a plane wave propagating in a surrounding elastic medium is a useful and sensitive indicator of the state of the interfacial bond between the cylinder and the medium. The results of such measurements can provide quantitative information about the fiber/matrix interfacial bond in metal matrix composite materials and about changes in the state of the bond when the material is subjected to thermal or mechanical testing. We have calculated the theoretical response of cylinders with various elastic properties to a normally incident plane compression wave propagating in an isotropic elastic medium. By calculating the response for a range of frequencies, a spectrum is obtained containing a series of dips that correspond to resonant modes of waves traveling through the cylinder and around its circumference. Model specimens have been prepared which contain elastic fibers embedded in an elastic matrix. We have measured the response of these fibers using a broadband pulsed transducer with a nominal center frequency of 50 MHz and a focal length of 0.5 inch. By applying standard deconvolution methods to the acquired signals, it has been possible to obtain the spectral response of the fibers. Comparison of the calculated and measured responses show reasonable correlation between the calculated response of a perfectly bonded cylinder and a well bonded fiber. For weakly bonded fibers, the measured response displays a much weaker sequence of characteristic dips and a shift in the resonant frequencies. We will present these results and discuss the possibility of obtaining a quantitative correlation between the changes in the response and the quality of the fiber/matrix bond. This work was sponsored by Rockwell Independent Research and Development funds.

Acoustic Emission Monitoring of Aging Aircraft Structures

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---Effective non-destructive testing and evaluation of complete aging airframes is impractical, if not impossible, using conventional techniques such as eddy current, ultrasonics, radiography or dye penetrant. This dilemma results from the enormous number of fatigue prone sites which result from fasteners. It will be demonstrated that acoustic emission has been successfully used to achieve large area coverage with a minimal number of sensors resulting in the location of fatigue cracks which were later confirmed by conventional NDT methods. The acoustic emission detection of fatigue cracks was carried out on-line without the removal of fasteners; the NDT confirmation required the removal of large numbers of fasteners (about 600) and extensive down-time. Further, it was often necessary to load the airframe to open the cracks before conventional NDT techniques could find them. It is proposed that acoustic emission be used to identify "regions of concern" thus enabling conventional NDT resources to be focussed on identified problem areas.

Sample Preparation Techniques and Material Property Measurements of Hard Alpha Titanium Samples

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---Titanium alloys are widely used in applications that require high strength at intermediate temperatures, good creep properties and light weight. Much of the demand for these alloys is safety critical areas such as jet engine components. The criticality of these components requires that they be free of defects that could lead to failure. A concern in titanium alloys is the presence of hard alpha inclusions. Hard alpha inclusions also known as high interstitial defects (HID) are regions of interstitially stabilized alpha of substantially higher hardness than the surround material. They are the result of very high localized oxygen or nitrogen concentrations that increase the beta transus and produce a brittle alpha region. These brittle regions then act as stress concentrators in the material and can be a source of crack initiation that eventually leads to failure. The purpose of this work is to produce samples that simulate hard alpha defects as might occur in commercially produced titanium. The simulated samples will then be used to develop detection plans. In addition to reporting on sample preparation techniques, material properties of hard alpha will be provided.

Determination of Elastic Constants Using Acousto-Ultrasonic Technique

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---Evaluation of mechanical properties of thick composite is an important aspect in the structural analysis of such materials. There are several methods that are used to determine the elastic constants of thick composites. The ultrasonic measurement of elastic constants usually requires cutting specimens from the structure and finding the ultrasonic wave speed in different directions. The objective of this paper is to extract the elastic constants of thick composites nondestructively using acousto-ultrasonic signals which consist of obliquely reflected echoes and carry the information about the elastic constants. In this study acousto-ultrasonic signals were used to determine the elastic constants of unidirectional composites. Sensitivity of the results to the accuracy of the experimental data was evaluated and ways to improve the determination of elastic constants were explored. --- This work is supported by the Office of Naval Research.

Nondestructive Measurements of Plating Thicknesses of Copper and Nickel on Shim Stock and Nickel on Steel

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---AC magnetic bridges have been used to make nondestructive measurements of thicknesses of platings of copper and nickel on shim stock (brass) and of nickel on steel. The measurements are preliminary in that they are limited by the destructive measurements through which the nondestructive measurements were correlated. Measurements on the plated shim-stock samples show interesting groupings which lead to a study of the shim stock. That study revealed that the bridge (which has directional characteristics) can distinguish between directions which are parallel and perpendicular to the direction of rolling of the shim stock. Apparently, the difference, is in the resistivity and may be related to grain orientation.

Ultrasonic Evaluation of the Hydration of Thin Porous Aluminum Oxide Membranes

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---In this work the environmental degradation of thin porous aluminum membranes produced by phosphorus acid anodization has been investigated. The work was motivated by the fact that the hydration of aluminum oxide in a human environment is a possible mechanism of failure for adhesive joints in service. The aim of this work is to demonstrate such hydration experimentally and to determine the properties of the hydrated oxide for use in ultrasonic models of the adhesive joint interface. The hydration has been studied by ultrasonic and x-ray diffraction methods. It is shown that amorphous aluminum oxide is transformed to crystalline aluminum hydrate. During this transformation the density and the elastic properties of the material change. The elastic property change was measured by the platemode antiresonance method, which is applicable to very thin membranes. Due to the porous structure of the membrane hydration occurs much more efficiently and at lower temperatures than in bulk samples of nonporous alumina. It is also shown that hydration is more intense in salt water due to the change of pH. It is also shown that hydration has been accompanied by microcrack development. --- This work was sponsored by the Center for Advanced Nondestructive Evaluation, operated by the Ames Laboratory, USDOE, for the Air Force Wright Aeronautical Laboratories/Materials Laboratory under Contract No. W-7405-ENG-82 with Iowa State University.

Real-Time Evaluation of Ultrasonic Weld Inspections

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---Ultrasonic inspections in accordance with NAVSEA 0900-LP-006-3010 "Ultrasonic Inspection Procedure and Acceptance Standards for Hull Structure Production and Repair Welds" accepts or rejects a weld defect based on 1) the ultrasonic signal amplitude, 2) the length of the defect, and 3) the proximity of the defect to other discontinuities. The 3010 instruction for Class I welds has been implemented in a high-level computer language for automated evaluation of weld inspections. The source code runs on an IBM PC compatible using EGA color graphics and employs a hybrid, dynamic-memory, data structure to facilitate real-time evaluation of weld defects. Alternatively, a data file containing a C-scan image of the weld can be post-processed to determine the location of acceptable and rejectable defects in the weld. Results for the automated 3010 acceptance criteria are written to an ASCII file for permanent storage. In addition, a Hewlett Packard PaintJet can be selected to produce color maps of the weld inspection area, indicating the location of both rejectable and acceptable defects.

On-Line X-Ray System for Texture Measurement and Analysis in Steels

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---As the need for better materials quality increases due to greater competition and more stringent market demands, it is becoming necessary to create the means whereby the effect of the various processing parameters on product quality can be quickly and accurately determined. This paper will outline the progress to date of work done at McGill University in developing an on-line x-ray system for texture measurement and analysis. Work done in the past on this project by the authors has led to conceptualizing the use of position sensitive or energy detectors, coupled to an x-ray source whose wavelength is sufficiently penetrating to do both transmission and reflection geometry diffraction. Because of the unreasonable time required to measure complete pole figures, a software has been developed which allows the calculation of the ODF from limited data collected on many different poles as opposed to complete data sets measured on three poles. In order to test these simulations a laboratory prototype has been built. Data collected on the CPSD-120 is exactly that which it would be in the "real" on-line geometry.

Measurement Model for Ultrasonic Inspectability of Slots in Tubes

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---A computer model has been developed which predicts the ultrasonic inspectability of small, surface breaking cracks in pipes or tubing. The slots are rectangular in shape, may occur at either the ID or OD of the tube, and are oriented either axially or transversely with respect to the tube's axis. Ultrasonic inspection is via immersion, using mode-converted, 45-degree shear waves. It is assumed that the tube walls are thick enough that bulk wave modes are applicable. The ultrasonic transducer may have either an elliptical or rectangular crystal and may be either spot- or line-focused. The ultrasonic beam is simulated by using the Gaussian-Hermite model and scattering from the slots is modeled by the Kirchhoff approximation. These effects are combined using Auld's electromechanical reciprocity integral. Use of the model to predict inspections for various tubing diameters and thicknesses and for different sizes of slots will be reported. In addition, since the full fields of the ultrasonic beam are modeled, use of the model to predict scan plans for optimal detectability will be presented. Comparisons will be made to experimental data obtained from thin-walled tubing containing both ID and OD slots.
--- This work was sponsored by Westinghouse Electric Corporation under Research Agreement No. 34-34238-PR and was performed at the Center for NDE, Iowa State University.

Ultrasonic Assessment of Axial Fatigue Life Testing on Heavy Gauge Aerospace Aluminum Plate Containing Microporosity

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---Microporosity generated during the casting of aluminum ingots can be found in varying degrees in finished plate products processed from these ingots. Large pores and/or high concentrations of pores have been shown to have detrimental effects on the results of axial fatigue life testing which is routinely performed on the plates as a check of their potential performance in critical aerospace applications. Recently ultrasonic measurements have been made using pulse echo, immersion techniques on 7050 aluminum to measure the extent of the porosity. The results have shown a correlation between excess frequency dependent ultrasonic attenuation and fatigue life tests. These results agree with other theoretical and experimental published literature even though the porosity in our case is nonspherical. A correlation with longitudinal velocity is also presented.

Crack Depth Measurement in Thin-Walled Tubing by Time-of-Flight Diffraction

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---Ultrasonic time-of-flight diffraction uses the time of arrival of weak diffracted waves from crack tips to accurately size these defects. In this particular application, the tubing is 4.2 mm thick, and defect depths have to be measured to an accuracy of ± 0.1 mm for structural integrity purposes. Access is only from the side of the tube opposite the defect, and requires an immersion technique. In contrast to commercial systems for thick wall applications, 20 MHz shear waves are used to obtain the required measurement accuracy. Full waveform data is collected and presented in B-scan format. A modified Synthetic Aperture Focussing Technique (SAFT) is used to improve the signal-to-noise ratio. Signal readability is enhanced by using processing techniques such as time domain digital filtering and magnitude of the analytic signal. Experimental results on these particular defects showed that 45° - 45° transmit-receive angles gave significantly lower signal amplitudes than 55° - 55° combinations, contrary to theoretical expectations. The experimental results on laboratory-made defects showed that this TOFD technique was capable of measuring depths to the required accuracy of ± 0.1 mm, even under simulated field conditions.

P-Version Finite Element Modelling for NDE
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---The P-version of the finite element modelling technique will be used to model ultrasonic NDE of composite materials. The finite element model coupled with the inverse method will be used to define the internal structure, including flaws and defects. The major idea would be to get into pattern recognition and flaw signature analysis. The P-version allows the use of FE mech with aspect ratios up to 480:1 as compared to 3:1 in conventional FE (h-version) mesh. This feature is very important in the analysis of laminated composites which contain extremely high aspect ratios, material discontinuities, and embedded crack - all typical singularities of advanced laminates. Thus not only the individual layers of the laminate can be modeled directly, without averaging their individual properties, but also the adhesive joints can be included as layers. Thus one type of defect or flaw is identified after an ultrasonic FE model is performed, one can perform a finite element stress analysis of the structure with the flaws or defect modeled and this will help the engineer in making a sound decision whether the structure is safe and acceptable. In summary, the P-version of the finite element will give us the advantage of both investigating the type of defect and how that effects the strength of the structure that we have at hand.

Comparison of the Different Mathematical Models of Acoustoelasticity and Experimental Validation
---A. KHEDER AND B. DE HALLEUX, CATHOLIC UNIVERSITY OF LOUVAIN, MECHANICAL ENGINEERING DEPARTMENT, LOUVAIN-LA-NEUVE, BELGIUM

---The analysis of different physical approaches on the effect of stress on sound wave propagation in a solid medium which is homogenous and isotropic in a non-stress state, underlines the fact that the theoretical relations obtained by linking velocity propagation to strain, are not the same but that significant differences appear in the different approaches. While we can consider that the elastic constants of the second order are parameters in which the definitions can be considered as identical for each approach, it appears that the elastic constants of the third order do not have exactly the same physical content in the different theories. The cause of the differences in the content of these coefficients will be discussed. Finally we will compare the different formulas linking velocities with the published experimental results, to point out the relations which are best confirmed by experiments.

Influence of the Precipitations on Phase Transition of TiNi Alloy.

