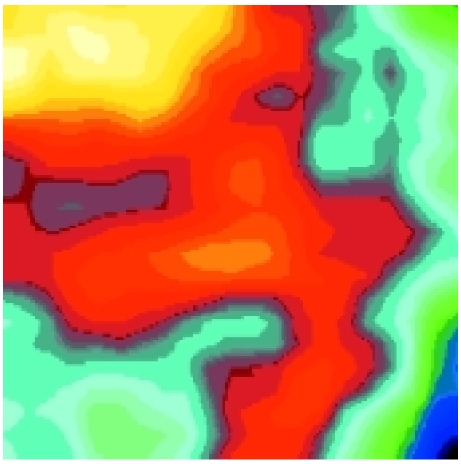
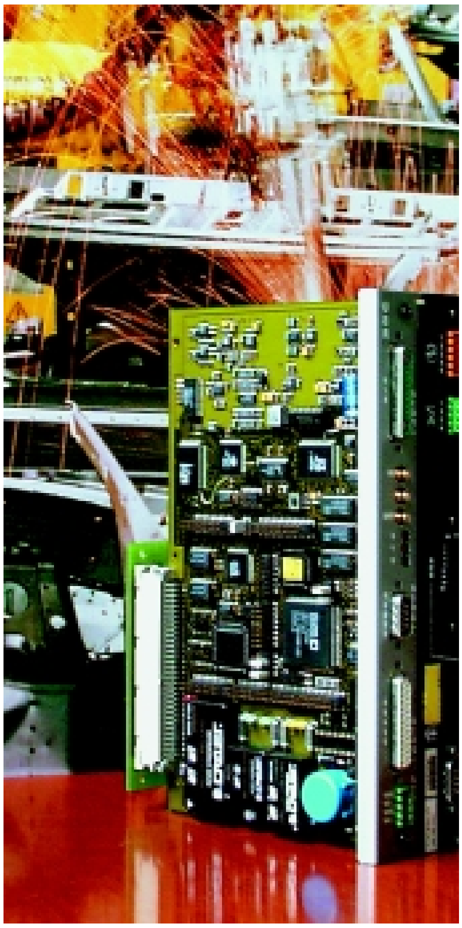
Fraunhofer Institut Zerstörungsfreie Prüfverfahren

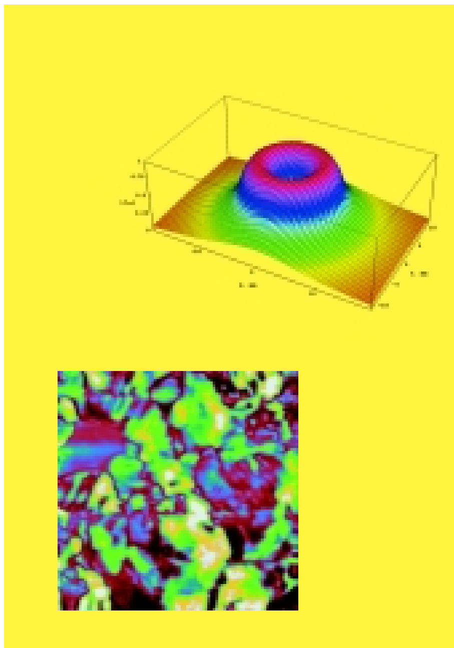
Annual Review 2000

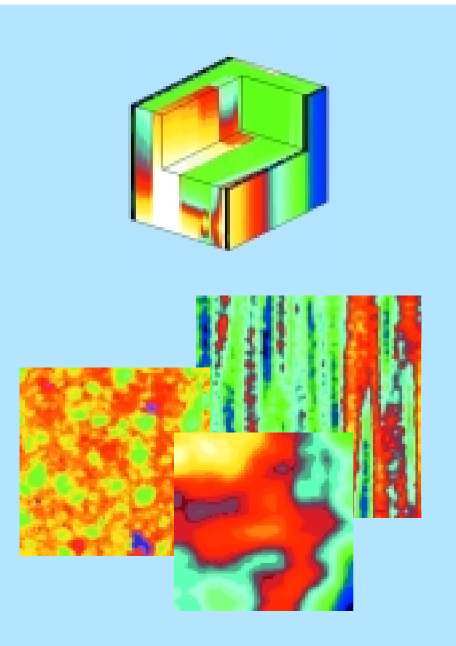


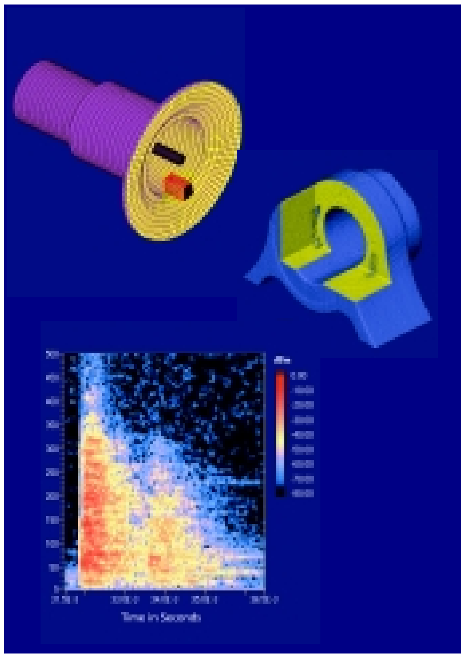



Annual Review 2000

Contents







Fundamental Scientific Research, The Foundation for Successful Innovation

Prof. Dr. Dr. h.c. Michael Kröning

The main area of expertise for the Institute, IZFP, is technology, which is also the source of our success in applied research and development.

In recent years, this success was guaranteed by innovative actions that lead to the development of market- and product-oriented new technologies and new business activities. The alignment of the institute's objectives has provided a significant increase in economic revenues and, in addition, promoted a market-oriented scope to our work, which has lead to a rejuvenation of the Institute.

IZFP has therefore been in accordance with the policies of the Fraunhofer Model, which demonstrates our capabilities at a time when public funding of projects is increasingly difficult to secure.

Strategic goals, though, must also include long-term aspects.

Market efficacy is the goal of any innovation process. The heart of market efficacy is technical proficiency that, these days, must also reflect an international level of expert knowledge. IZFP had the organizational responsibility to reach this goal in an efficient and effective manner. Short-term support comes from development strategies, joint ventures in technology, industrial partnerships, and through other arrangements. However, at the core of technical proficiency are sound scientific fundamentals.
The development of new technology required for long-term market effectiveness is much more difficult to organize. It requires vision, imagination, and creativity – in other words: scientific excellence that is open to market-oriented processes. The transfer of scientific fundamentals into useful technology is a process that cannot be rushed or forced. Basic conditions must be determined to pave the avenues of free development of individual ideas and to open up the possibilities of continuous interchange of information.

IZFP has lost some of its thematic freedom in the area of reactor safety prevention research. New goals were determined for which the scientific excellence of IZFP were apparent. As a result, IZFP has developed partnerships with two centers of excellence in the nano technology area. The realization of economic autonomy for fundamental research will be more difficult to achieve due to decreasing project funding.

The Institute must demonstrate its strength in its ability to show economic success for fundamental research. Successful innovations offer value-added products, which, in return, demonstrate the importance of fundamental scientific research.

Finally, to be successful, scientific research must also be enjoyable. Restraints interfere with the pleasure and therefore the success of fundamental scientific research, while the exchange of information, and continual openness in partnerships ultimately strengthen research efforts and thus promote success. The network of internal and external partners IZFP has built over the years has been the source of our scientific achievements, and will most certainly be the cornerstone for new technologies and products in the years to come. Our deepest gratitude and professional respect are extended to all those involved in these partnerships.

Activities and Objectives

Economic success and subsequent assurance of wealth and good standard of living can only be warranted through an effective scientific and technical infrastructure. The goal of applied research and development is to transfer contemporary knowledge and skills into innovative products and services in close cooperation with industry. A critical acceptance of technology must be fostered via result-oriented education leading to successful, lasting innovation processes. Fundamental research combined with supplementary research proficiency can portray the valuable capabilities of innovations and reduce their risks.

The purposes of applied research and development at the Fraunhofer-Institute for nondestructive testing, IZFP, is the improvement of product quality combined with a decrease in costs and the proof of technical safety of instruments, machines, and plants - often a required prerequisite for their operation.

The activities at IZFP result from the overall analysis of quality improvements and component safety. Cooperation with other institutes doing research on materials, production techniques, and microelectronics assists IZFP in determining testing and inspection problems and finding solutions. To this end, IZFP develops fundamentals for physical measurement techniques for the improvement of the understanding of applied testing methods. It develops methods and techniques for material characterization, analyses production sequences, processes, and production risks, develops market-ready test instruments and systems, and facilitates their industrial application through validation at our accredited application center.

Short Portrait

The Fraunhofer-Institute for Nondestructive Testing (IZFP) was founded in 1972 and is located in Saarbrücken, with a branch office in Dresden that was established in 1992. Professor Dr. Michael Kröning has headed IZFP since 1990. In addition, he also chairs the »Quality Assurance and Nondestructive Testing Methods« department at the university of the Saarland. The Institute is therefore closely tied to teaching and research at the University. The subject »Nondestructive Materials Testing« is part of the methodological education of students studying material sciences.

Fraunhofer-Institute IZFP in Saarbrücken

Fraunhofer-Institute IZFP (EADQ) in Dresden

IZFP is involved with the physical principals of nondestructive testing and material characterization and with control and monitoring of production processes and plant systems and components. The results achieved at the Institute are used in industrial applications when quality assurance and/or proof of technical safety are required. The methodological expertise encompasses the physical fundamentals, sensor technology, test instrument design and manufacturing, processing technologies, techniques for data evaluation and documentation, and, in addition, the qualification and validation of new inspection and testing procedures including maintenance, personnel training, and inspection and testing services.

A large number of joint ventures provide a network of international cooperation to penetrate international markets and to organize important resources that are available to our partners in industry. The organization of the Fraunhofer-Institute enables the use of state-of-the-art tools such as microelectronics, and the development of integrated quality testing systems. Financing of the required fundamental research is usually accomplished using public funding, while applied research and development and market implementation and commissioning are covered by orders from the industry.

In addition, basic funding facilitates scientific processing of fundamental and strategic subjects, the development of job opportunities, and the organization of the necessary proximity to industry.

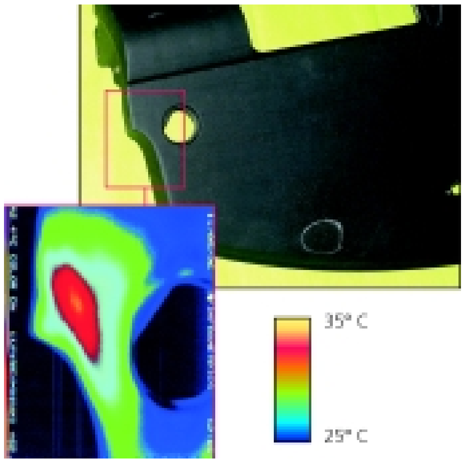
Main Emphasis

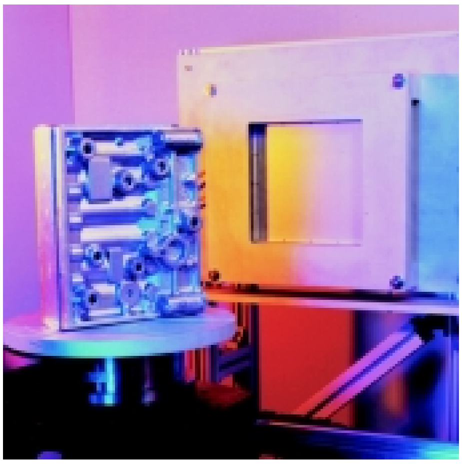
Our current emphasis results from methodological development potential and from new inspection and testing tasks and objectives. The traditional tools for developing nondestructive methods and techniques have experienced rapid progress in the fields of microelectronics, computer technology, micro-sensors, and in general applied testing and measurement technologies.