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---The purpose of this paper is to examine how the precipitations $Ti_{11}Ni_{14}$ and Ti_2Ni_3 change with heat treatment, and how the precipitations influence on R and M transition of Ti-50.7 at % Ni alloy. In order to determine transition temperature M_S, M_f, A_S, A_f, the R--T curves of 8 specimens have been measured, one of which is as hot-drawn, the others are annealed for 1 hour at 200, 300, 400, 500, 600, 700 and 800°C respectively, then cooled in furnace. Meanwhile, the metallographs and SEM/EDX of some selected specimens were observed. Combining the simultaneous measurements of internal friction, modulus and resistance in high temperature range, it is found that (1) in the specimens annealed at $T_a <$ 590°C (the recrystalline internal friction peak temperature is at 590°C), there appears a metastable phase $Ti_{11}Ni_{14}$, by which the transition of $R \rightarrow M$ is restrained and the transition of $B_2 \rightarrow M$ is promoted. As a result, the R phase is stabilized, M_S and T_R shift to the high-temperature with increase of T_a. The R--T curves appear to be flat and wide. (2) In the specimens annealed at $T_a > 590$°C, the phase $Ti_{11}Ni_{14}$ decreases with T_a, and a new phase Ti_2Ni_3 appears, the transition of $B_2 \rightarrow R$ is restrained. M_S and T_R shift to low-temperature. The R--T curves is narrow and sharp.

Study on Crystalline Kinetics of Metallic Glasses $Fe_{39}Ni_{39}Si_8B_{12}Mn_2$ and $Fe_{40}Ni_{40}P_{14}B_6$.

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---This paper deduced relation between the crystalline peak temperature T_p and heating rate ϕ theoretically, and confirmed experimentally. Firstly, the changes of internal friction Q^{-1} and Young's modulus E with temperature T for 7 specimens of the M.G. $Fe_{39}Ni_{39}Si_8B_{12}Nn_2$ have been measured by flexural vibration method at different heating rate ϕ from 2K/min to 8K/min respectively. Secondly, the measurements of DSC curves for the seven specimens have been performed at the same heating rate as mentioned above. Combining these results with that of DTA curves for 4 specimens of the M.G. $Fe_{40}Ni_{40}P_{14}B_6$ (the later was measured by Zhang Shou-Gou et al.(1)), it is found that all the relations between T_p and ϕ (which were obtained by means of the three methods) follow the equation $Ln(T_p/\phi) = H/RT + A$, by which the linear regression coefficient simulated is better than that by Kissinger equation. This paper presents an analysis on experimental results succinctly.

Identification of Acoustic Emission With Specific Cracking Events

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---Photoetched four point probe circuits are used to detect cracking events occurring as a result of micro-hardness indentations in glasses in ceramics. These tests are used to determine fracture toughness in very small samples of brittle materials. Acoustic Emission waveforms are recorded simultaneously with the output from the four point probe, thereby, permitting source identification of emissions with specific cracks. Measurements of the voltage drop across the four point probe will allow the detection of multiple cracking events and enable the determination of the final crack length. Environmental effects on crack growth and corresponding waveforms are also studied.

A Modified Self-Calibrating Technique for an Ultrasonic Bridge

---I. N. KOMSKY AND J. D. ACHENBACH, CENTER FOR QUALITY ENGINEERING AND FAILURE PREVENTION, NORTHWESTERN UNIVERSITY, EVANSTON, IL 60208

---A modification of a self-calibrating technique for the use of an ultrasonic bridge will be reported. The technique has been developed to measure the speed and attenuation of wave motion between the vertices of two wedge-like supports of the bridge, which are in dry contact with the test-specimen. The bridge is operated with four commercially available surface-wave transducers. Two of these are placed on the outer faces of the wedge-like supports of the bridge, and two on the specimen. In the modified technique the bridge is placed on the sample to be tested and measurements are carried out without further movements of the bridge, which greatly increases the reproducibility of the results. By an appropriate combination of measurements the effects of coupling between the bridge and the sample are eliminated and both the wave speed and attenuation are obtained.

A Frequency Domain Technique for Ultrasonic NDE of Sub-Half-Wavelength Structures.

---VASUDEVAN R. IYER AND VIKRAM K. KINRA, DEPARTMENT OF AEROSPACE ENGINEERING, TEXAS A&M UNIVERSITY, COLLEGE STATION, TEXAS 77843.

---Consider monochromatic plane-wave propagation through an elastic plate immersed in a fluid. Exact expressions for the transfer function of the plate in reflection, $H_r^*(\omega, s, h)$, and in transmission $H_t^*(\omega, s, h)$ are derived; ω is the frequency, s the slowness and h the thickness. To measure $H_t^*(\omega; s, h)$ two independent measurements are made using a pair of transducers in a pitch-catch configuration. In the first measurement, a "reference signal" through water is acquired. In the second measurement, the specimen in question is inserted in the wavepath and the "specimen signal" is acquired. The ratio of the Fast Fourier Transform of the specimen signal to that of the reference signal provides $H_t^*(\omega; s, h)$. In this paper we have developed a robust numerical scheme to deduce slowness (given thickness) or thickness (given slowness) from measured $H_t^*(\omega; s, h)$. Attention is primarily focussed on structures when thickness is less than on-half the wavelength of the ultrasonic wave. Results are presented for a variety of structures: metals, fiber reinforced composite materials, particulate composites, and metal matrix composites.

A Modelling and Experimental Study of the Efficiency of PVDF Film Transducers and Their Waveforms in Cylindrical Geometry

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---the efficiencies of PVDF piezofilm transducers were derived from the constitutive equations for both transmission and reception and for pulse-echo measurements. Experimental results were obtained and the efficiencies were compared to those of PZT transducers. The wave field produced by a piezofilm transducer applied to a cylindrical solid was modelled and the received waveforms were predicted for transmission and pulse-echo measurements based on the excitation source waveform. Analytical diffraction impulse responses were derived and its convolution with the source excitation was used to predict the received signals. Modelled results were compared with experiments and the agreements were good. --- Work supported by the Office of Basic Energy Sciences of the US Department of Energy.

Numerical Simulations of an EMAT Receiver System in the Time Domain
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---In a companion paper, a conservation law description of the Electromagnetic Acoustic Transducer (EMAT) transduction phenomenon is discussed. The governing equations and associated boundary conditions are formulated as part of a four-stage modeling approach. Field predictions are provided for the dominant Lorentz force contributions in two-dimensions. These particle displacement fields show excellent agreement with transient analytical results obtained based on the Cagniard-de-Hoop method. As an extension to the EMAT modeling process, this paper focuses on the development of an appropriate receiver model capable of converting the particle displacement field into a transient voltage response in an EMAT receiver coil. The same transient finite element code which describes the transmitter is then employed in reverse to compute the induced voltage response in the EMAT receiver coil. Theoretical simulations are presented to discuss the voltage response as a function of different receiver design parameters as well as variations of the incident elastic wave field. Especially the dependence of received voltage signals on the periodic wire spacing, angle of incidence of the acoustic wave fronts, and wave modes are examined. --- This project is supported by Timken Research, The Timken Company, Canton, Ohio 44706.

An EMAT Subsystem for Weld Inspection
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---Lasers and electromagnetic-acoustic transducer (EMATs) are two types of devices used in noncontact ultrasonics. These technologies are being combined as part of a system for automated weld inspection and control. In this project, laser-ultrasound is generated in a weldment several inches behind the torch. Part of the sound is incident on the sidewall of the weld pass, and is (partially) reflected from any defects there. An EMAT will be used to receive the laser-generated MHz-frequency sound. Because EMATs are inductive pickups (when acting as receivers) they are susceptible to electromagnetic interference (EMI) generated by the welder. Thus, special attention must be paid to suppressing the EMI. We describe various aspects of the design and construction of our EMAT and its electronics. The design philosophy of the EMAT receiver (coil geometry and resulting bandwidth and gain) is discussed. The EMI countermeasures are also discussed. The application of such countermeasures results in an estimated signal-to-noise ratio of about 20 when the EMAT is about 100 mm from the torch.

Realtime Ultrasonic Waveform Acquisition System
---RALPH HEWES, RICHARD HOGLE, LEWIS THOMAS, GENERAL ELECTRIC CORPORATE RESEARCH AND DEVELOPMENT, SCHENECTADY, NY 12301

---A high throughput waveform acquisition system has been designed for three dimensional ultrasonic inspection of industrial parts. The system architecture features a real-time 68030 processor for control of the data acquisition units, and a 68030 Unix processor for the operator interface and image processing portions of the system. The heart of the system is a 12 bit, 1 MHz to 2 GHz digitizer capable of digitizing and transferring to memory over 4 million samples per second, at rates up to 8000 waveforms per second. The system features a graphical user interface for selection of system parameters, an X-based image processing package that also performs real-time display of C-scans or B-scans during acquisition, and array processor capability for concurrent data analysis. Additional hardware units in a CAMAC crate are used to generate the C-scans and condition the signal for the waveform digitizer via linear and/or logarithmic amplifiers.

Measurements of Local Surface Wave Speeds by a Dual-Probe Laser Interferometer
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---A novel dual probe laser interferometer was presented at last year's meeting. This interferometer, which has the advantage over a single probe modality that it measures the surface displacements of the same signal at two locations, can be used for accurate determinations of propagation velocity and attenuation. In earlier work the wave pulse was short enough relative to the distance between the two points of detection to avoid overlap of the two signals. In the present paper, the applicability of the dual probe interferometer is extended to the case of overlapping signals. A signal processing method is employed to extract the surface wave velocity from the composite signal. Results are presented for the measurement of surface wave speed as a function of angle for an anisotropic material.

A Description of an Improved Homodyne Laser Interferometer

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---The characteristics of an improved stabilized Michelson laser interferometer are described. The interferometer uses a high-powered (90 mW), linearly-polarized, single longitudinal mode, diode-pumped, Nd:YAG laser operating frequency-doubled at a wavelength of 532 nm. The high power enables measurements to be made on surfaces which are considerably rougher than the mirror finishes usually required for this type of interferometer. On highly-polished surfaces the interferometer is operated using a neutral density filter to avoid saturation of the amplifier circuitry and keep the output linear with displacement. When investigating rough surfaces, the energy returned from the sample is only a few percent of the energy returned from the reference mirror. Due to the polarized nature of the laser beam the relative amplitudes of the light in the reference and sample arms can be adjusted by rotating a $\lambda/2$ plate, until the amounts of light returned from each path are approximately equal, yielding the maximum signal-to-noise ratio. Using a single longitudinal mode laser eliminates mode-beating effects, which are invariably present with more than one longitudinal mode. Although the individual longitudinal modes have frequencies which are normally in the hundreds of MHz range, the mode-beating caused by thermal drift between them has frequencies in the same range as the acoustic signals generated by laser ultrasound and tends to lead to a deterioration in the signal-to-noise ratio. The small size of the diode-pumped laser has enabled us to build a compact and readily portable device. Signal-to-noise ratio, bandwidth and sensitivity data are presented for typical rough and smooth samples. Acoustic waveforms generated by a pulsed, Q-switched Nd:YAG laser and detected by the interferometer are also shown.

Embedded Fiber Optic Sensors for Cable Evaluation

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---Optical fiber sensors have been embedded in wire and optical fiber cable to monitor strain or damage in the cable. In this paper we present an analysis of how both embedded point and distributed effect optical fiber sensors respond to axial and torsional effects on the cable. Several different cable geometries as well as cable sub-unit materials of both polymers and metals are considered. Experiments have been performed using in-line Fabry-Perot fiber sensors which have been embedded within a multi-strand cable during fabrication. The sensors have slightly different gauge lengths and are operated at two wavelengths to allow 1.) compensation for possible temperature-induced phase shifts, 2.) effective active interferometric system Q-point stabilization, and 3.) unambiguous determination of tensile or compressive axial strain. Preliminary experimental data indicates that such embedded fiber optic sensors may be used to determine axial strain during loading, maximum strain loads, as well as residual strain caused either by excessive cable loading or damage. The sensitivity and mechanical loading limits of the sensor and sensor materials as well as the possible hysteresis in the long term cyclic response of the embedded sensors are considered. This work has been supported in part by F&S Inc. and the Virginia Center for Innovative Technology.

Sapphire Fiber Interferometer for Microdisplacement Measurements at High Temperature

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---Standard silica based optical fibers are currently being used in a wide variety of sensing applications where the operating temperatures do not exceed 500°C. In many applications where higher temperatures are encountered and harsh environments are unavoidable, it is imperative that optical waveguides and coatings made of materials other than silica be considered. Sapphire (Al_2O_3) is a candidate material that possesses optical propagation properties in fiber or rod form, and can potentially perform without significant degradation under harsh conditions, including temperatures up to 2000°C. In experiments reported so far, unclad sapphire rods have been used only in intensity based sensors because of their large numerical apertures. Numerical apertures of silica-clad sapphire rods have been found to vary from 0.55 to 0.83 but their available core sizes are not sufficiently small to ensure single-mode operation at optical wavelengths. Since phase-modulated interferometric sensors are many times more sensitive than their multimode counterparts, methods of fabricating single-mode sapphire fibers are being investigated. In this paper, we report the use of a short-length, multimode sapphire rod as an extension to a Michelson configuration, but operated as a low-finesse Fabry-Perot cavity. We demonstrate the performance of such a device as an interferometric sensor, where the interference between the reflections from the sapphire-air interface and an air-metallic surface is observed for microdisplacement of the metallic surface which is placed close to the sapphire endface. We describe in detail the fabrication procedure and present results obtained from the detection of surface acoustic waves.

Thermal Wave Generation

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---Recent advances in laser induced thermal shock waves for use in Ultrasonic NDE have shown that there is a need for modelling the absorption of laser light into common structures. This is important for the optimal design of transducers, that will fully exploit the potential of the technique. The nature of the thermoelastic wave generated by the absorption of a very short pulse of high power laser radiation at the surface of a semi-infinite solid was predicted by, using Ready's equation to generate the temperature-time history. In the initial model the thermophysical properties of the target medium were assumed to be constant. The solution showed that the volume of material affected by the laser radiation is very small. Unfortunately the maximum values for the predicted surface temperature were unreasonably high. As a next step, temperature dependent thermophysical properties were introduced, and the resulting nonlinear equation was reformulated as a differential equation and solved numerically. The results showed that the peak temperatures decreased considerably. In pursuit of our goal in designing optimal transducers, a computer program has been written for multiple laser sources arranged in an arbitrary geometric pattern. The purpose of this is to enhance the generated Lamb or Rayleigh waves through suitable spatial and temporal arrangement.

Thermal Wave Lock-in Imaging of Cracks in Cu Microbridges Embedded in Polyimide*

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---Our thermal wave lock-in imaging technique has been applied to the detection of cracks in Cu microbridges, embedded in polyimide. Thermal wave images of such defects are presented for a range of lock-in frequencies from a few Hz to a few kHz. This imaging technique has been used successfully to predict failure rates for microbridge devices.

Transportable Photothermal NDE Equipment for On Site Measurements

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---We will present a transportable NDE equipment based on laser line scanning. The equipment consists of a remote control unit and a compact hand held measurement head that can easily be brought to the sample under inspection. The sample is heated with a line focused laser beam and the surface temperature of the sample is monitored with an IR line scanner located in the measurement head. The heating laser is placed in the remote unit and the beam is transferred to the measurement head via optical fibre. A two-dimensional scanning is obtained by combining the horizontal scanning made by a deflection mirror and vertical scanning made by the operator. The future applications will be in the aerospace and power plant industry.

Flying Laser Spot Thermal Wave IR Imaging.
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---We report calculations of flying spot signal profiles with realistic geometry, and compare with experimental data. Example flying spot thermal wave images are also presented. The implications of the calculations for interpreting our images are discussed. --- This work was sponsored by Army Research Office, under Contract No. DAAL 03-88-K-0089 and the Institute for Manufacturing Research, Wayne State University.

X-Ray Cone Beam Tomography with Two Tilted Circular Trajectories.
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---In X-ray cone-beam tomography, the only planar source trajectory that provides complete information is the infinite line. Such a source trajectory is not experimentally possible. To ensure complete data acquisition in cone-beam geometry we acquire data over two circular sources trajectories. The relative position of the two trajectories is related to the maximum aperture of the cone beam and to the sampling of the Radon space. We present here an exact method for performing this reconstruction using the first derivative of the 3-D Radon transform of the object. We analyze on simulated data the modulation transfer function (MTF) of the reconstructions codes (the object used for this analysis are sets of concentric spheres). Then we study the shape and level distortions along lines parallels to the rotation axis. We show that the MTF of this algorithm is homogeneous and follows the apodization function of the reconstruction code. For spherical objects along the axis of rotation, the relative mean square error for density stays within 2% for an aperture $\pm 30°$. (With a single circular trajectory, the relative mean square error may reach 20% at the same aperture.) With a double circular trajectory, horizontal artifacts are nearly suppressed, the only remaining artifacts are partial effect artifact. Finally we demonstrate the feasibility of this particular trajectory on experimental data, and compare the results of the double circular trajectory to those of the single circular trajectory.

Sharpness of Edges at Different Film Orientations in Film Based Tomography

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---The edge response in Film Based rotational X-ray Tomography (FBT) is being examined. The sharpness of the edge response is an important parameter indicating the system resolution and resolving power. It was found experimentally that in FBT the edge response is degradated much more than in conventional X-ray radiography and that this degradation in dependent on the film orientation. Analysis of the image generation process in FBT reveals that the blurring of edges is due to the generation of the intensity summation image. In FBT an image is generated by accumulating the radiation intensity passed through the object while rotating simultaneously the object and the film during the exposure. Keeping a one-to-one correspondence between a point in the imaged section at the object to a point in the film plane, a tomographic image, which is actually an intensity summation image is generated. The specific section of the object is selected by placing the film in a suitable orientation. In the present study, analytical expressions of the ideal response to the outer edges of highly absorbing objects, imaged by FBT with vertical and horizontal film orientations, are developed. Comparison of the theoretical calculations and experimental results are presented for objects with circular and rectangular cross section.

Ultrasonic Image Enhancement Using Order Statistic and Morphological Filters

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---Order statistic and morphological filters belong to a class of nonlinear filters that have recently found many applications in signal analysis and image processing. In this paper, order statistic and morphological filters have been applied to enhance the features of the ultrasonic signal when it has been contaminated by multiple interfering microstructure echoes with random amplitudes and phases. These interfering echoes (i.e. speckles or grain scattering noise) often become significant to the point where detection of flaw echoes becomes very difficult. We have examined order statistic and morphological filters for improved ultrasonic flaw detection. In particular, the performance of these filters is evaluated using different ranks of order statistics, and different shapes of structuring elements in the application of morphological filters. The processed experimental results in testing steel samples demonstrate that these filters are capable of improving flaw detection in ultrasonic systems.

Reduced-Parameter Deconvolution and its Application to an EC Probe Model

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---The typical deconvolution problem may be formulated as an n-dimensional minimization of an objective function, where n is both the number of points in the solution estimate and the number of parameters to be optimized. Introducing solution constraints or damping has been a popular way of limiting noisy or oscillatory behavior and of incorporating some *a priori* information. An alternative method explored in this paper is to represent the n-point solution by an m-parameter function ($m << n$). The selection of an appropriate function is highly problem-specific, but an insightful choice can produce a solution that is forced to exhibit known characteristics yet incurs very little increase in modeling error. The technique is illustrated with an example involving an axisymmetric EC bobbin probe designed to measure the annular gap between the pressure tube and calandria tube of the CANDU reactor.

Error Analysis and Ultrasonic Scattering Amplitude Estimation Using the Wiener Filter with Limited Prior Information

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---Flaw signals measured in ultrasonic testing include the effects of the measurement system. The measurement system response is both bandlimited and frequency dependent within the bandwidth resulting in flaw signatures which are blurred in the time domain and distorted in the frequency domain. The Wiener filter can be used to estimate the flaw's scattering amplitude by removing the effect of the measurement system in the presence of noise. The optimal form of the Wiener filter requires prior information about the noise and flaw distributions. Alternate forms of the Wiener filter can be stated when less prior information is available. This presentation will first address the theoretical error for scattering amplitude estimation assuming various levels of available prior information. Minimization of the error by balancing the contributions due to the bias of the error and the variance of the error will be discussed. The second part of the presentation will focus on application of the Wiener filter when an estimate of the average power spectrum of the noise is available but prior flaw information in unavailable. Results will be presented for a maximum-likelihood based method and for a residual sum of squares method.

A Model Based Approach to Acoustic Noise Power Spectrum Estimation for Normal Incidence Ultrasonic Testing

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---In acoustically noisy materials the effectiveness of pulse-echo ultrasonic flaw detection and characterization is limited by acoustic noise originating from non-flaw related scattering. The adverse effects of the noise can be minimized by digital signal processing techniques which incorporate an estimate of the average power spectrum of the noise. In principle, for a given ultrasonic measurement system configuration, acoustic noise signals can be measured and the average noise power spectrum can be estimated directly from the measured signals. However, since the power spectrum is a function of the system configuration, if a change is made in the system, the noise measurement and power spectrum estimation procedure would need to be repeated. This presentation introduces a model based approach to acoustic noise power spectrum estimation. The model incorporates a limited number of noise signals measured over a range of measurement system configurations. Regression procedures are used to establish a model capable of estimating the average acoustic noise power spectrum for any measurement system configuration within the range of configurations considered. The model accounts for transducer characteristics, instrument settings, water path length, angle of incidence, and depth of measurement into the material. Results are presented for the normal incidence case.

The Application of Seismic Tomographic Imaging in Nondestructive Testing of Piles.

---YANG XIN SHE, INSTITUTE OF GEOPHYSICS, ACADEMIA SINICA, P. O. BOX 9701, BEIJING 100101, P. R. CHINA.

---This paper describes a field evaluation of an algebraic reconstruction technique for the tomographic imaging of sub-surface velocity anomalies. We describe the construction of a three-dimensional concrete pile model and the acquisition and processing of seismic traveltime data through the model. Image reconstructions of the data sets, using an algebraic reconstruction technique and incorporating prior knowledge are presented and these are compared with the actual model. The hydroelectric spark vibrating sources are used and the distribution of defects in the model can be obtained. Reconstructions show that it is essential that accurate data are obtained as we demonstrate that relatively small errors in the traveltime data can seriously degrade the reconstruction. The other possible use in QNDE testing of material defects and the exploration of underground buried targets are also discussed.

Comparison of Neural Network and Markov Random Field Image Segmentation Techniques.
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---Digital images result from many nondestructive testing processes, and much current research is devoted to developing image segmentation techniques to perform automatic defect recognition. Neural networks and Markov Random Fields (MRFs) are two alternative technologies that are used for such analysis. Artificial neural networks are (simplistic) mathematical models of biological neural systems. The neural network approach treats object recognition as a functional mapping problem that associates an input pattern with a desired output pattern. For example, an image with a defect is mapped to an image with the defect highlighted. MRFs have been used to model localized texture characteristics. Techniques based on MRFs are founded in the well-established information theory developed in the 1940's by Claude Shannon and others. Bayesian hypothesis testing is the basis of image segmentation algorithms that produce interpretations that are "optimal" in a maximum likelihood sense. In recent years, both technologies have been successfully employed for various automatic image analysis tasks. This paper summarizes both schools and describes their relative strengths and weaknesses.

Artificial Neural Networks for Classification of Impact Damage in Composites
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---Ultrasonic RF signals obtained from impact damaged composites are processed using backpropagation and Kohonen's algorithms. Accuracies of classification in both time domain and frequency domain are compared. Time domain classification used the raw RF A-scans as inputs while for the frequency domain analysis, the signals were Fourier transformed and the magnitude spectra were the inputs to the networks. The backpropagation algorithm was implemented in a self-learning mode using correlation and nearest-neighbor approach for training the network. It has been found that the frequency domain implementation of the neural networks is very effective in classifying impact damages in composites. Classification accuracies of up to 88% have been obtained. This work was supported by Air Force contracts F33615-88-C-5402 and F33615-89-C-5612.

A Fourier Domain SAFT Algorithm for Ultrasonic NDE

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---A Fourier Transform Synthetic Aperture Focusing Technique (FT-SAFT) has been developed to attain high resolution in both scanning and depth directions, and to characterize the defects in size, shape and orientation. The conventional SAFT algorithm reconstructs each image element by summing up the received ultrasonic signals, which are properly delayed to compensate for ultrasonic path delays. The summing operation, however, reduces high frequency components and results in blurred images. Therefore, conventional SAFT has poor resolution compared to theoretical resolution. The newly implemented SAFT algorithm overcomes the blurring problem and provides us with a much higher resolution. The effect of the resolution is shown on simulated data produced by the Finite Element Method (FEM), and compared with the resolution of the conventional SAFT algorithm. In addition, it is shown that by using this new approach, computational cost is highly reduced.

A Finite Element Simulation of Ultrasonic SAFT Reconstruction

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---One particularly important factor in ultrasonic NDT studies is the detailed knowledge of the ultrasonic energy interaction with the material under test. Since the Finite Element Method (FEM) can be used to solve hyberbolic Partial Differential Equations (PDE), FEM does in fact provide an extended solution for the displacement of ultrasonic energy in simple elastic media. The goal of this work is to use the FEM as a test bed in order to simulate the action of a transducer array, and then use the resulting signals, along with the Synthetic Aperture Focusing Technique (SAFT), to study the parameters involved in the reconstruction of reflectors under test.

Ultrasonic 3-D Ray Tracing

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---This study is motivated by the need for application of three dimensional ray tracing of ultrasound to nondestructive evaluation of complex geometric models. A method is presented for solid objects whose surfaces are made up of nonuniform rational B-spline surfaces (NURBS). The nonlinear mathematical forms used in the geometric modeling of these surfaces are in the parametric forms rather than the implicit forms. The NURBS may be created analytically or by CAD packages such as the SDRC's Geomod geometric modeler. The information on the NURBS are included as part of the CAD model of a solid object and are readily available for post-processing. The numerical procedure of tracing all the reflected rays in the object is done recursively. Sample applications of the technique will be presented for objects of simple and complex geometrical shapes. This work was sponsored by Westinghouse Electric Corporation under agreement No. 34-34239-PR and performed at the Center for NDE, Iowa State University.