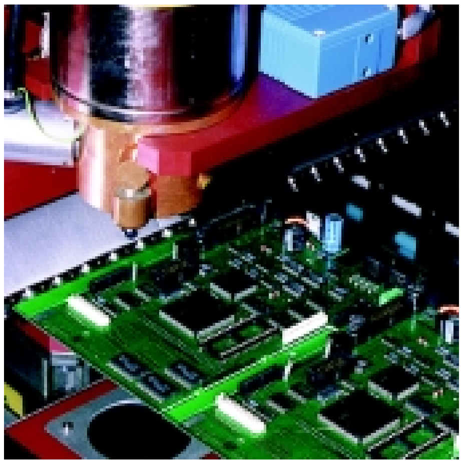
Innovative development and improvement of existing techniques is no longer economical on an individual basis as the costs for instrument development remain high, in addition more cost-effective instrument production leads to decreased prices in a very competitive market. This situation calls for a development platform with meaningful system architecture for a wide range of hardware and software developments. As a result, highly developed hard- and software modules are available to numerous companies for a variety of test instruments. This systematically oriented emphasis permits the development of testing instrument families, ranging from »low-cost« test instruments to large inspection systems, and including sensor technology, manipulation technology, and robotics.

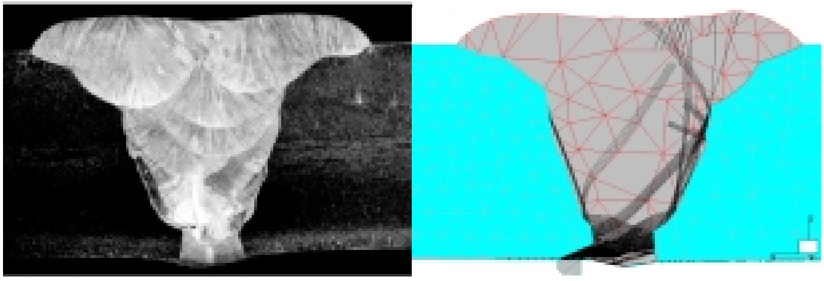
The multitude of new inspection applications have established additional areas of emphasis. Examples include the quantitative representation of material flaws, the characterization of material properties and parameters (hardness, strength, adhesiveness, etc), the development of nondestructive microscopy (µ-NDT), and process control through the surveillance of quality characteristics. In many situations, new physical methods must be developed or traditional methods must be integrated into hybrid techniques.

Another emphasis of the Institute's activities is closely tied to the necessity of industrial relevance. The Application Center – a testing and inspection facility, accredited to DIN EN 45001 – has the proven ability to qualify and validate new applications that were developed by the Institute. Accreditation encompasses not only implementation of standard nondestructive testing methods and procedures, but also new, internally developed inspection and testing methods and techniques can be implemented and existing techniques and procedures can be improved without prior approval of the accrediting agency. This permits the integration of innovative, quality-assured testing and inspection techniques into a company's every-day nondestructive testing operation, while also providing responses to feedback from the industrial partners for a demand-based development.

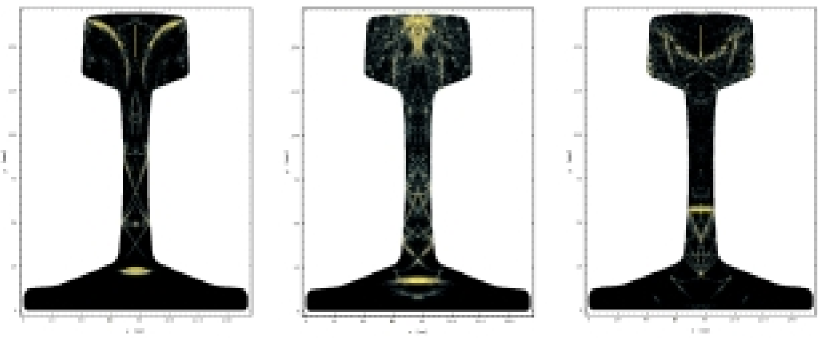




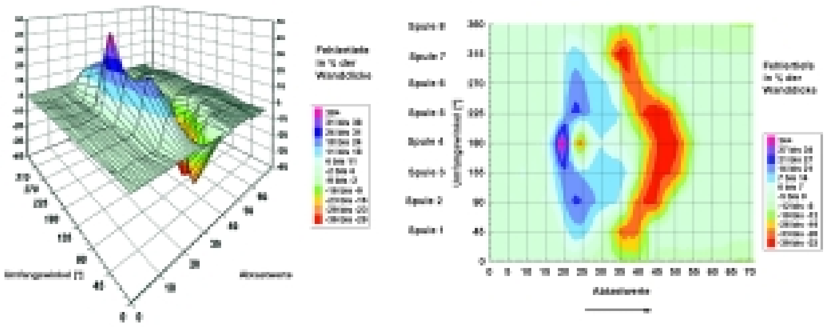




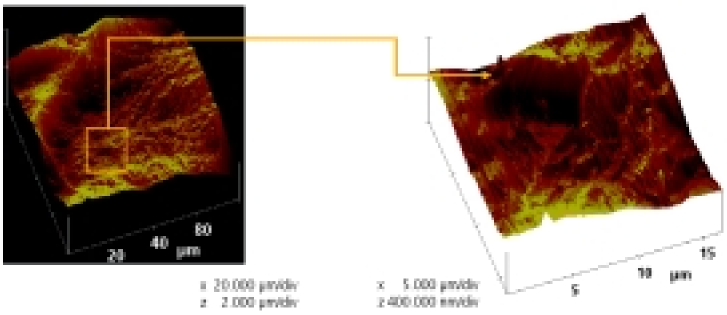
Beam profile modeling on a stainless steel weld (right figure); micrograph of the weld (left figure).



EFIT Simulation of a pulse/echo track inspection with a transverse crack in the track head.



Heat exchanger tubing inspection using a virtually rotating multi-element eddy current sensor – pitting indications in an area of corrosion.



AFM image of the surface of a stainless steel ((X6 NiCrTi 18 10) specimen after 13,000 stress cycles in an in situ LCF test. The enlarged detail depicts the fractured character of the structure.

Proficiency and Application

The main expertise of IZFP lies in our ability to merge methodological fundamental knowledge with professional instrument and sensor design and fabrication and testing and inspection services, i.e. a wealth of experience in nondestructive applications.

This expertise enables the Institute to utilize their development potentials for promising applications and to provide industry with useful research results.

Proficient testing and inspection applications are achieved when certain NDT situation can be modeled, when sensors and testing systems are developed or optimized for a specific application, and when inspections can be performed by qualified employees.

Our area of expertise includes the following nondestructive methods:

- Ultrasound
- Acoustic Emission
- Eddy Current
- Magnetic Methods
- Radiography
- Thermography

In addition, IZFP develops testing techniques for specialized applications based on:

- Visual (optical) Methods
- Nuclear Magnetic Resonance
- Microwaves
- Neutron Measurements
- X-Ray Diffraction (Synchrotron Radiation)
- Scanning-Sensor Microscopy

In cooperation with the Fraunhofer-Gesellschaft, the expertise of the Institute includes instrument design and fabrication, sensor and transducer manufacturing, and software development. Software development includes algorithms for data evaluation and display (including reconstruction, computed-tomography, correlation techniques, neural networks, imaging and image processing), signal processing, and instrument communication (user-interfacing, networking, documentation).

The above testing and inspection methods are used for the detection and evaluation of flaws and to determine stress conditions, and to characterize material properties to permit the assessment of usability of functional and structural materials.

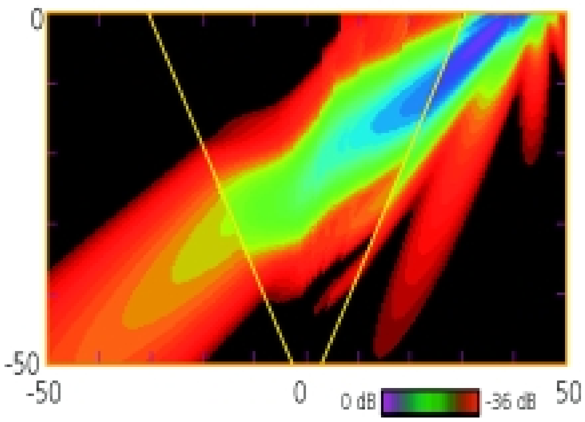
The materials include:

- Metals
- Ceramics
- Polymers
- Composite materials and Composites
- Construction Materials
- Semiconductors

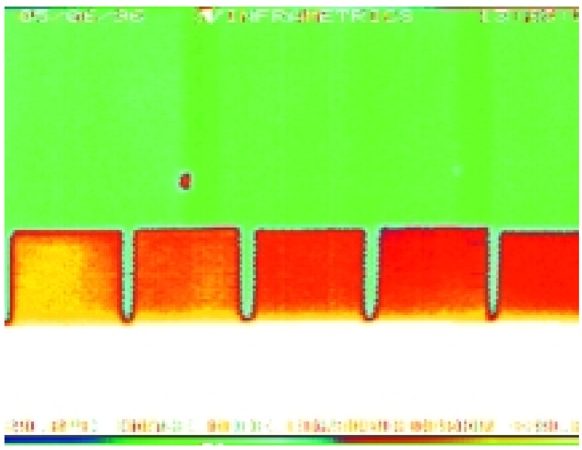
Nondestructive testing techniques are applied to production processes and material processing during processing or to the final product.

Industrial applications encompass everything from the metal fabrication and processing industry to the packaging industry and all are closely related to safety requirements (pressure vessel code) or quality management (quality assurance, quality control, cost).

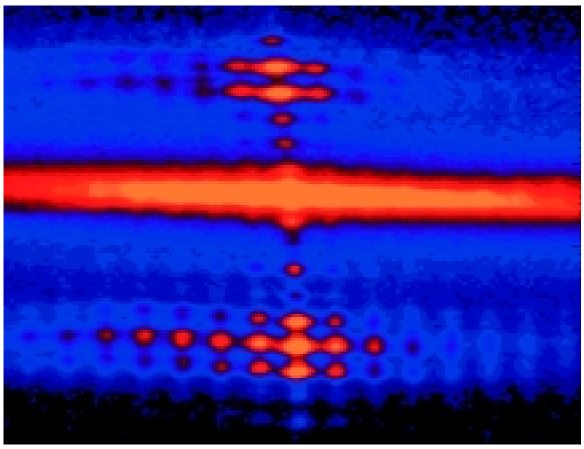
IZFP expanded their methodical proficiency with the addition of the branch office for Acoustic Diagnostic and Quality Assurance (EADQ). In addition to acoustic diagnosis for monitoring of plant operations and control of manufacturing processes, acoustic methods and techniques also permit the description of sub-micrometer structures. For example, acoustic methods applied in a laboratory environment can validate the use of new materials and composites for the electrics industry.



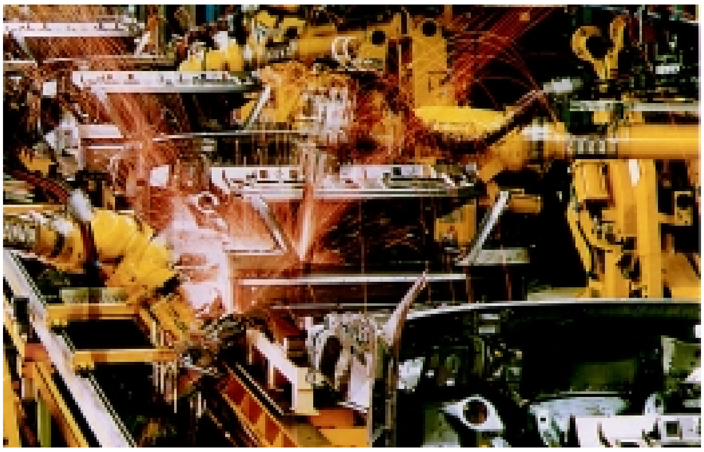
Beam profile of a 60° L-wave transducer on a stainless steel weld as a modeling result using Gausses Rays



Thermographic image of ceramic intumescing coatings of varying porosity

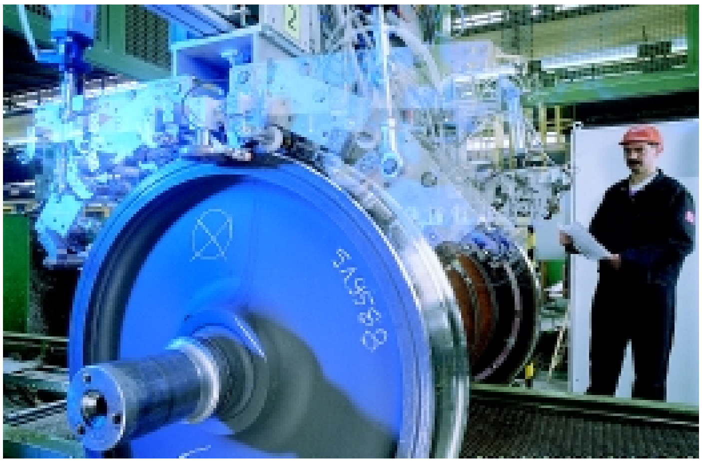


High-resolution X-ray diffraction image of a GaInAsP (Multi-layer surface lattice on InP)



Process inspection of automobile production

EMUS-Testing of pipelines



AURA - Automated ultrasonic railroad wheel set inspection system

Future Areas

Safety and quality are the dominant factors for the long-term success of new technologies. They are the trademarks of the German industry, which is adopting to a service- and information-oriented economic growth. Global markets and resources have shaped a sleek and flexible production process, which is the basis of a service-oriented industry. In this environment, the demand for higher quality and more safety elevates the significance of nondestructive testing.

In the future, the risk-based proof of plant safety and machinery governed by international regulations will be an increasingly important task for nondestructive testing. This development is already evident in the aviation, railroad, and nuclear energy industries.

Similar approaches will also become necessary for quality management. Supplied parts will only be used if evidence of quality is provided for each part delivered. On the global market, finished products will require individual quality certification, primarily to satisfy product liability issues. This will require a quality-driven production process with integrated nondestructive testing and inspection methods and techniques.

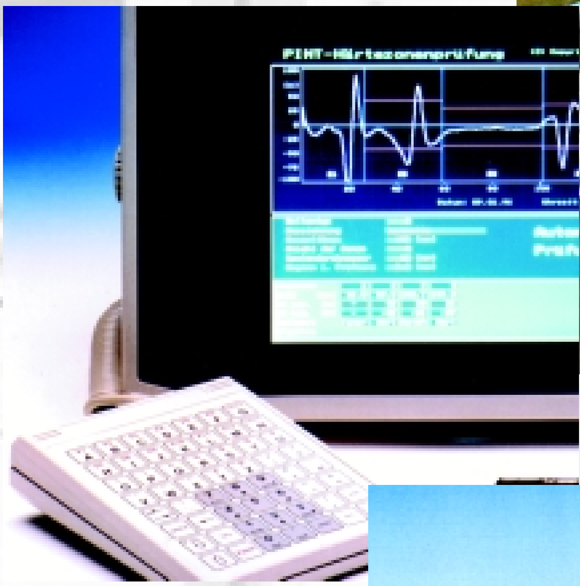
Besides risk-based quantitative NDT (RISQNDT) and process-integrated NDT (PINT) nondestructive material analysis, μ-NDT is another area for future considerations. The development of new materials and new manufacturing processes is required for new products to come with shorter innovation cycles due to global competition, markets, resources, and ideas. The time required for development is more important than the development costs and current testing methods are often not able to validate the applicability of new materials or to control new manufacturing processes. Therefore, new nondestructive testing methods and techniques are required, e.g., to reduce component lifetime analysis or to determine new quality characteristics. New types of physical measurement techniques with high microscopic resolutions will need to be developed.

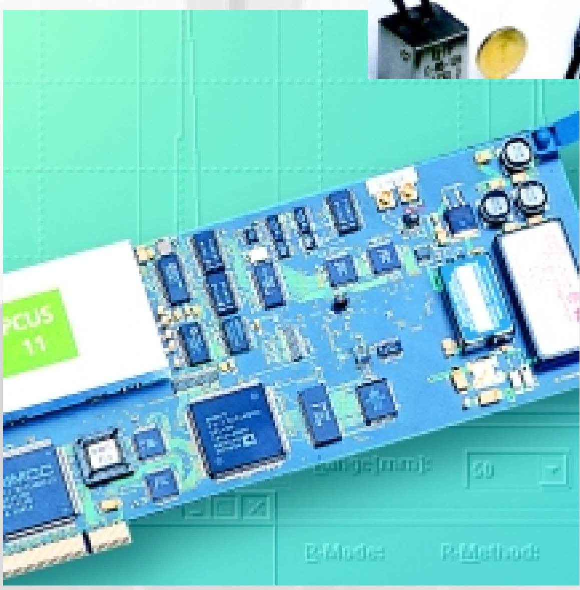
From a methodological point of view, new opportunities will arise in the search for new inspection and testing techniques, the development of economical test and inspection systems that are networked with plant operations management and information systems, and the development of signal processing, correlation, and reconstruction techniques for quantitative proof of flaw characteristics and/or to determine material properties.

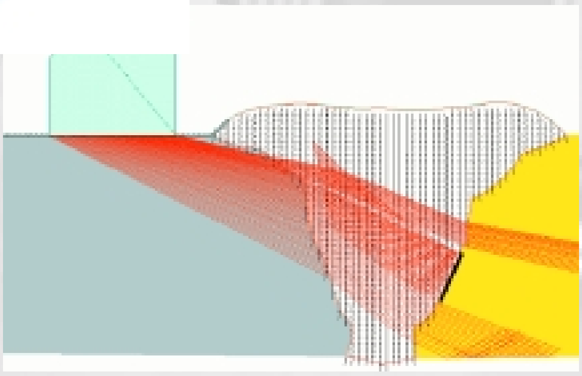
Turbine shaft inspection

Pressure vessel inspection in a nuclear power station

Products and Innovations







Product and Innovations
- Inspection Instruments and Systems

PCUS 10 - Ultrasonic Testing with your Portable PC

Applications:
- Manual ultrasonic testing with extensive documentation of inspection task and results
- Wall thickness testing of components susceptible to corrosion

Features:
- Compact, portable ultrasonic testing system consisting of laptop PC and PCUS 10 ultrasonic pulser/receiver board
- Computer-aided data acquisition
- Analysis software PCUSware3 with Distance-Amplitude-Correction and DGC Curves (AVG)
- A-Scans and comments are saved directly to hard disk

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UT-Reader – Container Identification using Ultrasound

Applications:
- Identification of radioactive waste containers using back-scattered ultrasound
- Control and verification of closure welds of high- and low-level radioactive waste
- Monitoring and control of spent-fuel containers; standard equipment used by international inspection agencies

Features:
- Robust, compact, and portable industrial case
- Dust and splash-proofed
- Battery and line-powered operation
- Online signal analysis
- Automatic parameterization and adjustment to present container using the container database
- Storage of all parameters and test data
- Documentation of test results
- Compliant to relevant safety requirements

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Multi-Channel Pipe Inspection System

Applications:
- Automated ultrasonic inspections of piping and piping systems in industrial plants

Features:
- Four or eight ultrasonic channels, contained in a portable PC
- Frequency range from 0.5 – 15 MHz
- Time-Gain-Correction (TGC) function
- 80 MHz sampling rate, 12-bit resolution
- Recording of RF data or reduced data (ALOK)
- CPS-N data acquisition/analysis software (Windows© NT)
- Modular scanner controller (IMS) for the inspection of straight piping, bent piping, elbows and nozzles

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Ultrasonic-Tomograph

Applications:
- Analysis of safety-relevant parts and components
- Wall thickness testing of components subject to corrosion

Features:
- Compact, portable ultrasonic testing system consisting of industrial-type laptop PC, PCUS 10 ultrasonic pulser/receiver board, versatile miniature scanner ISCAN-6 for manual or motorized scanning, and CPS-SAFT analysis software
- Computer-aided data acquisition
- Post-processing and display of three-dimensional flaw images using CPS-SAFT
- Post-processing and display of corrosion maps
- Suitable for field use in battery (12V) operation
- Protection Class IP 54

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AURA - Ultrasonic Wheel Set Inspection

Applications:
- Automated ultrasonic inspections of disassembled railroad wheels and wheel sets during regular service intervals

Features:
- Inspection of the wheel rim and disk
- Maximum wheel weight 2000 kg (4409 lbs.)
- Wheel diameter range from 780 mm – 1300 mm (30” – 51”)
- 10 to 15 minutes inspection time per wheel set
- 28 ultrasonic transducers, including two EMAT transducers are used for the inspection of the wheel disk
- PCUS 40 system with 40 ultrasonic channels
- Automated analysis and documentation
- Expandable by using intelligent data-management system for recording and assembling of individual wheel history data

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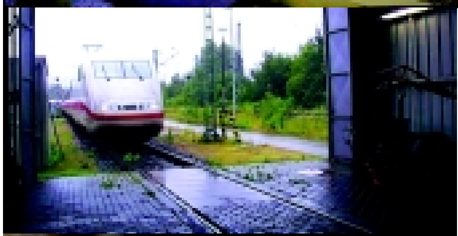

AUROPA II

Applications:
- In-motion, in-service inspection of the ICE (Bullet Train) wheels running surface using surface waves

Features:
- Detection of crack-like discontinuities oriented perpendicular to the circumference
- Analysis of pulse-echo and through-transmission signals
- Fully automated PC-controlled data acquisition
- Modular test electronics
- 0.4 MHz test frequency
- Four transducers in time-multiplexed arrangement
- PC-controlled instrument adjustments and system diagnostics
- Data acquisition, display, analysis, and storage
- A-scan presentation in RF and video format

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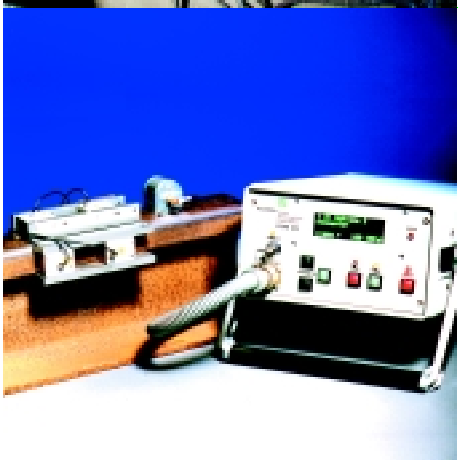

UES

Applications:
- Ultrasonic system for the nondestructive evaluation of stress states in new and continuousely welded rails

Features:
- Portable, battery-powered instrument
- Electromagnetic (EMAT) transducers permit sound transfer into the material without couplant agents
- Computer-aided data acquisition, data analysis, and documentation of results
- Interface for external PC and hardcopy printer

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UER-T

Applications:
- Ultrasonic system for the nondestructive evaluation of residual stress states in the rim of railroad wheels

Features:
- Portable, battery-powered instrument
- Network integration into computer-controlled processes, optional
- Fully automated stress analysis
- Comparison of results with preset limits for tolerable stress states
- High testing speed, approximately 90 seconds per wheel
- Complies with the requirements of Deutsche Bahn AG: 907.0801, UIC 510-2, ERRI B 169/RP 6

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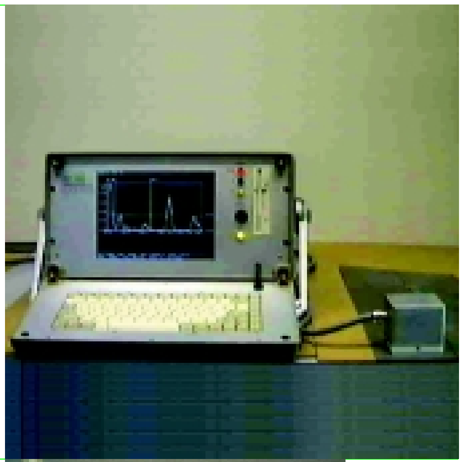
EMAT 2K – EMAT System



Applications:
- Manual ultrasonic inspections using SH-wave and guided waves
- Blanket-coverage corrosion inspection of inaccessible areas

Features:
- Two separate transmitter and receiver channels, computer programmable
- 35dB forward/backward ratio
- Expandable to transducer AC- magnet, optional
- Frequency range from 0.3 MHz to 1.5 MHz
- 60 dB dynamic range
- Capture and transfer of RF- and A-scan data

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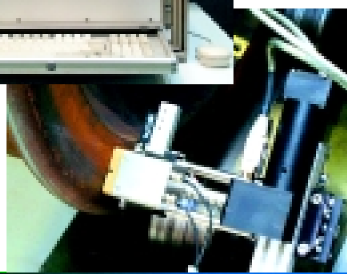
EMAT-RITIM



Applications:
- Detection of planar (crack-like) flaws oriented parallel to sound propagation
- Detection and sizing of transverse flaws in railroad wheels