Application of Artificial Neural Networks to Thermal Detection of Disbonds

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---Thermal NDE for nondestructively evaluating aircraft lap joints and adhesive joints between aircraft skin and reinforcing doublers is proving to be a fast and effective technique for scanning large areas of fuselage in a short period of time. A new approach to processing data from such a technique is presented in this paper that employs an artificial neural network to classify locations in the test region as being bonded or disbonded. A 3-layered neural network is trained using heating and post-heating curves obtained from a 3-D simulation run of a lap joint with an embedded disbond. The trained neural net is subsequently used to test other simulation runs with disbonds of various types in various sizes. A high classification accuracy is obtained even in the presence of a significant amount of "added" noise. The network yields a high contrast between bonded and disbonded locations, and clearly reveals disbonds. Network output can be easily thresholded for automated disbond detection to directly yield images of the extent of bond in the sample. The present study using simulation data has yielded an artificial neural network which has been successfully used for the classification of experimental data. --- This research was supported by NASA's Office of Aerospace, Exploration and Technology under Contracts NASI-18599 and NASI-19236.

Signal Processing Applications to the In-Service Inspection of a CF-18 Aircraft

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---To reduce the weight of fighter aircraft, such as the Canadian Forces CF-18, designers have employed large amounts of composite materials in the aircraft structure. For example, the CF-18 is 10% graphite/epoxy by weight and, more importantly from an inspection point of view, nearly 40% of the aircraft surface area is of graphite/epoxy construction. Because this material is susceptible to impact damage that is not visually detectable, it is necessary to inspect very large areas of the aircraft outer surface. The areas of principal interest in this work include the CF-18 upper wing doors and lower inner wing skins. These regions were inspected on an in-service aircraft using an automated pulse-echo ultrasonic inspection system capable of inspecting large areas. The primary advantage of this system is seen to be the collection of data representing a three-dimensional volume of the structure for post-processing purposes. This acquisition scheme allows for the formation of multiple ultrasonic images following a single scanning operation. In addition, it allows the application of signal processing algorithms, if necessary, to improve the axial resolution of ultrasonic signals. The benefits of deconvolution signal processing to the interpretation of the ultrasonic A-scans and to ultrasonic C-scan images are demonstrated by applying several of these algorithms to data collected from an in-service aircraft.

Reflection of Elastic Waves by a Periodic Surface Profile of Small Amplitude

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---Interfaces between the plies in composite laminates are slightly undulated because of non-uniform resin thickness and fiber spacing, or because of interfacial defects such as interface cracks and delaminations. This phenomenon is even more pronounced in thick composites. This interfacial waviness, although of small amplitude, must be taken into consideration in the development of ultrasonic techniques for the nondestructive evaluation of thick composite materials. This paper presents a theoretical and experimental study of the reflection of elastic waves by a free surface with a periodic profile of small amplitude. The theoretical analysis uses the method of asymptotic expansion in conjunction with Fourier transforms. Asymptotic solutions to the coefficients of reflection are derived as functions of the incident wave angle, the incident wave frequency and the characteristics of the surface profile. Experimental verifications of the asymptotic solution are performed on aluminum plates using through transmission tests. The specimens are polished on one side and have various degrees of periodic waviness on the other side. Incident waves of various duration are generated by a pulse ruby laser on the specimen's smooth side and the resulting out-of-plane displacements on the specimen's wavy side are measured with a heterodyne interferometer. The frequency domain reflection coefficient is obtained by taking the Fourier transform of the time domain signals. In this study, critical angles for the incident wave are investigated and the conditions for the existence of the surface waves are identified. Possibilities of using the critical angles and surface waves ion nondestructive testing are discussed.

Ultrasonic Determination of Layer Orientation in Multilayer Multidirectional Composite Laminates

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---In fabricating multidirectional laminates, especially thick ones, it is important to insure and verify the correct fiber orientation of the various layers. In some cases, local in-plane waviness may be present in various layers. Previous investigations of this problem were based on backscattering immersion ultrasonics. This technique may be very sensitive to surface conditions and not sensitive enough in the case of thick composites. A self-calibrating through transmission contact shear wave technique is proposed here. The method is applicable to any multidirectional n-layer laminate with all layers of equal thickness and the same material properties. Contact shear transducers are coupled to the outer surfaces of the laminate and oriented with their principal axes parallel to the fibers of the outer layers. A tone-burst single frequency polarized pulse is transmitted. As this pulse passes through the various layers, it is resolved into two polarized component pulses along the principal material axes of the layer and emerges as two out-of-phase pulses of different amplitude. The amplitude ratio and phase difference of these pulses are related to the layer orientation and its thickness, respectively. The theoretical model was verified experimentally for a three-layer $[0_{10}/\theta_{10}/0_{10}]$ graphite/epoxy laminate.

Wave Attenuation in Thick Graphite/Epoxy Composites

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---Attenuation of waves in graphite/epoxy composite laminates is studied through an ultrasonic experiment and theoretical analysis of the recorded waveforms. The specimens are immersed in water and insonified by a beam of acoustic waves in a pitch-catch transducer arrangement. The received signals are analyzed by means of a theoretical model in which the composite is assumed to be a transversely isotropic and dissipative medium. A simple model of dissipation is proposed and calculations based on wave propagation in the laminate are carried out. The values of the damping parameters are determined through comparison between the measured and calculated waveforms of the reflected signal. Results are presented for several unidirectional specimens of different thicknesses. The assumed model of attenuation is shown to yield excellent agreement between measured and calculated waveforms in all cases.

Interferometric Measurements of Elastic-Wave Velocities in Thick Composites

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---The propagation characteristics of elastic waves are very strongly influenced by the physical attributes of fiber-reinforced composite materials: elastic anisotropy, fiber volume, pore content, and others. For example, fiber volume influences the phase and group velocities of the elastic waves while porosity is one of the principal causes of frequency-dependent absorption. In most thin-section materials, the velocities of elastic waves can be determined using phase-spectroscopic methods. In this approach, the complex Fourier spectra of two different ultrasonic round trips are utilized to calculate the phase and group velocities. However, this approach is not generally useful, particularly in the case of very thick materials, which can exhibit high pore contents. Such materials often exhibit high absorption coefficients, which prevent the observation of more than one ultrasonic round trip signal. To overcome this limitation, we have employed a special-designed, high-power ultrasonic interferometer. Our system uses a high-voltage (400 v) pulser with a very low (3 ohm) output impedance. The pulser, which can operate either in single-pulse or pulse-burst mode, is synchronized by a very stable, computer-controlled RF signal source. To determine the phase of the signal as a function of frequency, the system employs a phase-sensitive receiver, which is synchronized by the same RF signal source. Currently, our system can operate in the 50kHz-5MHz frequency range. Using this system in a pulse echo mode, we have been able to measure the elastic-wave velocities in 50-mm-thick materials that were fabricated using wet-filament-winding and undirectional-prepreg-tape processes. We used both 0.5- and 1.0-MHz ultrasonic transducers. Previously, in the case of the wet-filament-wound materials, only the through-transmission mode could be used. However, through-transmission measurements are fundamentally limited by more-demanding fixturing requirements and in that they are inherently group-velocity measurements. In this paper, we report our experimental results and interpret them in terms of local fiber and pore content. We also briefly address the calibration and other experimental issues.

Wide Field-of-View Ultrasonic Arrays for Thick Composites

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---Ultrasonic wavefields propagating in polymer composites are redirected by the material's anisotropy and their wavefronts experience phase aberrations due to inhomogeneities. An array of small piezoelectric receivers provides a means for sampling the amplitude and phase of the ultrasonic field at the surface of the composite. The small size of the receiving elements (less than half a wavelength) also yields a wide directivity pattern (which is determined by the composite anisotropy). Ultrasonic fields steered by the anisotropy of the composite and scattered from its interior are then more faithfully sampled by the small element at oblique angles of incidence than conventional transducers which are ten or more wavelengths in diameter. A new array-receiver system has been assembled. There are 32 elements in the linear array, each 1 mm in diameter. The use of piezopolymer film (PVDF or PVDF-TrFE) as the piezoelectric material produced receivers with wide bandwidth (0.1 - 10 MHz). Signal-to-noise ratio and low-frequency response been improved over our earlier array systems. Waveforms and wavefields measured with the wide field-of-view array will be presented. The features of a unique set of calibration specimens used to evaluate the arrays will also be detailed. We are employing the array for evaluation of thick composites, using reflection seismology processing schemes for imaging and materials characterization.

Elevated Temperature Deformation Analysis of Composites

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---Many composite parts exhibit large variations in material properties within a single part, making traditional prediction of the part's performance subject to large uncertainties. With large uncertainties, either a large factor of safety is required, or their is a high risk of failure. However, where variations in the local properties within the part can be measured nondestructively, a finite element structural response code can be used to predict the part's "as built" performance with significantly greater accuracy translates into lower mass, higher performance, and lower cost. This paper describes recent work to demonstrate the feasibility of extracting spatially varying elastic moduli at elevated temperature from nondestructive tests. X-ray computed tomography is used as an instrumentation technique to measure the deformation of the composite part under load at rocket nozzle operating temperatures. The significant results of this work were: (1.) X-ray CT has been demonstrated as an instrumentation technique to measure global deformation of a rocket nozzle composite part with accuracies sufficient to predict local elastic moduli, (2.) the ability to obtain accurate deformation data at elevated temperatures (2000°F) by CT has been demonstrated, and (3.) an algorithm to solve for the local elastic modulus of a ring based on its deformation under load has been developed and demonstrated. CT as an instrumentation technique has potential application to testing at higher temperatures and in other harsh environments than other methods. It is adaptable to a wide range of part geometries and materials, and is applicable to in-process monitoring for composite materials development. This work is sponsored by the United States Air Force Contract AL-F04611-90-C-0049 with the Air Force Astronautics Laboratory, Edward, California. Joe Hildreth was the technical monitor.

Condition Monitoring Techniques for Composite Wind Turbine Blades

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---Pulsed ultra-red thermography has previously been shown in this project to be capable of revealing some types of inclusions (PTFE) in glass/polyester composite plates. The inspection technique has been optimized using both 1-D and 3-D heat flow models and predictions for the detectability of various classes and sizes of defects made. The current paper will outline the numerical modelling work and show experimental data for techniques which can be used to detect and size air filled voids in 10 mm thick glass/polyester plate and a wood laminate sample. The extension of the work to consider the characterization of growling flaws in a 12 m long wood laminate blade in the course of a fatigue test is reported and results obtained working at a range of 5.5 m from the blade root, for growing flaws will be shown. Significant heat generation was also detected at a butt joint in the same blade for a substantial period prior to failure.

Thermoelastic Characterization of Stress During Crack Growth

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---This paper considers the application of thermoelastic stress analysis for characterizing the sum of the principal stresses in the region near a fatigue crack. A thermographic system has been developed for synchronously detecting variations in temperature due to periodic loading of structure. The output of a scanning radiometer is digitized and periodically averaged for a given time period. A timing signal to a material test machine synchronizes the applied load with the time series. The system is calibrated by comparing a measurement of the thermoelastic effect around a hole in an aluminum plate, dynamically loaded in uniaxial tension, to theoretical and numerical results. The technique is then shown to be applicable to characterizing fatigue crack growth.

Some Critical Issues on Thermoelastic Stress Analysis of Graphite Epoxy Laminates

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---Thermoelastic stress analysis (TSA) is an inspection technique whereby one measures the small, cyclic temperature variations occurring in a cyclically-loaded material and calculates stresses in the material based on the amplitude and phase of such variations. Recent papers on infrared TSA have illustrated the well-deserved virtues of the technique for quick, noncontact, full-field stress measurement and nondestructive evaluation. However, yet to appear in the literature are results of a number of critical experiments for the conclusive validation of the technique as a full-fledged quantitative stress analysis and NDE technique for laminated, fiber-reinforced, polymeric materials such as graphite epoxy. This investigation was designed to address the validation issue by providing results from several of these critical experiments and thereby illustrating some of the remaining problems in the application of TSA to graphite epoxy laminates. Graphite epoxy specimens with several lamination arrangements are included in the results. Experimental considerations such as loading frequency, stress range, mean stress, and lamination arrangement are investigated and compared to previously published results of independent investigators, where possible. Suggestions for further validation experiments and analytical needs are provided.

Time Resolved Elastic Waves Generated by Modulated Ion Beams

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---Ions impinging on metals and other materials have been used to modify near surface properties through ion implantation. This study investigates the mechanisms of elastic wave generation in aluminum by fast ions using a pulse modulated ion beam of variable energy in the range of 1-15MeV. Detection is accomplished using a small PVDF (polyvinylene diflouride) transducer. These time resolved experiments measure through transmission acoustic waves produced by 750 nanosecond pulses of energetic ions. The measurements were made as a function of ion beam energy and distance of the acoustic detector from ion beam epicenter. The experimental results show arrival times for longitudinal and shear waves at all positions which are in reasonable agreement with nominal acoustic velocities. The pulse shape varies with offset having the form of a "longitudinal wash" near epicenter and a distinct pulse shape at larger offset. The shape of the combined compressional and shear wave response for all offsets is in excellent agreement with a theoretical calculation based on a thermoelastic model developed for interpreting laser ultrasound experiments. This result is surprising since particle beams carry both momentum and energy unlike the laser case and were expected to produce wave shapes characteristic of both impulsive and thermoelastic sources. The experimental findings will be discussed in terms of the competition between these two source mechanisms in the regime where substantial implantation of the incident ions occurs. --- Support for this work has been provided by Los Alamos National Laboratory.

Optically Stimulated Electron Emission: Current-Voltage Response and Spectral Sensitivity

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---Experimental and theoretical results show that the phenomenon of optically stimulated electron emission (OSEE) is based on established principles of gaseous electronics. In the inspection of steel surfaces for residual protective grease employed in Solid Rocket Motor (SRM) manufacture, the sensitivity to grease amounts is ascribed to three processes, two of which are identified as absorption of light at specific wavelengths in the mercury emission spectrum. Factors involved in the persistent variability of OSEE encountered in practice are shown to include photo-activated chemical reactions with atmospheric constituents. In particular, water vapor is shown to have a profound effect on OSEE response which is ascribed to two physical processes. A variation in probe geometry from the commercially available equipment is shown to have potential for an increase in instrumental sensitivity in the SRM inspection.

Nondestructive Evaluation of Porous Materials by Using Airborne Ultrasonic Waves

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---Certain important properties of porous materials such as porosity, tortuosity, permeability and internal damping are not directly accessible from conventional acoustic measurements made on the frame itself. These quantities can be better assessed from measuring the slow wave propagation properties i the fluid-saturated sample, at least whenever the slow wave is detectable at all. We present a novel experimental technique based on the transmission of airborne ultrasound through air-filled porous samples. The suggested technique can be readily used to measure the frequency dependent velocity and attenuation of the slow compressional wave in a wide frequency range from 30 to 500 KHz. This technique is so sensitive that it can be used on low-permeability materials like natural rocks, too, where the more conventional water-saturation techniques have never been really successful. In good agreement with theoretical predictions, the slow wave velocity was found to be strongly dispersive at low frequencies where the permeability can be assessed. At higher frequencies, the slow wave velocity becomes more-or-less dispersion-free and the tortuosity can be determined as the principal parameter. Depending on the average grain size and the inspection frequency used, the attenuation coefficient is dominated by viscous or scattering losses and it also can be used to characterize the porous material. --- This work was sponsored by the U.S. Department of Energy, Basic Energy Sciences Grant No. DE-FG-02-87ER1374.9A000.

Time-Domain Ultrasonic Measurement of the Thickness of a Sub-Half-Wavelength Layer.

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---Measurement of the thickness of extremely thin layers is a problem of immense technological significance. Classical methods of ultrasonic nondestructive evaluation (NDE) of thin specimen break down for $h < 3\lambda$ where h is the specimen thickness and λ is the wavelength of the wave used to interrogate it. By using the theory of Fourier transforms, Kinra and his co-workers have developed a *frequency-domain* technique which extends the range to $(h/\lambda = O(10^{-2})$. The objective of this paper is to report the development of a *time-domain* NDE technique for the determination of the thickness of a sub-half-wavelength layer. Full time domain information of an incident wave measured in conjuction with the exact solution of the transmitted wave field through a layer were used to construct the transmitted time domain signal. This constructed signal was then compared with the measured transmitted wave to "INVERT" the thickness of the layer. Ultrasonic water immersion technique was used to measure the incident and transmitted wave fields. Results of this investigation showed that over a wide range of the ratio of the layer thickness to the wavelength, $0.014 < h_c/\lambda < 2$, the ultrasonic measured thickness, h_{NDE}, compared well with the mechanically measured thickness, h_C; see Table 1. It is envisioned that this new technique, which does not require the use of the theory of Fourier transforms and its attendant FFT hardware, will considerably expand the existing technology base.

Advanced Shearography NDT

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---Since 1987, electronic shearography has been applied to various critical inspection problems in a wide variety of aerospace programs. Recent developments that include Phase Mapping Shearography have made very significant improvements to image quality and simplified interpretation. Advanced shearography provides fringeless images of unbonds and delaminations in honeycomb, composites and bonded metallic structures. New test methods also can provide an NDT capability that is completely remote and non-contact. These techniques have been used on the Space Shuttle to inspect thermal protection materials up to 5 feet from the side of the External Fuel Tank, yet can image 1/2 inch unbonds through several inches of foam insulation in seconds. This paper discusses the theory of advanced shearography NDT and recent important aerospace applications.

Nondestructive Evaluation Using Shearing Interferometry

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---Shearing interferometry is becoming a valuable tool for nondestructive testing because it is nonintrusive and potentially applicable to large structures. Shearing interferometry is also less susceptible to environmental vibration than other optical techniques such as holography. Among the many different types of shearing interferometers are wedge shearing techniques and grating shearing interferometers. The common principle underlying all shearing interferometers is that a duplicate of the scattered wavefront from a test object is created, spatially shifted and made to interfere with the original unshifted wavefront. The various shearing techniques only differ in the way the duplicate image is created and spatially shifted. In this work, we undertake a comparative study of wedge shearing and grating shearing methods for identification of disbonds and crack-like defects in test structures. In addition, we propose a computer-shearing technique analogous to a double exposure scheme. Here the scattered light from the test object is collected in a CCD camera and digitized into an image processing computer as a two-dimensional integer array of gray level values. The creation of a duplicate image, the shifting process and the subsequent interference are done numerically. The relative merits of the three techniques as potential tools for nondestructive testing are evaluated.

Computed Speckle Decorrelation (CSD) and its Application for Fatigue Damage Monitoring

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---A video-based laser speckle technique has been developed for non-contact surface deformation analysis and mapping at speeds approaching video frame rates. This technique, Computed Speckle Decorrelation (CSD), makes use of the speckle decorrelation associated with surface deformation. In its current application, CSD is a method of full field inspection which has been used both to locate fatigue damage sites and to measure damage severity during fatigue deformation in reverse bending fatigue of a cylindrically notched aluminum specimen. With the development of the CSD method it will now be possible to examine in greater detail the progression of fatigue damage in thick graphite/epoxy composite materials, allowing a much faster and much more quantitative analysis than was previously available through film based techniques.

Light Scatterometry as an NDE Technique for Damage Evaluation of Infrared Ge Window after Rain Drop Erosion

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---Witness samples of Ge, uncoated with a thin diamond film, were impacted with a liquid jet impact device which simulates liquid drop rain erosion. The Ge samples were then characterized in transmission using a Nicolet FT-IR spectrometer (8-12 micron region) and in scatter using a TMA light scatterometer (0.67 micron). Transmission data was compared to scatter data in order to correlate the registration of damage as a function of transmission loss to the registration of damage as a function of scatter intensity. Metallography, SEM, IR transmission and light scatterometry results will be presented.

Nanosecond Scale Optical Pulse Separations for Holographic Investigation of High Speed Transient Events

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---High speed pulsed holographic techniques have proven useful in the field of nondestructive evaluation for the study of transient events. Typically, multiple Q-switching of a pulsed laser allows optical pulse separations no shorter than 10 microseconds, thereby imposing a lower limit on the lifetimes of events thus studied. In an effort to investigate events with lifetimes less than this 10 microsecond limit, new techniques for high speed holography are being developed. By employing a beam profile conserving optical delay line, pulse separations ranging from 25 to 450 nanoseconds have been generated. Using this delay line to produce optical pulses for holographic recording, shock fronts travelling near Mach 20 have been recorded.

The Random/RMS Full-Field NDE Technique Employing Scanning Laser Doppler Vibrometry.

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--- The Random/RMS full-field NDE method is introduced and described in this paper. The method, which appears to have great potential for in-field detection and monitoring of damage, employs scanning laser doppler vibrometry (LDV). LDV produces an output that is proportional to the instantaneous surface velocity component in the direction of the measuring beam. The velocity signal can also be used to determine structural mobility and hence offers another route for NDE. The Random/RMS method is explained along with several examples of defects that have been successfully detected in parts that include a honeycomb panel, engineer seal and electronic circuit board. The advantages and limitations of this technique will be critically appraised. The LDV sensor that was used is capable of testing structures up to 200 m away with a retroreflective surface and a sub 1 mW laser output. This means that at closer distances objects such as satellite dishes and aircraft can be tested in their natural state with no surface preparation and a relatively safe laser.

A Theory of Error in Photothermal Measurement of Weak Absorption of Optical Thin Film

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---In measuring weak absorption of optical thin film by applying photothermal deflection spectroscopy, we analyzed errors caused by theoretical approximations and a lower limit of absorbance of 2 x 10^{-7} was determined. It was achieved by first deriving theoretical formulas of weak absorption and then making thin-film approximations. Hence, it is proposed that carbon-black powder, should be used as the calibration sample in order to minimize error. This 'intrinsic' error was also calculated for various optical thin film.

Three-Dimensional FEM-BEM Computation of Electromagnetic Responses of Flaws

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---Electromagnetic (EM) nondestructive testing of a lossy dielectric material involves exciting the material with an external EM source, measuring responses on a measuring surface, and inferring the location and properties of possible flaws. But the interaction of electromagnetic fields with the material is a highly complex process. Three-dimensional computation is therefore required to accurately predict the overall interaction of EM fields with the material and flaws. The coupling of FEM and BEM provides an efficient tool for this purpose. But spurious solutions frequently occur. The tangentially continuous, "edge" element based FEM-BEM model, however, is found to be free of spurious solutions. In addition, curvilinear "edge" elements allow a good approximation to material interfaces. This model is used to compute the electromagnetic response of arbitrarily shaped flaws buried in non-conducting materials. In particular, we examine the change of responses on the measuring surface when the size, location and properties of the flaw are varied. These changes provide quantitative indications for identifying the flaw. --- This work was supported in part by NSF Grant #EET8714628 and in part by The Ohio Board of Regents Academic Challenge Program. Computational Resources on the Ohio Supercomputer Center CRAY Y-MP are gratefully acknowledged.

Microwave Scattering Properties of Dielectric Cylindrical Bodies with Defects.

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---The problem of detection of defects and inclusions in dielectric cylinders is investigated. The approach has been to study the scattering properties of such a body at microwave region as a function of the incident signal look angle, polarization and frequency. A plane electromagnetic wave with time harmonic variation strikes an arbitrary shaped dielectric body with homogeneous relative dielectric constant of ϵ_r. The incident field causes an equivalent current density to be induced in the body. This equivalent current density is often called the polarization current. The expression for the scattered field as a function of an incident plane wave is governed by Levine-Schwinger integrodifferential equation. Method-of-Moments (MoM) is used to solve for this scattered field for a finite radius and length cylindrical body with defects and inclusions. Results are given for defects with various shapes, sizes and dielectric properties.

Analysis of Microstrip Patch Antennas for Dielectric Measurement

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---For their low profiles, low weight and conformability, microstrip patch antennas have been widely used in some radar and communication systems. These antennas have also been employed in the measurements of properties of some materials and objects. In such applications, the material or the object interacts with the near field of the antenna, causing changes in the resonant frequency and the input impedance of the antenna. In connection with the measurement of dielectrics using microstrip patch antennas, no theoretical analysis seems to have been reported in the literature. In this paper, an outline of a theoretical analysis based on the spectral domain method for accurately quantifying the behavior of an ordinary and a stacked rectangular microstrip antennas under dielectric loading is presented. The variations of the resonant frequencies and the input impedances of these antennas with the dielectric constant, the loss tangent and the thickness of the dielectric load representing the material under test, are investigated. In the analysis, the antenna is assumed to be fed by a coaxial line from the back side. The effects of the feed position and the antenna thickness on the accuracy of the measurement of dielectrics are reported. Further potentials of the microstrip patch antennas in some NDE areas are addressed.

Exact Solution of Fields Outside an Open-Ended Rectangular Waveguide for Microwave Thickness Measurement of Dielectric Slabs.

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---The problem of an open-ended rectangular waveguide radiating into a dielectric medium is presented. A combination of Lewin's formulation for the admittance of an open-ended rectangular waveguide radiating into a dielectric half-space, and a modified Green's function expansion is used to model a finite dielectric layer. Calculation of the phase and amplitude of complex effective reflection coefficient is then used to formulate the geometrical properties of the dielectric layer namely its thickness. This technique is then modified to take into account the effect of the addition of a conducting plate to the dielectric slab. Results of several measurement comparisons are also given. This exact technique is quite simple to use particularly for industrial applications.

Microwave Imaging of Defects in Graphite Reinforced Composite Materials.
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--- Microwave reflectivity measurements are a potentially useful adjunct to Radiographic and Acoustic Imaging in locating and quantifying flaws in composite structures. Two-dimensional Fourier-Transform processing permits the localization of small scatterers in the presence of much larger reflections, provided complex reflectivity data can be acquired with very high accuracy and stability. Experimental data demonstrates that the sensitivity and resolution achievable are adequate to detect and localize flaws not easily observable with other techniques.