Features:
- Ultrasonic testing using linear polarized shear waves in straight-beam mode
- Computer-controlled test instrumentation and scanner control
- Computer-controlled data acquisition, analysis, and data display
- Testing frequency at 2.5 MHz
- A-scan presentation (RF- and video signal)

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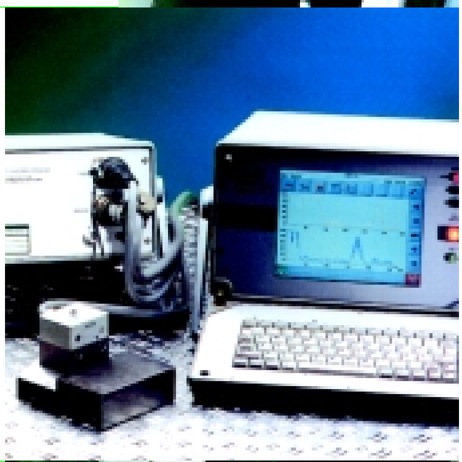
EMAT PAS 8 – EMAT/Phased Array System



Applications:
- Inspection of stainless steel (austenite), bi-metallic, and dissimilar metal welds of piping and vessels

Features:
- Variable and multiple angle-beam inspection using Phased Array principles
- Maximum of eight individual transmit/receive channels
- Computer controlled setting of incidence angle(s) (0° to 90°) and other inspection parameters
- Test frequency ranging from 0.3 MHz to 1.5 MHz
- 60 dB dynamic range
- A-scan presentation in RF and video format
- Automated inspections in combination with suitable scanning equipment and CPS data acquisition/analysis software

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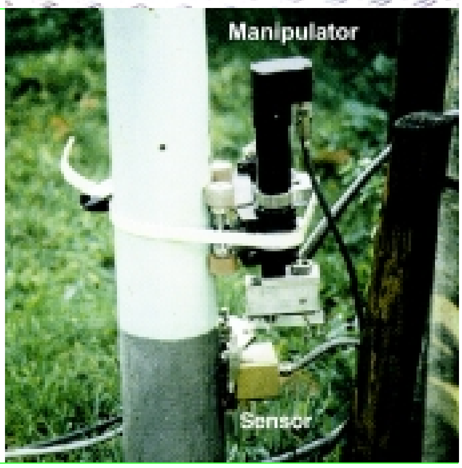
EMAT-LIMATEST



Applications:
- Fast blanket coverage inspection of light poles and piping systems for corrosion in areas inaccessible from the outside surface

Features:
- Compact and portable system consisting of EMAT electronics PCUS 11 pulser/receiver board, data acquisition/analysis PC, versatile miniature scanner ISCAN-6 for manual or motorized scanning, and CPS software
- Computer-aided system setup, and data acquisition and analysis
- Post-processing of corrosion maps with B-scan and C-scan presentations
- Suitable for field use in battery (12V) operation

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AUSTRA

Applications:
- Automated stress and texture analysis using ultrasound
- Determination of the elastic modulus of metals and ceramics
- Detection and localization of material inhomogeneousness and variations in material conditions
- Characterization of rolled sheet textures and deep drawing ability
- Determination of stress states of steel and aluminum components

Features:
- Portable ultrasonic test instrument
- Computer-aided data acquisition, data analysis, and documentation of results
- Transmitter and receiver designed for piezoelectric and/or electromagnetic (EMAT) transducers
- Time- or position-dependent data acquisition
- Interfaces for data transfer and printer

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Case Hardness Tester

Applications:
- Manual determination of the case hardness depth on induction heat-treated parts using ultrasound

Features:
- Portable, robust instrument
- Industrial-strength case, dust and splash proof
- Touch-screen operation
- Battery and/or line-powered operation
- Test frequency ranging from 15 – 20 MHz
- Sampling rate at 80 MHz

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Case Hardness Test Station

Applications:
- Automated measurement of the case hardness depth on heat-treated parts for quality control of part/component production

Features:
- Industrial rack design, line-powered
- Easy operation
- Test frequency ranging from 18 – 20 MHz
- Sampling rate at 160 MHz
- On-line signal tracing in FPGA (Field Program Gate Array)
- Automatic depth measurement for 8 channels
- Determination of eight (maximum) processing parameters
- Hard disk storage of all collected data
- Documentation of system setup and test results
- Custom-specific features are optionally available

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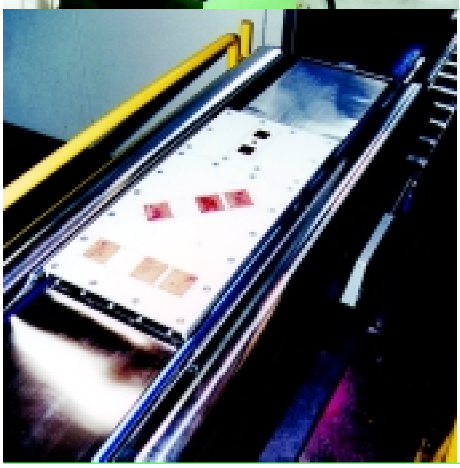

Nondestructive Strip Analyzer

Applications:
- Sheet metal testing in steel processing industry
- Determination of anisotropic structures in sheet metal processing industry
- Continuous monitoring of skin-passing
- Residual stress measurement after forming

Features:
- Process-integrated technology
- Determination of anisotropic structures using ultrasonic time-of-flight measurements
- Yield strength determination using permeability quantities
- Stationary and/or portable
- Electromagnetic (EMAT) and/or 3MA sensor technology
- Continuous contact-free analysis of product properties
- Interfaces to process-control systems

EMAT and 3MA Sensor technology in a hot gavanizing facility

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USWM – Ultrasonic Welding Monitor

Applications:
- Process-integrated measuring of weld-nugget size (diameter) during spot-welding

Features:
- Applicable to all metallic materials such as iron, steel, aluminum, lead, copper, etc.
- Online welding process control
- Applicable to joining and micro-joining using the resistance spot-welding method

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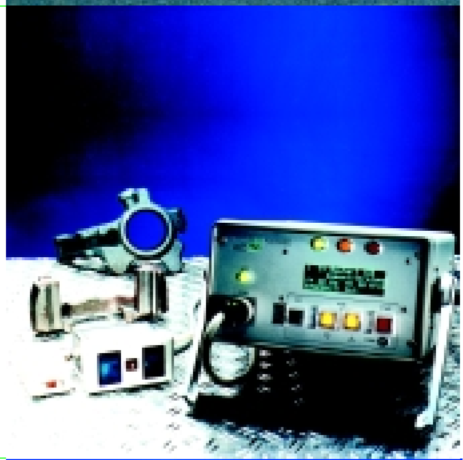
WE 21 – Cementite Tester



Applications:
- Characterization of the microstructure of gray cast iron, specifically to detect chilling
- Inspection of heat-treated parts and components for hardness and hardness depth
- Residual stress measurements on ferromagnetic materials

Features:
- Portable inspection system
- Magnetization frequencies ranging from 20 Hz to 200 Hz
- Magnetic field strength up to ±90 A/cm
- Easy control with accept/reject indicator in testing mode
- Expandable to testing station in combination with external keyboard and monitor
- Software support for system calibration
- Various interface options for peripherals and/or process integration

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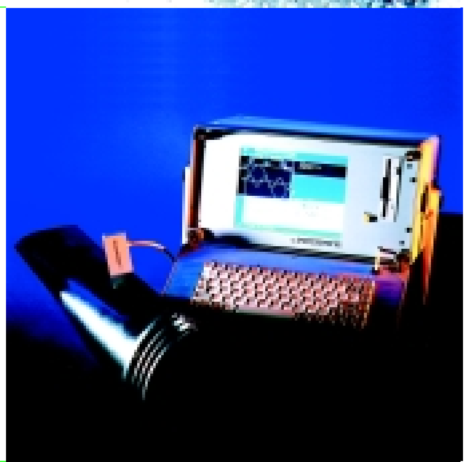
3MA-ES-HV – Hardness and Stress State Analyzer



Applications:
- Inspection of heat-treated parts and components
- Weld inspections

Features:
- Portable electromagnetic inspection system
- Modular equipment architecture
- Multi-frequency eddy current module, a Barkhausen Noise module, a harmonic distortion module, and an incremental permeability module for analysis
- Multi-parameter sensors
- Computer-aided control of the system functions
- Digital signal processing
- Menu-driven interface for system calibration and data acquisition
- TFT display

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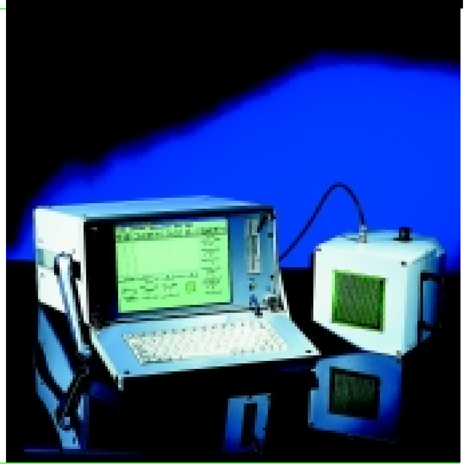
OSA-NMR



Applications:
- Diagnosis of moisture contents, moisture distribution, and porosity in construction material (concrete, masonry)
- Measurements of density, moisture, and bonding agent distribution in wood and chipboard
- Characterization of polymer and elastomer materials

Features:
- Portable, battery powered system
- Transmitter pulse at 30 kW maximum output power
- Frequency for NMR-signal ranging from 0.1 MHz to 10 MHz

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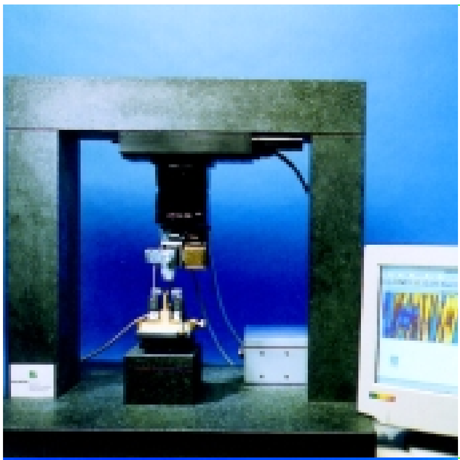

BEMI – Barkhausen Noise and Eddy Current Microscope

Applications:
- High-resolution measurements of the Barkhausen Noise and high-resolution eddy current inspections
- Characterization of properties, thickness, and structure of layers and layer systems
- High local resolution measurements of mechanical properties and residual (inherent) stress states
- High local resolution measurements of magnetic properties such as the coercive field strength

Features:
- Local resolution from a few µm to 10 µm, sensor dependent
- Positioning accuracy better than 1µm
- Excitation frequency (1 Hz to 250 Hz) for Barkhausen Noise measurements
- Frequency range from 10 kHz to 10 MHz for Barkhausen Noise Analysis
- Frequency range from 100 Hz to 10 MHz for eddy current measurements
- Menu-driven software for microscope control and image presentation

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WS98 – Digital Multi-Channel, Multi-Frequency Eddy Current System

Applications:
- Detection and characterization of material discontinuities
- Determination of material properties on electrically conductive parts and components

Features:
- Four ET channels through modular electronic components
- High signal dynamics, better than 86 dB
- Multiplexing of four test frequencies at 2 kHz maximum
- High computing power through integrated digital-signal-processor (SHARC)
- Numerical high- and low-pass filtering
- Powerful analysis algorithm (multi-dimensional regression analysis)

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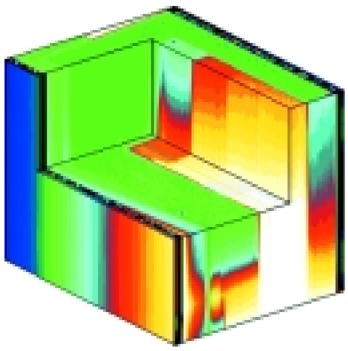

Application of video pulse thermography to the measurement of coating thickness for an aluminium specimen with polymer layers of different thickness

Multi-Channel Thermography

Applications:
- Determination of the wavelength-dependent emission coefficient for high-temperature materials at temperatures above 2000 °C (3632 °F)
- Temperature measurements with emission coefficient correction
- Characterization of surface conditions

Features:
- Wavelength Range: 0.4 µm to 1.1 µm and 3 µm to 12 µm
- Maximum of six (6) spectrum channels
- Menu-driven software for data acquisition and analysis

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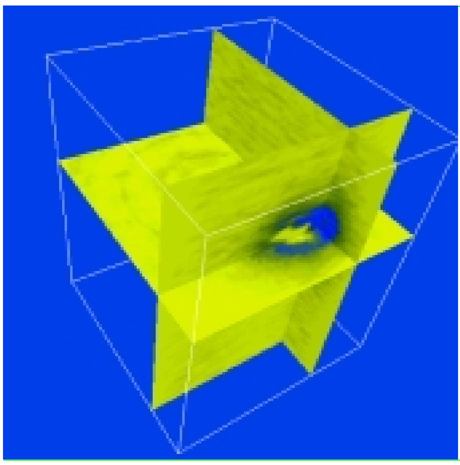

Industrial 3D Computer-Tomography

Applications:
- Three-dimensional display of the inside and outside contour of parts and components
- Detection of discontinuities and density variations
- Measurement of inside and inaccessible contours and geometry
- Used for applications in automotive, transportation, casting, molding, rubber, and plastic industries

Features:
- Modular design and open system architecture
- High-speed testing
- Optimized, high-speed reconstruction algorithms (in parallel)

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Scanning Equipment

ISCAN-6 – X/Y Scanner for Analysis

Applications:
- Manual, semi-automated and automated (motorized) scanning with ultrasonic and/or eddy current techniques on flat components or piping and vessels with diameters of 200 mm (8”) or larger

Features:
- 2-axis with approximately 250 mm (10”) scan area
- Expandable, flexible guide track, available with rare earth magnets or suction cups
- Manual or motorized operation with suitable motor controllers
- Motor, gears, and encoder unit are splash proof for field usage
- Two ultrasonic transducers or two eddy current sensors can be mounted to the scanner
- Scanner weight is less than 2 kg (4.5 lbs.)