Measurement of Crack Depth in a Transition Weld Using ACPD
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---A tube of 316 stainless steel joined by an austenitic stainless steel weld to a tube of low alloy CrMo steel had a surface-breaking crack at the bond line with essentially constant depth and extending over the circumference of the weld. This paper is concerned with the measurement of the depth of this crack by the ACPD method. The method uses a uniform thin-skin field to interrogate the crack and measurements of surface potential difference made before and across it are then used to infer its depth from a one-dimensional formula derived on the assumption that the material is homogeneous. For a discontinuity in material properties, the theoretical model has been modified to produce Multipliers for the junction which can be used to reinterpret the homogeneous predictions. The paper compares measurements of actual depth with predictions obtained using Multipliers from both a simple theory and from more elaborate models, details of which will be published separately. Excellent agreement between actual and predicted depths is obtained.

Three Dimensional Modeling of the DC Potential Drop Method Using Finite Element and Boundary Element Analysis

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---Numerical analysis techniques are continually developing and their application to the modeling of electromagnetic NDT phenomena needs to be analyzed in order to quantify the relative advantages and disadvantages of each technique. This paper compares and contrasts the finite element method (FEM) and the boundary element method (BEM) as applied to three dimensional modeling of the DC Potential drop technique for characterizing fatigue cracks. A compact tension specimen with a finite thickness, is modeled. Calibration curves for crack depth prediction are compared to published experimental and numerical data. Computer resources required for the two techniques are also discussed. FEM, being a domain method generates full field solutions, ideal for energy/defect interaction studies, while an integral method such as the BEM is attractive due to the potential savings in the computer resources as it requires only surface discretization.

Friday

Friday, August 2, 1991

8:30 AM	Session XXXIII	NEW SYSTEMS **W. Rummel**, Chairperson Kresge Auditorium Pages 174-178
8:30 AM	Session XXXIV	UT TRANSDUCERS, CALIBRATION, and STANDARDS **J. Heymann**, Chairperson Lancaster Lounge/Moulton Union Pages 179-183
8:30 AM	Session XXXV	MATERIAL PROPERTIES (METALS) **O. Buck**, Chairperson Smith Auditorium Pages 184-188
8:30 AM	Session XXXVI	NONLINEAR TECHNIQUES in MATERIAL CHARACTERIZATION **L. Adler**, Chairperson Cleaveland Hall Pages 189-193

Nondestructive Magneto Inductive Testing of Rolled Plate and Sheet Quantitatively Determines Their Mechanical Properties and Reduces the Need for Traditional Destructive Tests

---B. LUTZ, INSTITUT DR. FOERSTER INSTRUMENTS, INC. PGH PA USA, MR. HAIDER, VOEST-ALPINE STAHL LINZ GES. M.G.H., AUSTRIA, E. L. MOSER, VOEST-ALPINE STAHL LINZ GES M.B.H. AUSTRIA

---Tensile strength and hardness of flat rolled products are mechanical properties that can be determined quantitatively with a modern Magneto Inductive Test System. By utilizing multidimensional regression analysis, it is possible to obtain absolute values for hardness and tensile strength. This method of analysis provides accurate information due to its ability to suppress interference phenomena, such as effects of material thickness and temperature. In our paper, a good correlation is shown for several steel grades between actual nondestructive test results and destructive test results. System calibration which is based on preparing samples with known mechanical properties is described. The quality and accuracy of the measurements obtained are dependent on the system calibration; which is essential to the level of success achieved. The resolution of the calibrated system is high enough to determine mechanical property variations across the sheet as well as over the length of a coil. Test measurements are accomplished within seconds allowing multiple readings to be taken rapidly. This permits accurate tracking of the measured properties during production. Test results can be immediately printed out, recorded, and/or used for further statistical process control. The entire program developed for successful testing can be stored for later use. The implementation of a modern magneto-inductive test system clearly improves the user's ability to measure mechanical properties during the production process. Proper utilization of test results improves the user's ability to assure quality standards are maintained and controlled for the properties being monitored.

SQUID Based System for Passive NDE of Ferromagnetic Materials During Deformation

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---An experimental system is described for in situ passive measurement of changes in the magnetic field of ferromagnetic materials subject to tensile deformation. Changes in magnetic field are monitored using a SQUID gradiometer. A single axis second-order gradiometer or a three-orthogonal axes first order gradiometer can be used. The gradiometer is held in a fixed position while the horizontal load frame can be scanned in two dimension. The horizontal load frame has been constructed from non-ferromagnetic materials. Preliminary results will also be presented.

A Host-X-Unix Based Image and Data Processing System for NDE Applications

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---A versatile, extensible NDE targeted image processing development environment (IPDE) that runs on a wide variety of platforms (SUN, DECstation, VAX, Motorola, Tektronix, and Data General) has been developed. Using the UNIX shell for its command interpreter, shared memory for data storage and communication between the various modules, and X for image display and interaction, IPDE is fully prompting and capable of obtaining "mouse" input. IPDE supports scale and offset information for as many of its up to six dimensions that each image requires, so that even after extraction, expansion, or reduction operations physically meaningful measurements are possible. In addition to the support of arbitrarily large arrays, IPDE supports linked lists together with operations for decision processing of image features after processing with its hundreds of algebraic, morphologic, frequency domain, and array manipulation operations. A large number of commands exist for display and I/O facilitate the use of data from many sources and presentation. Region of Interest processing, session scripting, and commands of specific interest to NDE (e.g. cscan and bscan of 3D ultrasonic waveform images) are additional features of IPDE. IPDE is currently used to process X-RAY, Eddy Current, and ultrasonic data for a variety of applications including aircraft engine parts and nuclear components.

Spreadsheet-Like Image Analyzer

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---The Army has implemented several nondestructive inspection systems which automatically analyze digitized images for defects. The systems archive the raw data and the inspection results in a digitized format on Sony 8mm. Each tape contains a file of thousands of images; each image represents one manufactured device; each device and image should be identical within spec to a standard device. The Army is now post-processing this large data base (up to 2.3 gigabytes per tape) for such purposes as to verify the results of the present inspection analysis algorithms, to develop new analysis paradigms, and to perform statistics on the anomalies of the product under inspection. This paper describes a software system being built by the Army for the recall and post-processing of these data sets. The controlling factor in the system's design is that the system be able to process thousands of nearly identical images. The user interface is similar to that of a spreadsheet, i.e. the user programs each cell with a process or function whose result is then displayed within a cell. The data, instead of being single values as is common in spreadsheets, are arrays of values. The arrays can be as simple as one number having no dimension or as complex as a multiple dimensional array of many numbers. The functions in the cells operate on the arrays with an array as the output result. The result can be displayed in numeric form, image form or chart form. The power in the system is that whenever any input value is changed all cell results which are dependent directly or indirectly on that value are updated automatically. The system is quite versatile, having the capability to analyze one image, or thousands of images with equal ease. What-if games, similar to the capability of spreadsheets, can be played.

High Resolution Ultrasonic Volume Scanning System Used to Inspect Composite Airplane Parts
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---A high resolution ultrasonic scanning system that digitizes the entire ultrasonic waveform is described. The operator can then simultaneously display A, B, and C-Scans, for subsequent analysis. All of the scan displays are related, changing one updates the others, allowing unambiguous inspection of the volume of data. Digitizing the entire waveform allows three dimensional images of the scanned part to be reconstructed as well as allowing interactive dimensional measurements of part structure or flaws. Images from laboratory and production scans of composite parts including impact samples with various ply layups, I-stiffened laminates, and honeycomb core cells will be shown.

Spartacus: A New System of Data Acquisition and Treatment for Ultrasonic Examination
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---Improved computer technology and technical advances in data analysis have significantly modified the methods employed to perform ultrasonic inspections. The SPARTACUS system developed by the CEA (French Atomic Agency) in an example of this progress. The nerve center of the system is a graphic workstation. The system permits full digitization of waveform while retaining high data acquisition rates of conventional system. In addition, it enables ultra fast analysis with comprehensive interactive imaging including signal processing (filtering, correlation, deconvolution...), image processing, spectrum analysis, automatic edition of report, 3D presentation. Some examples of applications are shown: improvement in sizing capabilities, examination of austenitic weldments; composite applications; thickness measurement, automatic detection.

PFS-GAP: A Large-Area Ultrasonic Gap Profile Measurement System

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---Some recent airframes require the fastening of fiber-composite and titanium structural components along large-area complex mating surfaces. To provide a more uniform fit, which prevents over-stressing portions of the composite mating surface, custom shims must be fabricated. Designing the shim requires accurately measuring the gap profile between the mating surfaces. However, this is extremely difficult due to the limited access once the structures are brought into close proximity. As part of a feasibility study for this application, a complete ultrasonic gap profile measurement system was designed, delivered, and demonstrated for Northrop Corporation. The PC-based system uses very thin "blankets" of piezo film sensors (PFS) to ultrasonically measure the spacing between two variable gap profile plates. The sensor blankets, which are double-sided taped to the mating sides of the movable plates, contain 3/4" diameter transducers located on 1" centers. The computer multiplexes each of the sensor locations, measures the time of flight between the sensor blankets, computes the actual plate spacing, and then displays the 2-dimensional gap profile. Broadband ultrasonic waveforms and gap profiles are shown which illustrate the system's ability to measure close-quarter gap profiles to an accuracy of ± 0.001".

The Concept and Implementation of Scan Plan Within the Integrated Design, NDE, and Manufacturing Sciences

---PETER JEONG, CENTER FOR NDE, IOWA STATE UNIVERSITY, AMES, IA 50011

---With the serious concern of U.S. industries on international competitiveness in manufacturing technology, a new program for integrated design, NDE, and manufacturing sciences was established at Iowa State University (ISU) in collaboration with Northwestern University (NU). The program integrates a variety of rapidly emerging disciplines associated with the integrity, or quality of a critical component or system, and couples with the established techniques of computer-aided design (CAD) and computer-aided manufacturing (CAM). The contributing disciplines quantitative nondestructive evaluation (QNDE), statistical modeling for quality assurance, process control, fracture mechanics, and materials engineering, finite element method for stress analysis, life-cycle reliability and cost modeling, and expert system (AI) networking. The result is a new engineering methodology that allows life-cycle integrity to be explicitly considered as a part of the synthesis of new designs for critical components and systems, thereby providing a realistic framework for design optimization. Research in NDE at ISU has injected models into this concept that permit, for the first time, consideration of NDE requirements to be made during the design process (NDE inspectability). In this new engineering methodology, NDE inspections are simulated during the computations of probability of detection (POD) model. Then, the NDE inspections simulated in the POD models must be translated into physical "scan plan" in the testbed. Scan parameters are initially established by the theoretical modeler and transmitted to an automated data acquisition system. Then, the system performs a data acquisition process according to the input parameters provided by the modeler. When the scan is completed, the image data and all pertinent scan parameters are sent back to the designer for further image processing and data analysis as necessary. The results of these analyses are then used for determining whether further improvement of product design might be necessary. This paper concentrates on the concept and implementation of the scan plan as part of the integrated design, NDE, and manufacturing sciences.

Emerging QNDE for Large Area Scanning.
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---A need exists for a QNDE technique that can scan large areas of an aircraft to determine whether that aircraft can be returned to service or should be placed into maintenance. The requirements for this "Large Area Scanner" technique and the system to perform the examination are that it: must cover large areas rapidly; will work in the depot and flight line environment; can be moved about and operated by a small (2 to 4 person) crew; provides the detection of flaws such as impact damage, cracking, disbond, and delamination; and yields data that can be archived and easily interpreted. Techniques have been found that promise to satisfy the above criteria. The more promising techniques include: D-Sight, Shearography, and Pulsed Thermography. Each of these systems will be described and discussed in terms of applicability and flaw detection capabilities.
--- This work was sponsored by the Department of the Air Force, SA-ALC, under Contract No. F04606-89-D-0039.

A Novel Micro-Spot Dielectric Film Measurement System.
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---The semiconductor industry is continually moving to thinner dielectric film (<100A), more complex film structures (e.g. oxide on polysilicon on oxide on silicon) and smaller lateral geometries (<1μm). The attendant measurement requirements demand more than incremental improvement of existing methods. In this paper, a novel laser-based dielectric film measurement system is described that meets these requirements by bridging the gap between spectrophotometer speed and ellipsometer precision and versatility while measuring with a 0.9μm focused laser spot. The operating principles of this new system are discussed and thickness and refractive index data presented for a number of single and multi-layer film structures used in IC processing.

A New Conservation Law Description of an Electromagnetic Acoustic Transducer in the Time Domain

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---Electromagnetic Acousti Transducers (EMATs) generate elastic surface and bulk waves through electrodynamic principles over practical lift-off distances of up to 3 mm. They are therefore ideally suited as noncontact sensors in industrial applications where high temperature and surface roughness of the specimen as well as rapid inspection are of interest. In this paper a novel unified theoretical formulation describing the electromagnetic-acoustic transduction processes governing an EMAT is presented. This approach establishes separate description for electrical, mechanical and material subsystem based on the momentum conservation forms of Maxwell's field equations in the quasi-static limit and Cauchy's law of motion. The formulation takes into account Lorentz forces, magnetostriction and magnetization. As a result, the complete set of coupled partial differential equations and associated boundary conditions can be derived from first principles in a concise way. The subsequent solution process for the dominant Lorentz force mechanism in terms of particle displacement and magnetic vector potential is carried out in the time domain by employing numerical analysis techniques. Transient two-dimensional electro- and elastodynamic computer simulations are provided for 5 to 10 wire pair single layer pancake coils driven by 3 or 10 cycle toneburst currents of 1 MHz centerfrequency. In particular, the efficiency of generating surface and bulk waves based on different lift-off values is investigated in detail. --- This project is supported by Timken Research, The Timken Company, Canton, Ohio 44706.

Production of a Diffractionless Ultrasonic Beam

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---There has been recent interest in the production of approximately diffractionless ultrasonic beams. This interest initiated with the investigation, by Durnin, of diffractionless optical beams. If a practical transducer can be constructed with the capability of producing a nondiffracting beam over a useful range, it would have significant potential benefits for detection and imaging. Based on Durnin's optical experiments, analogous ultrasonic experiments have been performed, using a modified conventional transducer, to produce an ultrasonic beam which has a narrow width and a large depth of field over which the transverse beam profile remains essentially unchanged.

A Near-Field Measurement Model for Ultrasonic Reference Standards

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---A small scatterer is often placed in a fluid to serve as a "standard" ultrasonic reference reflector. Such reflectors can be used, for example, to evaluate the wavefield of a transducer or to determine system efficiency factors. Existing models of this type of reference measurement configuration, such as the measurement model of Thompson and Gray, require that the scatterer be in the far-field of the transducer in order to reduce the model to simple analytical forms where the transducer diffraction wavefield and the flaw response (far-field scattering amplitude) are decoupled. Here, we will show that an analytical model of the measurement model type is also able to be derived for a small, arbitrarily-shaped flaw on the axis of a piston transducer in a fluid even when the flaw is in the very near-field. Although the flaw response and transducer wavefield are indeed coupled in this model, this coupling is made explicit and it is shown that the flaw response can still be described in terms of an averaged far-field scattering amplitude. In some special cases, such as an elastic sphere or rigid disk, the averaging process can be carried out exactly and a simple analytical model developed for the entire measurement process.

A Geometrical Interpretation of the Echo Formation of Short Pulses on Simple Shaped Targets

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---Combination of theoretical, numerical and experimental works allows a simple geometrical interpretation of the mechanism of echo formation. It is adapted to wide-band beams and deals with echo response from targets of simple geometry. This work has been achieved in order to explain by simple arguments the mathematical relation observed between echoes arising from different target geometries. The interpretation is based on both the decomposition of the incident field in terms of geometrical and edge waves, and an adaptation to transient cases of Freedman's interpretation of the mechanism of echo formation. Geometries treated here are disk, sphere, cone. Comparison are interpreted in terms of time derivative relations and it is shown that it is easier to deal with impulse responses than with the actual echoes. These simple interpretations are in good agreement with experiments and numerical results.

Self-Calibrating Ultrasonic Technique for R/T Measurements

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---Measurements of the coefficients of reflection and transmission of ultrasonic waves by a discontinuity are of interest for many applications in ultrasonics. When transducers must be moved for a sequence of measurements, conventional experimental techniques using contact transducers require either absolutely predictable coupling conditions between material surfaces and ultrasonic transducers or special calibration procedures before each measurement. The first requirement is almost impossible to achieve, and the second introduces many complications. In this paper a configuration of transducers is proposed for self-calibrating measurement technique. By means of this technique, the ratio of the reflection and transmission coefficients (R/T) can be obtained in a reliable and accurate manner. Examples presented are for the reflection and transmission of surface waves for oblique incidence on a 90° edge of a specimen and on a surface breaking crack. Information on R/T for the latter case can be used to determine the depth of the crack. For both cases experimental measurements of R/T show excellent agreement with theoretical results.

NDE of Cylindrically Symmetric Components with Piezofilm Transducers

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---Flexible polymer piezofilms such as polyvinylidene fluoride (PVDF) possess distinct advantages as ultrasonic transducers for inspecting cylindrically symmetric components, including rods, pipes and cladded tubing. The curvature conforming nature of the film transducer ensures normal incidence and avoids mode conversion. In this work PVDF transducers are used in several NDE applications, including the evaluation of interfaces in coaxially extruded tubes. The same PVDF transducer was used as both the transmitter and the receiver. Observed signals were analyzed and reflection coefficient as small as 0.006 was accurately measured. Comparisons will be made with conventional transducers. --- Work supported by the Office of Basic Energy Sciences of the US Department of Energy.

Procedure for Alignment of Ultrasonic Beam for NDE Applications

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---Ultrasonic transducers are critical for acoustic nondestructive evaluation of material properties. Proper alignment of the transducer and specimen is essential for accurate results. Conventionally, one maximizes the amplitude of reflected echo by adjusting the polar and azimuthal angles of the incident beam with respect to the specimen plane. However, this procedure is incomplete for certain applications, such as, precise measurement of time-of-flight for evaluation of elastic constants, using oblique angle immersion technique. The direction of the acoustic beam is adjusted systematically so that the time-of-flight or reflected echos from a point reflector is a minimum and the beam propagates normal to the scanning plane. For transmission measurements, the receiving transducer is adjusted such that it also satisfies the above criterion. In this paper we will describe the procedure used for the alignment of the transducer beam for some precision quantitative NDE measurements and discuss its implications.

Optimum Implementation of the Specified Notches for Ultrasonic Detection of Longitudinal Defects on Steel Tubes.

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---Over the years the Ultrasonic Testing looks likely to be operating on Steel Tubes just as it was developed a long time ago. Actually, for the operators in the field, things have been deeply changed, for 2 main reasons:--The natural defects to be detected are getting smaller and smaller, in their depth and length.--A good reliability of detection is expected. Thanks to the development of the electronic devices, needless to say that all the necessary settings are now currently made very accurately, and self-tested in a glimpse. In addition to that, we have carried out an extensive study to optimize the main acoustical parameters, namely the Ultrasonic Frequency and the Incidence Angle of the transducer. It covers a wide range of diameters, wall-thicknesses and wall-thickness/diameter ratios. For every size of tubes manufactured for the Boiler and the Nuclear industries, typical curves showing the variation of the Ultrasonic echo versus the Incident angle have been drawn in order to dictate the proper choice. This is made once for all, and the computer will restore the correct setting. It is worthy to mention that our experimental results are in perfect concordance with the theoretical investigations which would take into account the depth and width of the notches (3% to 5% of wall-thickness) and the acoustical interference patterns.

Standardization for the Quantitative Ultrasonic Evaluation of Polymer Composites

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---Issues of ultrasonic standardization are addressed with emphasis on polymer composite applications. To date, the inherent variability of composites has defied most attempts at standardization and industry relies on material-specific composite standards and accept/reject criteria which have no foundation in engineering data. The authors propose the introduction of universal system standards which are applicable to a broad range of materials and thicknesses and a call for extensive effects of defects (EOD) programs. The requirements for a "generic" standard are discussed with respect to ultrasonic parameters such as absolute amplitude, gain linearity, transducer characteristics, beam effects and the concept of a spectral envelope requirement as well as the frequency response of the materials and their defects. Results from the Lockheed programs on standards for composites, effects of defects and fatigue characterization will be presented as they pertain to quantitative ultrasonics and standardization.

New Concepts for Characterization of Ultrasonic Transducers

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---Ultrasonic nondestructive techniques are widely used in aeronautical industry for critical parts inspection. Deviations of results are observed when a part is inspected on two different facilities. Major part of deviation comes from the transducer. Despite of transducer frequency and geometrical acoustic characterization and previous calibration with artificial defects, deviations of results are also observed when a transducer is replaced by another one with same nominal characteristics. A study has been realized to determine what physical parameters control ultrasonic response on real defects. 16 parameters (electrical, time and frequency domain response) have been selected, and compared with the amplitude of the signal reflected on a real defect. Results show that the main parameter is the frequency domain response on an infinite flat surface. If the frequency spectra to two transducers on a flat surface are identical, 80% of sensitivity deviation on real defects is corrected by calibration. Finally two methods are proposed to increase repeatability and reliability of the ultrasonic technique: 1) a new transducer specification, where frequency domain response on a plane reflector is compared with a reference one. 2) adaptation of the emission signal for each transducer to obtain the specified frequency response.

A Comparative Study Between DC and RF Surface Resistivity Measurements

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---Two common methodologies in measuring the surface resistivity of sheet materials include the four point probe and microwave transmission measurements, both of which are nondestructive in nature. The four point probe, which is a DC measurement method, is a technique by which a voltage drop is measured with respect to the applied current to yield the resistivity. The microwave transmission technique, which is an RF measurement method, takes into account transmitted amplitude and phase through the material to provide the resistivity. This paper analyzes these methods from both a theoretical and practical standpoint and compares resistivity data obtained using each method.

Response of Tensile and Bending Specimens Using an AC Magnetic Bridge

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---AC magnetic bridges have been used to detect changes in the stress state in steel and aluminum specimens. In a previous study test samples were cycled ten times prior to taking data and input conditions to the bridge were constant. The present work considers in detail the relaxation times for the material and bridge and provides a preliminary relationship to allow quantitative determination of the strain (stress) in steel based on bridge response. The effect of variations in strain over the depth of the material and an approach for determining the strain (stress) below the surface is also considered. The results indicate that the AC magnetic bridge will allow the nondestructive determination of subsurface strain. These preliminary studies may provide the basis for residual stress measurements in materials.

Effect of Preferred Grain Orientation and Grain Elongation on Ultrasonic Wave Propagation in Stainless Steel

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---The influence of grain size on the attenuation of ultrasonic waves in randomly oriented, equi-axed polycrystals is well known. In a series of recent papers, the authors have used the unified theory of Stanke and Kino to develop solutions for a case found in cast stainless steel, in which grains have one cube axis aligned with a preferred direction and are elongated along the direction. In this paper, we present results based on numerical evaluations of those solutions. Included are plots of attenuation and velocity as a function of propagation direction, grain aspect ratio and grain size to wavelength ratio. The dominant physical factors controlling the solutions and their practical implications for inspection of nuclear power plant components will be discussed. This work was sponsored by the Electric Power Research Institute under contract RP-2687-01 and was performed at the Ames Laboratory. Ames Laboratory is operated for the U.S. Department of Energy by Iowa State University under Contract No. W-7405-ENG-82.

X-Ray Diffraction and Acoustic Prediction of Elastic and Plastic Anisotropy of fcc Metal Sheet.

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---Both the elastic and plastic anisotropy of a thin metal sheet are dictated by the preferred orientation of grains (texture). Two nondestructive techniques: X-ray diffraction and Leaky Lamb wave velocity measurement were applied in order to characterize the copper and α-based sheets cold rolled to various deformation levels. The deformation textures were described quantitatively by means of the crystallite orientation distribution functions (ODFs) derived by both techniques independently. The planar variation of elastic moduli was predicted using Voigt and Reuss averaging techniques. The planar variation of plastic strain ratio was determined in the framework of Taylor theory. The validity of the elastic and plastic anisotropy prediction was evaluated by means of mechanical measurements. A relatively good agreement between the predicted and experimental values was demonstrated in the case of elastic moduli. Large discrepancies were observed for the plastic strain ratio analysis.

Measurement of Hydrogen in Zr-2.5%Nb Using High Accuracy Velocity Ratio Measurements

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---The formation of zirconium hydride platelets is known to decrease the fracture toughness of Zr-2.5%Nb pressure tubes in CANDU reactors. It is therefore desirable to be able to measure levels of hydrogen using a nondestructive technique. It has been demonstrated that hydride platelets tend to increase the longitudinal and decrease the shear wave velocities in Zr-2.5%Nb. A method which accurately measures the ratio of shear to longitudinal velocity in pressure tubes has been developed. The method uses a single normal beam probe and extracts the velocity ratio of both the axially and circumferentially polarized shear waves to the longitudinal wave by comparing the longitudinal echoes in the plate to the mode converted shear signals. The choice of the probe is critical to the accuracy of the ratio and a wide selection of probes for the technique was studied with a theoretical model which uses temporal and spatial Fourier transform techniques to predict the waveform generated by each probe when it reflected from the tube. Velocity ratio maps made of several pressure tubes indicate a drop in the velocity ratio of about 1 part in 10^3 for a hydrogen content of 100 parts per million.

On the Relationship between Fracturing of a Microcracking Solid and the Change of its Elastic Stiffness

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---It is argued that, contrary to the spirit of many damage models, there is no simple correlation between fracturing of a brittle microcracking solid and the change of its effective elastic moduli. Physically, the absence of such a correlation is explained by the fact that the fracture-related properties (like stress intensity factors) are determined by klocal fluctuations of the microcrack field geometry whereas the effective elastic constants are the volume average quantities relatively insensitive to such fluctuations. Therefore, prediction of the remaining lifetime by the deterioration of elastic stiffness may not always be correct.

Acoustic Emissions From Titanium Aluminides Produced During Microhardness Testing

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---Acoustic emission (AE) has been applied to monitoring the microhardness indentation of various titanium aluminides AND Berkovich nanohardness indentation of single crystals of germanium. The aluminides investigated were Al_3Ti, TiAl and a two phase TiAl plus Ti_3Al alloy. Results have shown AE waveforms are produced during the application of the indenter loads. Using signal processing these waveforms have been separated into two specific types of emissions which are directly correlated with slip band formation and cracking events. Correlation of AE signals with load-displacement curves, microstructure, environmental effects, and deformation mechanisms will be discussed.