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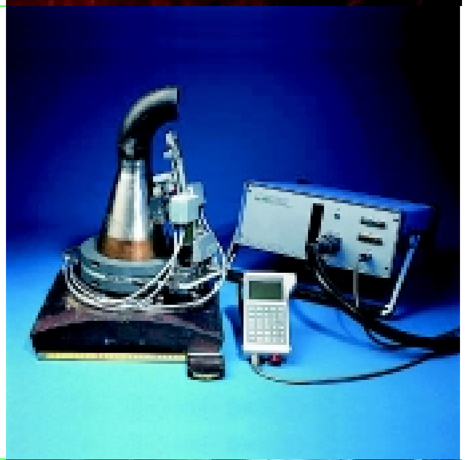
IMS 50/250 ST – Nozzle Scanner



Applications:
- Automated ultrasonic and/or eddy current inspections of pipe or vessel nozzles with diameters ranging from 50 to 250 mm (2 – 10”)

Features:
- 360° circumferential coverage
- The scanning arm can be delivered in various lengths
- Scanning arm adjusts to nozzle size and configuration
- Minimum height (clearance) of 50 mm (2”)
- 0.5 mm (0.02”) positioning accuracy
- Maximum scanning speed 50 mm (2”) per second

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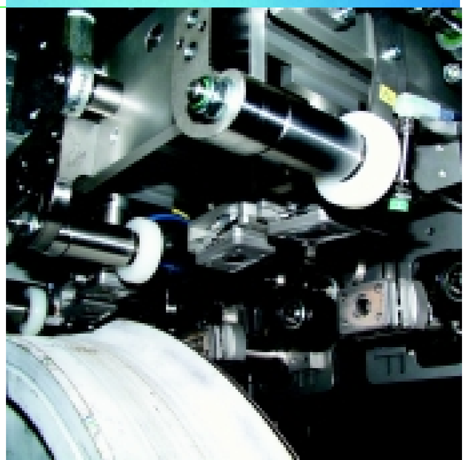
Railroad Wheel Manipulator



Applications:
- Automated ultrasonic and/or eddy current inspections of railroad wheel sets

Features:
- Inspection of disassembled wheels
- Inspection of complete wheel sets
- Modular design permits configuration for various wheel diameters and different number and size transducers/sensors
- Pneumatic transducer/sensor control using SPS modules

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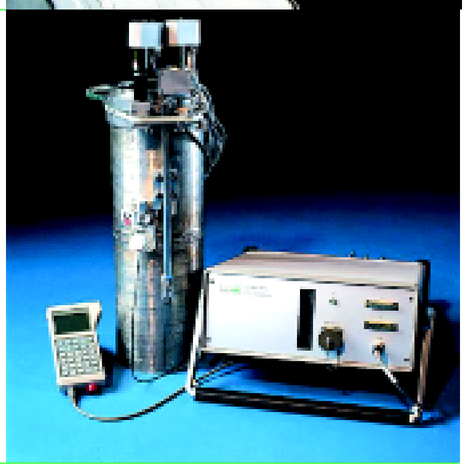
IMS – Pipe Inspection Scanner



Applications:
- Automated ultrasonic and eddy current inspections on piping with diameters ranging from 100 mm to 500 mm (4” to 20”)

Features:
- Inspection of straight pipe sections, bends, and elbows
- Adaptable to various elbow and bend dimensions
- Minimum radial clearance as low as 80 mm (3.2”)
- Various scan-arm lengths
- 0.5 mm (0.020”) positioning accuracy
- Scanning speeds up to 50 mm (2.0”) per second

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Sensors and Transducers

Conventional and custom-designed transducers. All transducers are made in-house using proprietary piezoelectric composite material

Piezoelectric Composite Materials

Applications:
- Design and manufacturing of conventional straight-beam and angle-beam ultrasonic search units
- Design and manufacturing of straight-beam and angle-beam ultrasonic search units for special applications

Features:
- Low acoustic impedance (between 8 – 12 MRayl) thus providing excellent acoustic matching
- High electromechanical conductive coupling (typical 0.7)
- Broad bandwidth (low mechanical grade)
- Low cross-directional coupling
- Moderate malleability
- The mechanical, dielectric thermal, and piezoelectric properties of composite materials can be largely modified to achieve the performance requirements of the search unit

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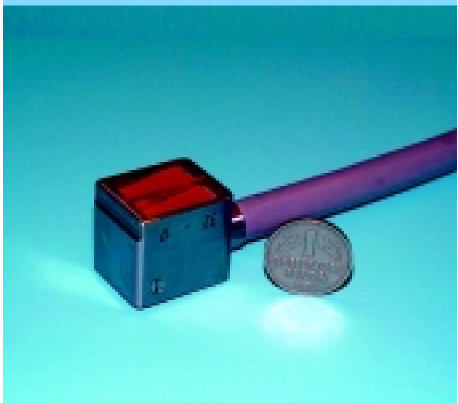

Multi-function transmit/receive search unit, 2x16 elements

Phased Array Transducers

Applications:
- Detection and analysis of weld discontinuities through fast electronic sound field variation (variation of focal depth, angle of incidence, and skew angle) and radar-like image display
- Electronic compensation for sound field distortion and sound redirection during the inspection of anisotropic materials (stainless steel welds, dissimilar metal welds, etc.)
- Inspection of components with complex shape and geometry, in particular for the discrimination of relevant indications
- Wall thickness testing of piping from the ID (pigging systems)

Features:
- Frequencies ranging from 0.5 to 15 MHz
- Maximum of 100% bandwidth
- Linear, circular, ring, and matrix arrays
- Generation of longitudinal, shear, Rayleigh, and surface wave modes
- 0.1° angular steering resolution

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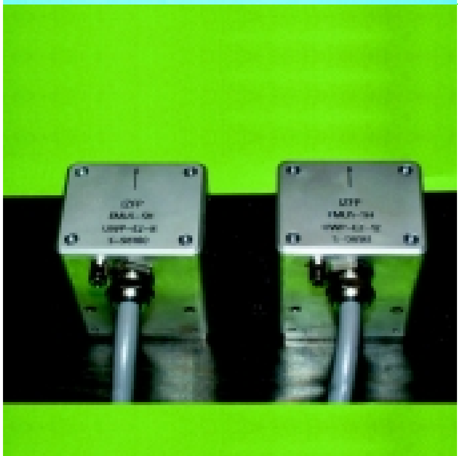

EMAT Transducers for Corrosion Testing

Applications:
- Detection of corrosion in piping systems and storage tank floors

Features:
- 90° angle of incidence
- Test frequency range from 200 kHz to 400 kHz
- SH-wave (horizontal polarized shear wave) mode

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EMAT Transducers for Elevated Temperatures

Applications:
- Inspection of heavy wall components at elevated temperature for planar flaws parallel to the test surface

Features:
- 0° angle of incidence (straight beam)
- Test frequency at 1.3 MHz
- Linear polarized shear wave modes
- 300 °C (572 °F) maximum operating temperature

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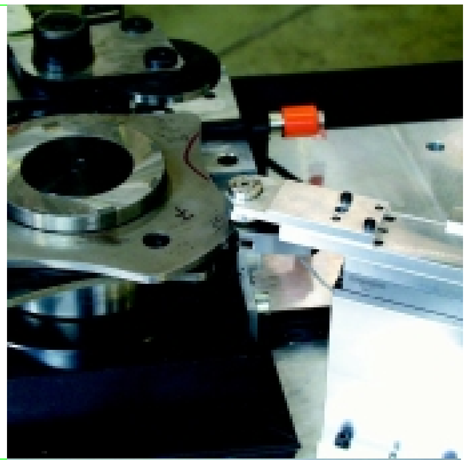
Eddy Current Sensors for Material Characterization



Applications:
- Determination of hardness, hardness (case) depth, material strength, and stresses
- Characterization of grain structure gradients in depth direction
- Wall thickness and coating thickness testing
- Material identification

Features:
- Test frequencies ranging from 500 Hz to 500 kHz, matched to the required penetration depth
- Broad-band design for Multi-Frequency applications
- Effective measuring areas from 5 mm^2 (0.200” x 0.200”), matched to required lateral resolution
- Available as coaxial, pick-up, or true transmission sensor

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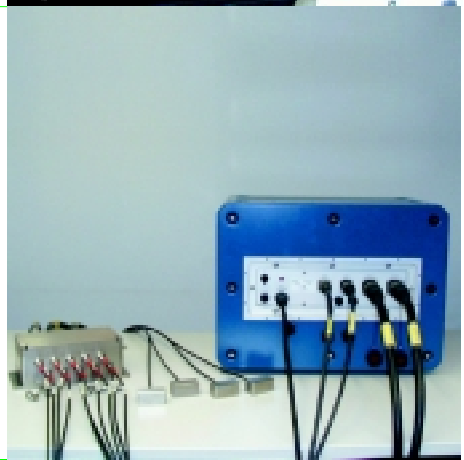
Low-Frequency Eddy Current Sensors for Stainless Steel Testing



Sensors (center) and driver circuity (left)

Applications:
- Inspection of weld deposit cladding: detection and characterization of buried, laminar and volumetric flaws, sub-clad flaws, thickness measurements, and determination of δ-ferrite content
- Inspection of stainless steel piping and welds up to 12 mm (0.5”) wall thickness: Detection and characterization of discontinuities at the ID

Features:
- Inductive sensors:
  Frequency range from 500 Hz to 10 kHz
- Giant Magneto Resistance (GMR) sensors:
  Frequency range from 30 Hz to 10 kHz
- 12 mm (0.5”) maximum penetration depth
- Integrated, active driver circuitry for cable lengths up to 60 m (180 feet)

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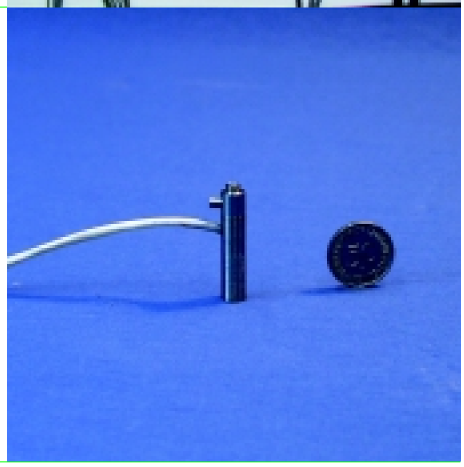
Miniature Eddy Current Sensors



Applications:
- All metallic materials
- Flat and curved surfaces and edges

Features:
- Test frequencies up to 20 MHz
- Effective measuring areas from 1 mm^2 (0.040” x 0.040”), matched to flaw size
- Detection of flaws in depth of 30 µm and deeper
- Differential/Absolute circuits
- Integrated driver circuitry for cable length up to 60 m (180 feet)