Microstructural Noise in Titanium Alloys and Its Influence on the Detectability of Hard-Alpha Inclusions

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---In ultrasonic inspections of aircraft engine components the detection of weakly-scattering defects can be limited by microstructural noise. In this work we seek to estimate signal to-noise (S/N) ratios (i.e., flaw signal amplitude/rms microstructural noise amplitude) for hard-α inclusions in titanium alloys. One ingredient in our estimation procedure is a simple model for backscattered noise which incorporates both material properties and measurement system parameters. Given backscattered noise data, the model can be used to extract a figure-of-merit (FOM) for noise severity which is independent of the measurement system. Conversely, if the FOM has been determined for a metal specimen, the model can be used to predict absolute noise levels for various inspection scenarios. We present backscattered noise data for normal-incidence, immersion, tone-burst inspections of titanium alloys. We describe how the FOM is extracted, and show that it is approximately indepedent of depth, pulse duration, and transducer characteristics. For some specimens the FOM depends strongly on the direction of beam propagation. By combining the noise model with the Thompson-Gray measurement model, one can estimate S/N ratios for isolated defects in materials whose noise FOM has been measured. We demonstrate this approach with representative calculations of S/N rations for postulated hard-α inclusions. --- This work was sponsored by the Center for Advanced Nondestructive Evaluation, operated by the Ames Laboratory, USDOE, for the Air Force Wright Aeronautical Laboratories/Materials Laboratory under Contract No. W-7405-ENG-82 with Iowa State University.

Effects of Interstitial Oxygen on the Ultrasonic Properties of Titanium Alloys

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---Interstitial oxygen and nitrogen change the material properties of titanium alloys, and cause the appearance of hard alpha inclusions. The detectability of these inclusions depends, in substantial part, on the modification of the alloy's ultrasonic response. In the early 1980's, motivated by problems associated with welding titanium in ship hulls, the Navy fabricated a set of specimens, which had controlled additions of a small amount of oxygen. At that time, the ultrasonic properties (as well as other NDE related parameters) of these samples were measured by several different groups. Since that time, other samples have been fabricated that are partially representative of the hard alpha inclusions. In this talk, we report new measurements of the ultrasonic properties of the Navy samples, compare them with previous reports, and contrast them with the currently available measurement of hard alpha inclusions. In particular, we discuss the effects of oxygen on the wave speed, the attenuation and the ultrasonic backscatter. We discuss various possible causes for the changes in ultrasonic properties such as direct changes in the density and modulus, as well as changes in the microstructure induced by the addition of oxygen and heat treatment. --- This work was partially sponsored by the Center for Advanced Nondestructive Evaluation, operated by the Ames Laboratory, USDOE, for the Air Force Wright Aeronautical Laboratories/Materials Laboratory under Contract No. W-7405-ENG-82 with Iowa State University.

Nonlinear Acoustics and How She Grew

---M. A. BREAZEALE, NATIONAL CENTER FOR PHYSICAL ACOUSTICS, UNIVERSITY OF MISSISSIPPI, UNIVERSITY, MS 38677

---The subject of nonlinear acoustics of fluids has been investigated almost two centuries. Nonlinear acoustics of solids evolved from nonlinearity of fluids, but there have been some growing pains. One key to understanding the nonlinearity of solids has been the realization that Hookes law represents the zeroth approximation in a perturbation solution around the wrong ground state. Now that we know what's broke we can fix it. This is the reason for the definition of third order elastic (TOE) constants and nonlinearity parameters. TOE constants and nonlinearity parameters have been evaluated for a number of materials, both crystalline and amorphous. Now the intermediate state beckons: fluid mixtures, ceramics and suspended gases or solids in fluids. Since additivity assumptions are not appropriate for nonlinear systems, recent results demand the attention of knowledgeable scientists. Results for crystalline and amorphous solids are presented and compared with recent measurements of ceramics such as PZT and the high T_c superconductor $YBa_2Cu_3O_{7-\delta}$. In some cases the measured nonlinearity parameters are anomalously high, and in some they are vanishing small. Correlation of nonlinearity parameters with physical properties is helping untangle this mess.

Acoustic Nonlinearity in Plastics

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---The second-order acousto-elastic effect was used to study nonlinearity in different plastic materials. The ultrasonic velocity was measured at 2 MHz as a function of the low-frequency bending load at approximately 0.1 Hz. The maximum bending deformation was between 5-30% of the ultimate value and the relative velocity change was on the order of 10^{-3}-10^{-4}. Simultaneously, linear parameters such as the low-frequency (quasi-static) elastic modulus, and the high-frequency (ultrasonic) velocity and attenuation were also recorded. It was found that the nonlinearity parameter was far more sensitive to the slow deterioration of material strength under long-term fatigue load than any of its linear counterparts. Regardless of whether the plastic exhibited softening or hardening in the initial part of the experiment, the nonlinearity monotonously increased throughout the experiment. The way nonlinearity increased in different materials was found to be very characteristic of the type of material. In ductile materials, like ABS, the nonlinearity gradually increases to as much as 25 times its original value while in more brittle plastics, like PVC, it changes only 30% before shooting up to 2.5 times its initial value just before failure. In especially tough materials, like nylon which we could not break in fatigue at all, the nonlinearity does not increase after some initial change caused by settling of the material. These results demonstrate that nonlinear inspection might provide an excellent NDE tool for assessing the structural integrity of plastics and plastic joints. --- The work was done for the United States Air Force Aeronautical Laboratory/Materials Laboratory under contract number W-7405-ENG-82.

Determination of Nonlinearly Viscoelastic Behavior of Adhesive Bonds

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---The adhesive material being considered here is assumed to display nonlinearly viscoelastic behavior in shear. The relation between shear stresses and strains is of the form

$$\tau = f(\epsilon) + \kappa \dot{\epsilon}$$

An analysis is presented related to the measurement of $f(\epsilon)$ and κ by an ultrasonic technique. The configuration consists of two metal strips which are adhered to each other by a thin layer of adhesive material. The composite strip is subjected to low frequency bending, which shears the adhesive layer into the nonlinear range. A superimposed small-amplitude but high frequency transversely polarized signal is subsequently applied and the reflected field is used to obtain the wave speed and hence $df/d\epsilon$ as a function of the pre-stress in the nonlinear range. The viscosity parameter κ is obtained from amplitude decay.

Nonlinear Elastic Effects on the Energy Flux Deviation of Ultrasonic Waves in GR/EP Composites

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---In highly anisotropic media such as composite materials, the direction of the energy flux of an ultrasonic wave does not coincide with the wave normal except along symmetry directions. The energy flux deviation angle is a function of the elastic coefficients of the material. Due to nonlinear elastic effects, the elastic coefficients and thus the deviation angle is a function of stress. The shift in deviation angle has been calculated in unidirectional T300/5208 graphite/epoxy using the previously measured complete set of second and third order elastic coefficients. Calculated were the effects of uniaxial compressive and tensile stresses along the fiber direction (x_3) and along the laminate stacking direction (x_1) for waves propagating at various angles in the x_1x_3 plane. These calculations indicate that the shift in the deviation angle is greatest for the quasi-transverse wave with a shift as large as three degrees for a stress equal to the ultimate tensile strength applied along the fibers. This nonlinear effect on the energy flux deviation offers the potential for a novel new method of nondestructively evaluating stress in composites or for characterizing their nonlinear properties.

Surface Acoustic Wave Nonlinearities in Surface Sounding

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---Nonlinear generation of second harmonic waves in Surface Acoustic Wave (SAW) propagation can be used as a means for sounding the homogeneity and roughness of the propagation surface. An integral evaluation can be given by the nonlinear coupling coefficient Γ, defined by

$$dA_2/dx = k^2 \Gamma A_1^2$$

where A_1, A_2 are the amplitudes of the first and second harmonic waves, respectively, of wavenumbers k and 2k. Amplitude and phase of the coupling coefficient are studied as they are indicative of dispersion effects in SAW propagation, due to surface roughnesses. Investigation of the coupling coefficient is done, and few examples are presented of nonlinear SAW generation in specific geometries of crystal propagation.

Parametric Beam Formation in Rock

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---The highly nonlinear elastic properties of rock may enable a new means of imaging Earth structure through parametric formation of a difference frequency beam from the interaction of two collimated primary elastic waves. Because the difference frequency beam can have the narrow collimation of the higher frequency primaries, it could ultimately be used as a directional wave source. Such a low-frequency wave propagates farther than the primary signals to locate features not currently detectable by waves generated from conventional sources. Compared to other materials, rocks have a significantly larger nonlinear response because they contain numerous microcracks that readily compress under applied stress and cause large changes of elastic moduli and wave velocities with pressure. Nonlinear coefficients in rocks can have values two order of magnitude greater than the uncracked materials typically studied in nonlinear acoustics. We are currently working in two areas aimed at source development. First, low frequency (0.1 - 100 Hz) attenuation studies using a torsional oscillator are currently focused on enhancing nonlinear response in rock. These studies showed that nonlinear coefficients can be greatly increased by inducing additional microcracks in the material. Second, current ultrasonic studies demonstrate strong nonlinear effects generated inside laboratory samples. Most notably, when two collinear, primary pressure waves were simultaneously injected into a 183-cm long sample at primary frequencies between 200 and 600 kHz, we detected strong difference frequency signals across the sample but found that the higher frequency primary waves had been entirely attenuated. We also showed that the intensity pattern of the difference frequency beam created in the rock was narrow as compared to the identical frequency signal input from the transducer, as theory predicts. Finally, we developed a sensitive, continuous wave phase method for measuring travel time of signals across a sample. This method is of general applicability for accurate measurements of travel time in the presence of noise.

Nonlinear Acoustics and the Thermal Expansivity of Glass

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---Nonlinear acoustics is playing an increasingly important role in understanding a wide range of material properties. At the center of this understanding is an appreciation of the intrinsic relationship between the nonlinear acoustic phenomena and the basic atomic arrangement and microstructure of the solid under consideration. As the complexity of the material increases so does the nature of the acoustic nonlinearity. For crystalline solids the acoustic nonlinearity is dominated by the interatomic anharmonicity and is quantified by nonlinearity parameters that are ordered according to the lattice structure. The lattice anharmonicity give rise to experimentally verified modal acoustic radiation stresses that, among other thermodynamic manifestations, appear directly in an expression for the thermal expansion coefficient of the crystal derived from stochastic dynamics considerations. In glass where the atomic arrangement is more complex a substantial velocity dispersion resulting from long-range structural disorder give rise to the generation of solitary nonlinear modulations (solitons). Measurements of the nonlinearity parameters of UL glass having an effective zero thermal expansivity at room temperature are reported and the relationship of acoustic nonlinearity to the thermal expansivity of glass is discussed.

Pulsed Phase-Locked Loop Methods for Measuring Acoustic Nonlinearity

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---The determination of the third-order elastic constants of solids is often made from measurements of the variations of the sound velocities as functions of the applied stresses. Similarly, the state of stress can be assessed from measurements of the variation of the sound velocity from the zero-stress state, if the elastic constants of the solid are known. A new instrument based on a constant frequency pulsed phase-locked loop concept has been developed to accurately measure the ultrasonic phase velocity in condensed matter. Measurements of the sound velocity in ultrapure water are reported in which both damped and undamped transducers are used with the instrument together with reflectors of various thicknesses placed in the sound propagation path. An analysis of measurements made with the new instrument and similar measurements, taken under identical experimental conditions, using a popular variable frequency pulsed phase-locked loop instrument is reported. Uncertainties in both measurement systems are analyzed and discussed. A method for measuring inherent phase shifts, neglected by previous investigators, within the variable frequency pulsed phase-locked loop system and a derivation of the correct equations that govern its most common use as a bolt-tension measuring device are presented.

Measurement of the Displacement Amplitudes of a Harmonically Distorted Ultrasonic Wave Using a Fluid-Coupled Contact Transducer

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---Presently there is interest in the NDE community in the application of nonlinear acoustic techniques to the characterization of microstructure and interface structures in engineering materials. One measure of a material's nonlinearity is the acoustic nonlinearity parameter, β. The calculation of β requires measurement of the harmonic distortion of an initially monochromatic toneburst as it propagates through a material, as a minimum, determination of the displacement amplitudes of the fundamental and second harmonic components after the toneburst has travelled through the material. Historically a number of techniques have been employed to measure displacement amplitudes, the capacitive detector being the most common. However, due to the difficulty of the capacitive detection method, this technique has not gained popularity outside the laboratory. Presently, we are developing a technique that measures displacement amplitudes using a fluid-coupled contact transducer. The immediate objective is to test the validity of this method by measuring the nonlinearity of fused silica. This will then be applied to the characterization of materials through measurements of the nonlinearity parameter, β. This work was funded in part by the CNDE (applications) and in part by Ames Laboratory (equipment development) at Iowa State University. Ames Laboratory is operated for the U.S. Department of Energy by Iowa State University under contract No. W-7405-ENG-82.

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