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Air-Coupled Ultrasonic Transducers for Concrete Inspections

Applications:
- Wall thickness testing of structures made of concrete
- Detection of cavities, foreign material inclusions, cracks, and delaminations

Features:
- Test frequency ranging from 50 to 250 kHz
- Large bandwidth
- Single element and dual-element modes
- Sound transmission without coupling medium
- Improved energy input through compressed-air cushion design
- Air-cushioned contact surface permits easy transducer movement

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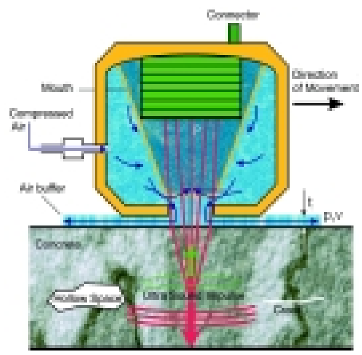

Air-coupled ultrasound transducer with air-cushion contact surface

Hardware Modules

PCUS 10 – Ultrasonic Pulser/Receiver Board

Applications:
- Manual PC-aided ultrasonic inspections in combination with PCUSware3 data acquisition and analysis software with complete documentation of system setup and test results

Features:
- Frequency range from 0.5 to 20 MHz
- 100 dB dynamic range
- Maximum sampling rate at 80 MHz, 8-bit resolution
- Recording and storage of RF- and A-scan data
- 3/4 length ISA board
- Fits in standard desktop PC and suitable laptop PC
- Low power consumption permits battery operation

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PCUS 11 – Ultrasonic Pulser/Receiver Board

Applications:
- Manual PC-aided ultrasonic inspections in combination with PCUSware3 data acquisition and analysis software
- Single-channel and multi-channel automated ultrasonic testing in combination with suitable software, e.g. CPS, and scanning equipment
- High-resolution ultrasonic data analysis using SAFT

Features:
- Frequency range from 0.5 to 20 MHz
- Maximum of 4 kHz pulse repetition rate
- 110 dB dynamic range
- DAC and TGC functions
- Maximum sampling rate of 160 MHz, 10 bit resolution
- Signal averaging up to 128 samples
- Recording and storage of RF- and A-scan data

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PCUS 40 – Modular Multi-Channel Ultrasonic System

Applications:
- Automated multi-channel ultrasonic testing for industrial plants (pre-service and in-service examinations)
- Quality control during production of semi-finished and finished parts and components
- Pre-service and in-service inspections for the railroad industry

Features:
- Modular expansion to a maximum of 64 channels using 4-channel P/R boards
- Customizable data acquisition and analysis software
- Frequency range from 0.5 to 15 MHz
- Maximum of 5 kHz pulse repetition rate
- DAC and TGC functions
- Maximum sampling rate at 80 MHz, 12-bit resolution
- Recording and storage of RF data
- Online data reduction, e.g. ALOK and/or gating technique

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Single-Channel Acoustic Emission Board

Applications:
- Detection of discontinuities in parts and components
- Analysis of damage mechanisms

Features:
- PC plug-in module, ISA bus
- High sensitivity
- High burst rate
- Capable of processing a large number of AE parameters
- Simultaneous recording of load indices and processing variables
- Optional two-channel operation
- One AE data acquisition channel and three analog parameter channels
- Test frequency up to 1 MHz
- Amplification (gain) ranging from 0 to 40 dB
- 12-bit A/D Converter resolution

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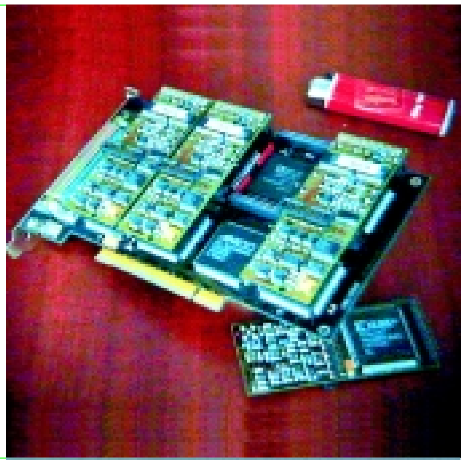
FDTE 41 S - Multi-Channel Fast Analog Measuring System



Applications:
- Processing analysis, e.g. determination of the impact on AE by parameter deviations in production processes
- Manufacturing process monitoring, e.g. analysis of time variations of AE and their relationship to the process condition

Features:
- Online recording of process parameters and comparison with the set-point values
- Four AE data acquisition channels and eight analog parameter channels
- Test frequency ranging from 50 kHz to 5 MHz
- Long-term monitoring of processing parameters
- Automatic data analysis and report generation
- Optional customer-specific software design

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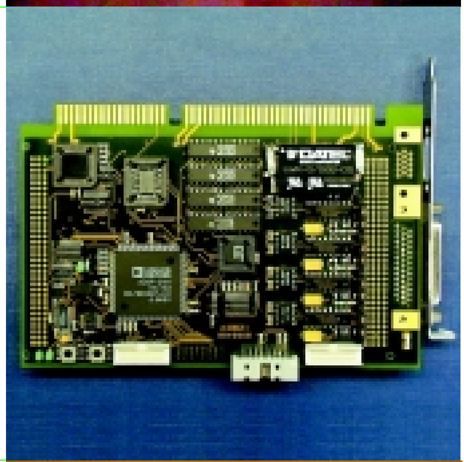
KDI 40 – Coordinate Interface



Applications:
- Intelligent position coordinate and scan area data capture and transfer for semi-automated and automated NDT

Features:
- Intelligent DSP-based ISA interface board
- Four encoder input channels
- Galvanic isolation of input signals
- Differential or uni-polar input
- 4 digital inputs, 2 digital outputs
- Integrated scanning programs
- Maximum of 100,000 location data per second
- Serial, bi-directional interface (SSI) for data transfer to external systems such as USKDI

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USKDI – Ultrasonic Front-End and Coordinates Module

Applications:
- Assembly of multi-channel ultrasonic modules for front-end based ultrasonic systems for production testing

Features:
- Integrated coordinates module for the assembly of compact front-end systems for production-line testing
- Analog 4-channel ultrasonic module with DSP controller for relative position data-dependent trigger conditioning and host computer linking
- Expandable with 4-channel modules
- 4-channel T/R mode with pre-amp control, programmable filters, and variable high-voltage generation
- Computer-aided control of the ultrasonic parameters and scanning control software on Windows95/98© and Windows NT© via RS422 interface (SSI)
- Integration through trigger signal and multiplexed RF-out signal into various data acquisition systems

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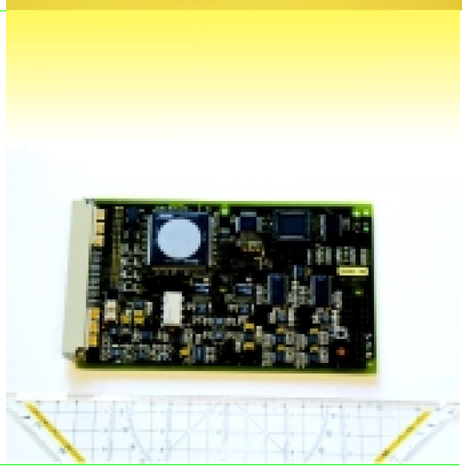
WS-98 – Eddy Current Main-Module



Applications:
- Detection and characterization of material discontinuities
- Determination of material properties of conductive parts and components

Features:
- Multi-channel design using modular components
- High signal dynamics (>86 dB)
- Frequency multiplexing at up to 8 kHz (4 test frequencies)
- Powerful computing using integrated digital signal processing (SHARC)
- Numerical high- and low-pass filtering
- Powerful analysis algorithm (multi-dimensional regression analysis)

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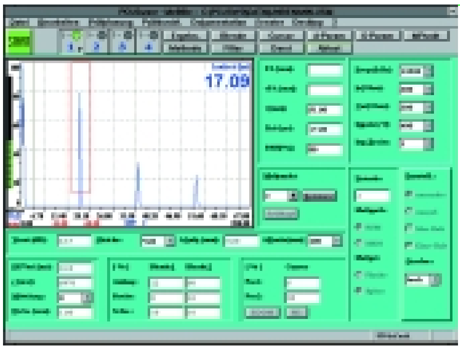
Software Modules



PCUSware3 – Software for Manual Ultrasonic Testing

Applications:
- Manual ultrasonic testing
- Wall thickness testing

Features:
- Used in combination with PCUS 10 and/or PCUS 11
- User-friendly, customizable menu-driven data acquisition and analysis software running on Windows3.*©, Windows95©, and Windows98©
- Integrated transducer database
- Menu-driven system calibration
- Storage and administration of recorded A-scan data and setup parameters
- Customizable inspection result reports

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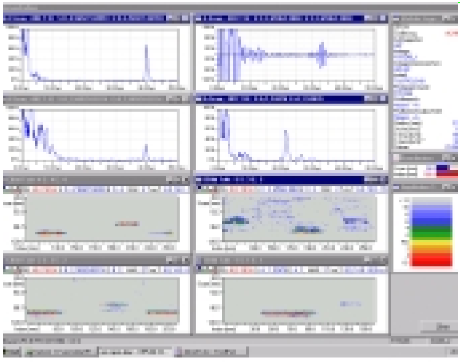

Online display of A-scans and C-scans during data acquisition

CPS-N – Software for Automated Ultrasonic Testing

Applications:
- Mobile manual and automated ultrasonic in-service testing in industrial plants
- Manufacturing and pre-service ultrasonic testing

Features:
- Single and multi-channel ultrasonic testing in combination with the PCUS 40 system
- Inspection setup module with transducer and transducer system database and component management database
- Online display of A-scans and/or C-scans for up to four channels simultaneously
- Data analysis using A-scan, C-scan, and CBD-scan presentations
- Flaw analysis using SAFT reconstruction software
- Windows NT© platform
- Customization optional

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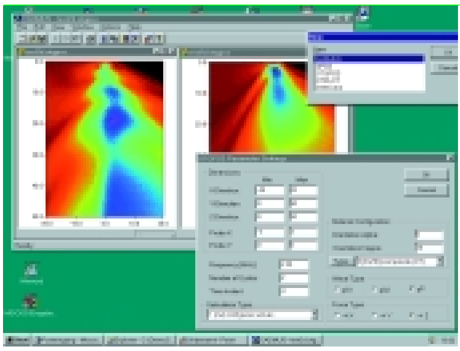

CADMUS – Modeling Software for Ultrasonic Testing

Applications:
- Simulation and optimization of ultrasonic sound fields in isotropic and anisotropic materials
- Modeling of beam spread in complex component geometry
- Search unit optimization
- Parameter studies

Features:
- Windows95© and/or Windows NT© platform
- MFC-Multiple Document Interface
- Object-oriented 32-bit application
- Custom-specific update modules

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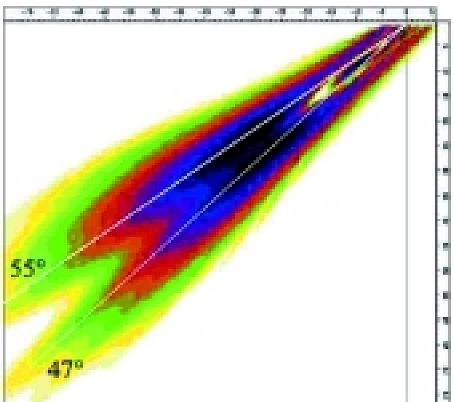

Sound field of a Focused Shear Wave Transducer on a Cylindrical Component

Soundfield Characterization and Modeling Software

Applications:
- Preparation and setup of ultrasonic examinations of isotropic materials
- Calculation of sound beam pattern for focused transducers on flat and curved surfaces
- Determination of optimum sound field properties for ultrasonic examinations
- Parametric description of curved components such pipes and rings with varying curvature
- Modeling of sound propagation of longitudinal and SV-wave modes
- Free placement of virtual flaws or reflectors

Features:
- Runs on DOS (with DOS-Extender), Windows 95©, and Windows NT©

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VISOTHERM 5.0 – Software Package for Dynamic Thermography

Applications:
- Software for pulsed thermographic testing system control and analysis of data
- For mobile testing and production line-integrated test systems
- Contactless and fast detection of near surface flaws
- Characterization of layers and layer-systems for layer thickness and material properties

Features:
- Quantitative analysis of instationary heat diffusion processes for materials characterization
- Running under Windows95© and Windows NT©
- Modular and flexible software concept
- Specific, problem-oriented, add-on software modules

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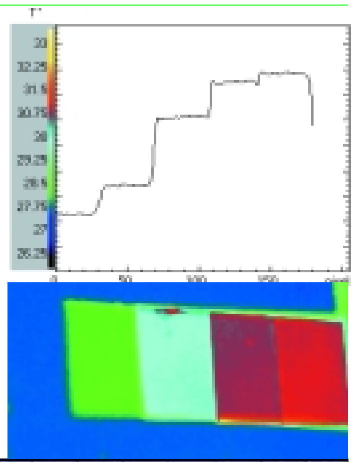

Thickness measurement of a graded polymer coating on an aluminium part

3D-SAFT – Ultrasonic Analysis Software

Applications:
- Flaw analysis via SAFT (Synthetic Aperture Focusing Technique) data reconstruction
- Analysis of ultrasonic data from metals, plastics, composites, ceramics, and concrete

Features:
- Runs on various operating systems, such as DOS (with DOS-Extender), Windows 95©, and Windows NT©
- Analysis of flat, cylindrical, or otherwise curved components
- Recording of the three-dimensional surface configuration during data acquisition
- Display of reconstruction results in cross-sectional images

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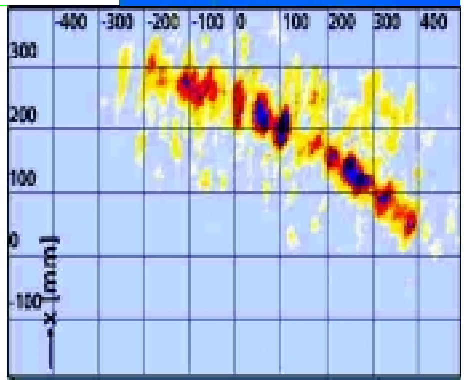

3-D Reconstruction of a Reinforcement Channel of a Concrete Component in 250 mm (10”) Depth

3D CAD-SAFT – Modeling Software

Applications:
- Flaw analysis using SAFT reconstruction for flat and contoured components

Features:
- Windows95© and/or Windows NT© platform
- Parametric description of components such as piping or plates
- Generation of three-dimensional images from CAD (dxf) formats
- Generation of cross sections and imbedding to component drawings
- Search unit database
- Material property database
- Animation in virtual (reconstruction) space

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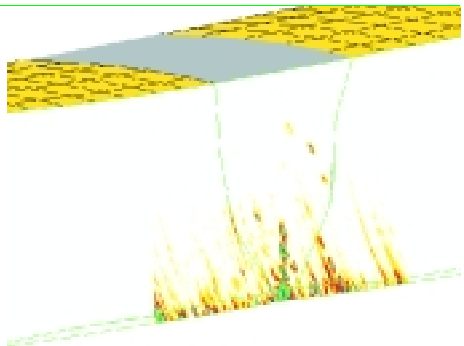

Reconstruction of an ID-connected crack in a weld

IQMS – Feedback-Information System

Applications:
- Quality management software for NDT (component history, analysis records, archiving)
- For plant construction and plant surveillance, power plants, railroad, chemical plants, aviation and aerospace, offshore, etc.

Features:
- Automatic transfer of inspection data and analysis data; automated report processing
- Interfaces to third-party CAD and QA software
- Maintenance and service management
- Processing and control of test and inservice inspection documentation
- Integrated image database and image management
- Cost planning and cost control
- Optional custom-specific design; expandable

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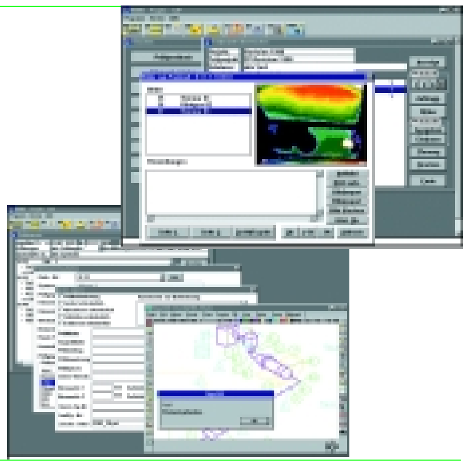

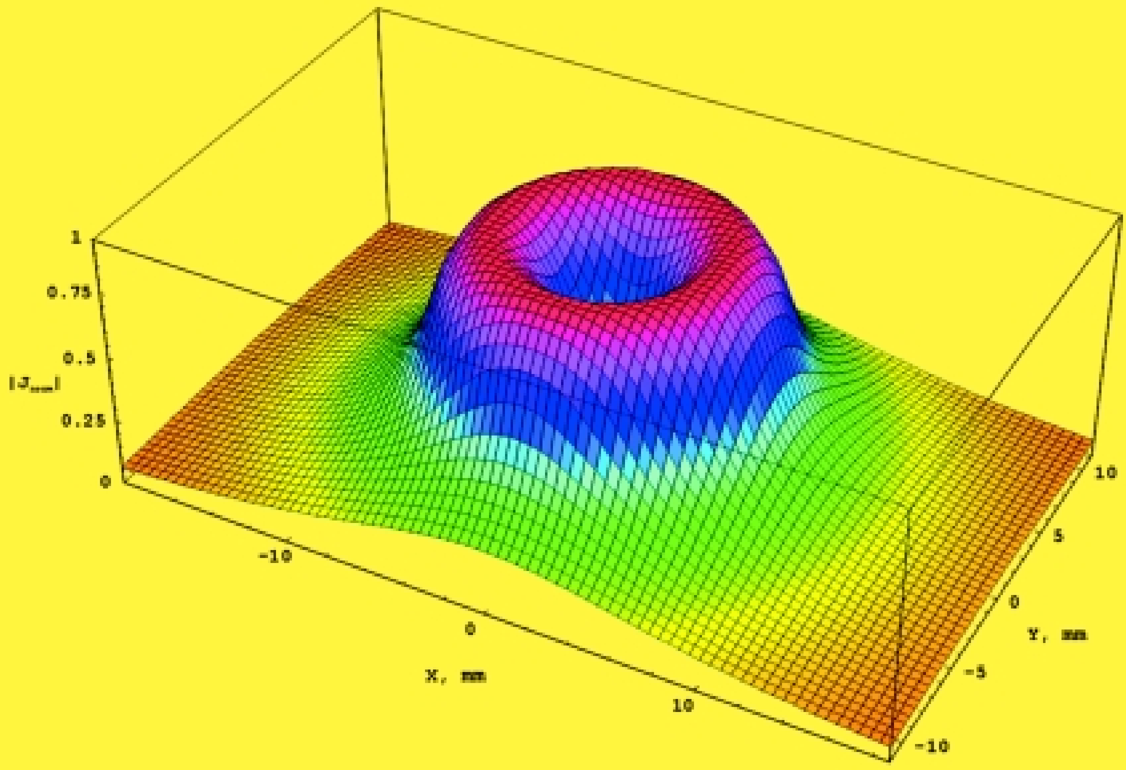
1
0.75
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0
10
X, mm
10
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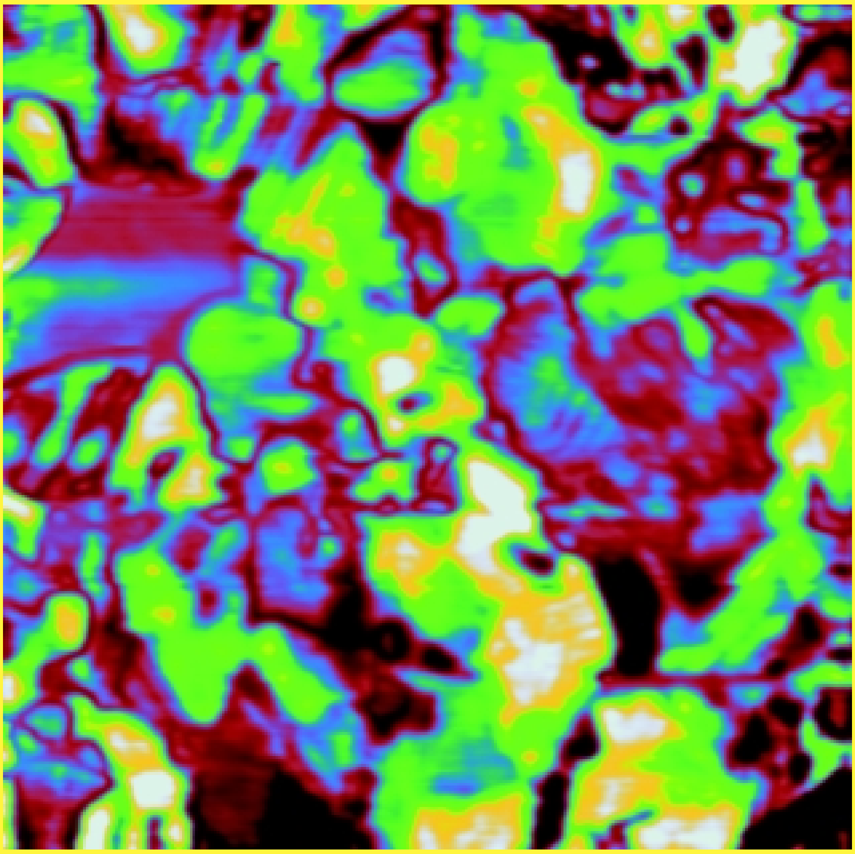
Y, mm



Quantitative Contact-Spectroscopy Using the Ultrasonic Atomic Force Microscope

Problem

High-resolution acoustic imaging techniques are important research tools in material science and for nondestructive material testing. Mechanical material characteristics can be revealed using conventional ultrasound techniques. The spatial resolution is determined by the wavelength of the ultrasonic mode being used and is therefore limited to approximately 1µm. Using so-called »Near-field Techniques« this limit can be improved without decreasing the wavelength or increasing the frequency of the ultrasound. One such near-field technique is the Atomic Force Microscope (AFM). Ultrasonic waves can be detected and sound fields can be displayed using the sensor tip of the Atomic Force Microscope. The detection of ultrasonic fields with the sensor tip of the AFM permits acoustic images of material surfaces in the nano-meter range, typical for an atomic force microscope.

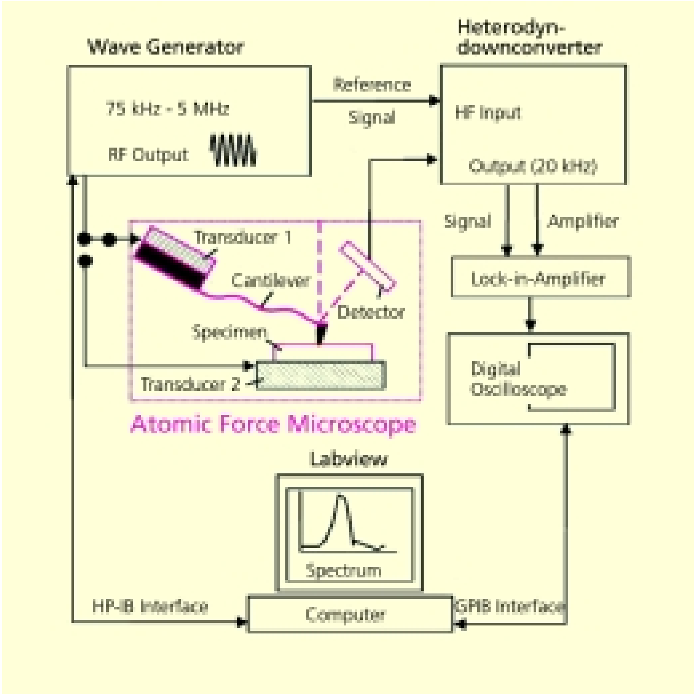


Figure 1: Contact-spectroscopy test setup of the AFM

Mission

During the acquisition of an ultrasonic image with the atomic force microscope, the amplitude or phase of the oscillations transmitted to the leaf spring, or the shifting of the mean excursion of the AFM leaf spring via the ultrasound excitation of the sample as a function of the sample surface coordinates, are recorded. The numerical evaluation of the contrasts in these images combined with appropriate models for the interaction of the sensor tip and the sample permits the measurement of local material parameters of the sample. Investigations on the behavior of the oscillations of the AFM leaf springs during contact with the sample demonstrate that, in principal, mechanical spectroscopy could be accomplished in the nano-meter range, a typical resolution for the AFM. Ideally, ultrasonic AFM images can be generated where the contrast is dependent only on the local elastic characteristic of the sample. On this basis, a technique was developed and calibrated that determined the local elasticity module.

Results

The miniaturized cantilever of the atomic force microscope can be seen as a small mechanical bending bar, which has an infinite number of bending-resonances (self resonance or natural resonance) with increasing frequency. When not in contact with the sample, the bar is firmly attached on one side and free on the other end. When the sensor tip makes contact with the surface of a sample, the force affects the sensor tip so that the mechanical conditions of the previously free end are altered. The self-resonant frequencies of the cantilever are therefore displaced, generally to higher values for repelling forces in the contact mode. The contact stiffness between the sensor tip and the sample can be calculated from the displacement of the self-resonant frequency. From this, the elasticity module of the sample surface can then be calculated using a force rule (in this case the Herzian contact). As a prerequisite, the material characteristics and the geometric data of the leaf spring must be sufficiently known. The unrestricted resonance and the contact resonance of a cantilever can be determined using the

ultrasonic setup illustrated in Figure 1.
A commercially available AFM (Dimension 3000, Digital Instruments, Santa Barbara, CA USA) was augmented as described below.

A function generator (HP33120A) generates continuous wave sinusoidal signals, which can excite either a piezo-element or an ultrasonic transducer (Panametrics A 106S or A103S) below the sample. Test measurements using excitation on the fixed end of the cantilever were not performed because the mounted ultrasonic transducer was designed for frequencies in the kHz-range and was therefore not suited for the MHz-range. The oscillation response was measured using the internal position detector of the Dimension 3000. The signal was merged down to a fixed frequency of 20 kHz using a heterodyne-down converter (working range 75 kHz to 10 MHz), which also received a reference signal from the frequency generator, and was subsequently evaluated with a lock-in amplifier (Ithaco 393). The resulting analog DC-output signal was sent to a digital oscillo-scope (Le Croy 9450). A LabVIEW (LabVIEW, National Instruments, Austin, Texas, USA) based program enabled simultaneous control of the frequency generator and oscilloscope. The frequency of the excitation signal was computer-controlled and incrementally varied, the lock-in output signal (at the prevailing frequency) was read in, and finally, the amplitude of the leaf spring oscillation (in random units) was saved as a function of the frequency. Amplitude calibration was not performed because absolute values for contact resonance measurements are not necessary. The frequency range used for the measurements and the increments are freely settable. In this case, increments between 1Hz and 2 kHz were used depending on the width of the resonance curve.

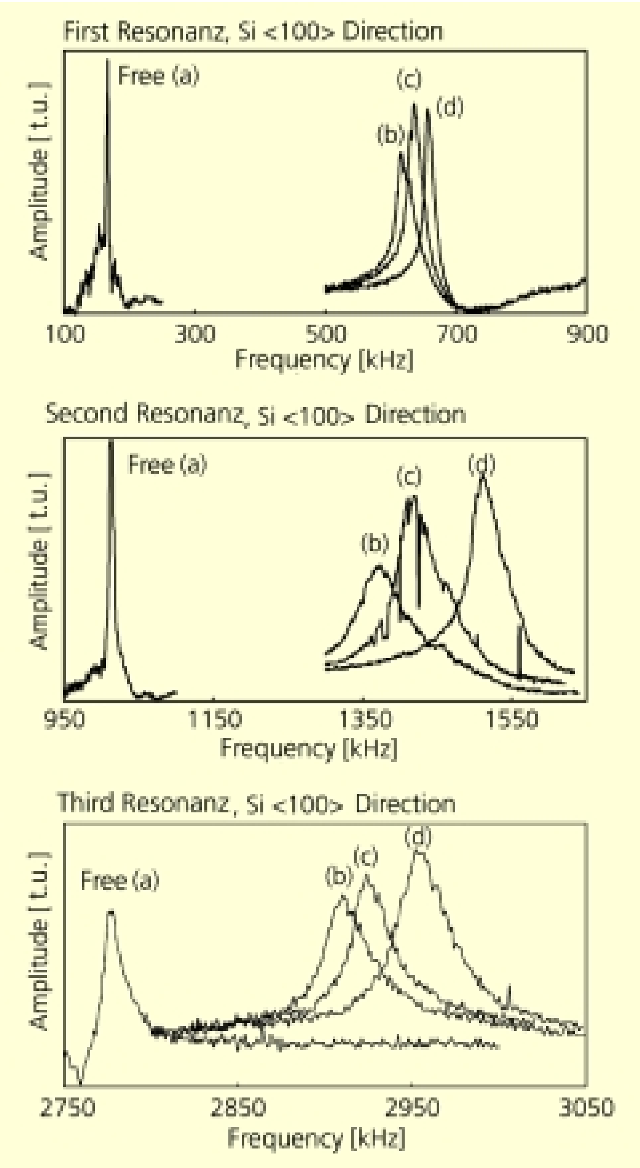


Figure 2: Contact-resonance of the AFM leaf spring in contact with a silicone mono-crystal

Figure 2 shows the first three recorded contact resonance images of an AFM leaf spring using the described measurement criteria in contact with a silicone mono-crystal in the <100> direction used as a reference sample and the corresponding unrestricted resonance. The figures demonstrate that with increasing contact force the resonance frequencies are shifting to higher frequencies. In addition, the shifting of the frequencies depends on their mode number (in this case n= 1, 2, and 3), due to the fact that the mechanical impedance of the leaf spring and the tip is different for the various modes, resulting in more or less sensitive reaction to variations in contact stiffness of the materials under investigation.

Piezo ceramics were imaged using the setup described above. The acoustic images contain significantly more information than the corresponding topographic images. Some images allowed the assignment of the contrast to a ferro-electric domain based on the form of the

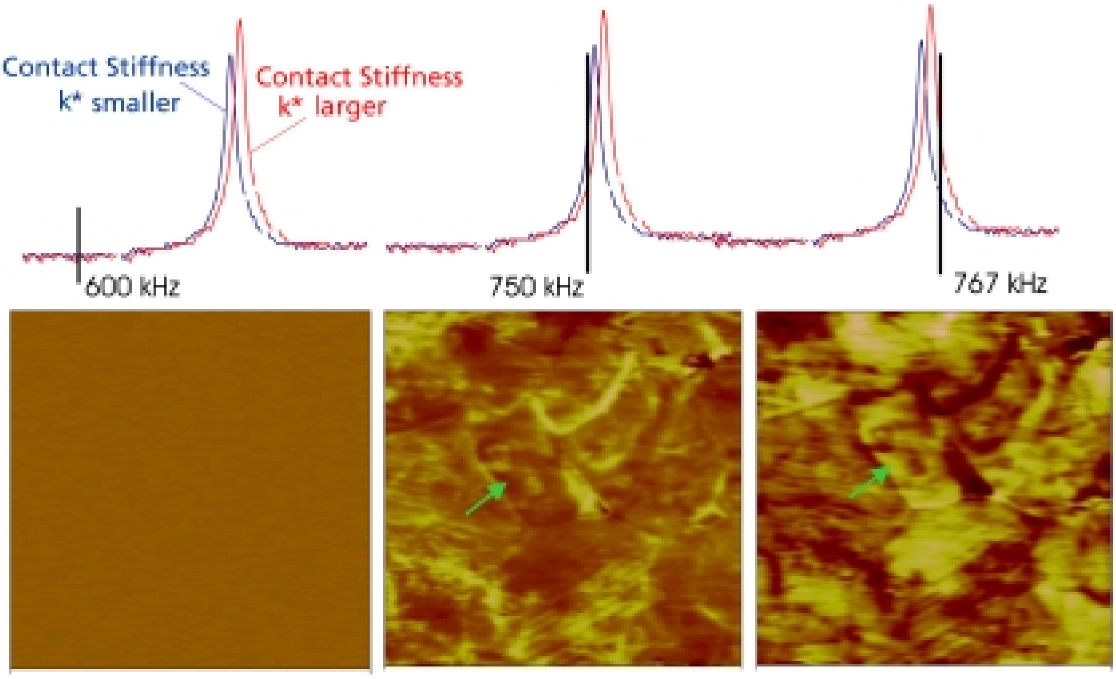


Figure 3:
Frequency-dependency of the AFM Ultrasonic-contrast

Ultrasonic amplitude, amplitude graduation 2 V, image size 12 x 12 μm^2, specimen: Lead-Zirconate-Titanate-Ceramic (PZ 29)

substructure of some crystals having the typical lamellar-type arrangement of the domains in tetragonal crystallites. Different gray-scale values of the ultrasonic images are caused by differences in elasticity as depicted in Figure 3. Figure 3 also displays contrast changes caused when varying the image frequency. The left image was generated at a frequency of 600 kHz (well below the first contact resonance of 750 kHz), the center image at a frequency of just below 750 kHz, and the third at 767 kHz (slightly above the first contact resonance of 750 kHz). The left image shows no contrast whereas the crystal structure is clearly visible in the center and the right image. In addition, the contrast of the right image is the inverse of the center image contrast.

A technique to permit the calibration of the resonance-shift and the recalculation of the local elasticity modules (without the knowledge of the exact leaf spring data) was developed. The evaluation of the results from at least two dissimilar resonance modes allows ignoring of the leaf spring parameters.

Project Description

The quantitative atomic force spectroscopy was developed as parts of three different projects: The network »Atomic Force Microscopy and Micro-Acoustics« of the »Human Capital and Mobility« (HCM) program of the European Union (EU) was presented in IZFP's 1995 Annual Report. The EU joint project is based on the experience of the individual network partners for acoustic imaging and measurement techniques, including scanning microscope techniques.

The research project »Measurements of Elastic and Non-Elastic Material Characteristics including Spatial Resolution in the Nanometer Range using the Atomic Force Microscope« was sanctioned within the main research project »Micro-Characterization of Materials and Components« by the Volkswagen grant for a duration of two years, beginning 06/01/96.

The technique for the »Investigation of Piezo-Ceramics« was utilized in the DFG-Cooperation as part of the »Interaction between Electronic and Mechanical Characteristics of Ceramic Multifunctional Materials« program.

Project Sponsors

Germany Research Association
European Union (EU)
The Volkswagen Foundation

Keywords

Acoustic-Microscopy
Elasticity
Atomic Force Microscope
Modeling
Nano-Technology
Scanning Microscopy
Spectroscopy, Ultrasound

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GMR-Based, High-Sensitivity ET Sensors

Situation

In general, all eddy current techniques provide the highest sensitivity in close proximity to the sensor due to the skin effect. Several modern techniques permit testing beyond the near-surface areas, which used to be reserved for ultrasonic testing. Now, eddy current testing of those areas can be performed alternatively or supplementary to ultrasonic and/or radiography testing using different physical fundamentals. This new technique is especially advantageous when testing stainless steel (austenite) materials.

The maximum achievable inspection depth is primarily determined by the lowest test frequency produced by the eddy current sensor. When inductive sensors are utilized, the measurable electromagnetic effects of eddy currents diminish proportional to the decrease in test frequency due to the induction effect. As a rule of thumb, the lowest test frequency for eddy current testing of stainless steel (austenite) materials is approximately 100 Hz. Further decreasing of the test frequency requires different sensors, e.g. Giant Magneto-Resistance (GMR) sensors, which provide uniform testing sensitivity down to the DC-field (0 Hz).

Objective

GMR sensors exhibit a very high testing sensitivity of 1 pT/√Hz, which places it between a SQUID-type sensor (1 fT/√Hz) and a Fluxgate-type sensor (1 nT/√Hz; e.g., Förster sensor) in terms of sensitivity. The following GMR sensor-specific characteristics are important for eddy current applications:

- Sensitivity independent from test frequency and no high-pass characteristic
- Application at ambient temperature
- Small housing design and simple integration with various sensor arrangements
- Highly-integrated processor (chip) with all components and shielding required for bridge circuits

Results

A practical eddy current sensor design to detect concealed flaws in stainless steel parts and components is the transmitter/receiver arrangement. The transmitter is spatially separated from the receiver, where the receiver employs a GMR sensor.

One of the test samples, a stainless steel plate with a thickness of 6.0 mm (t), used during the experiments is shown in Figure 1. The plate contains several saw-cut notches with varying depths (d) on the opposite side of the scanning surface serving as reference flaws.

During testing, the surface of the plate was scanned with the GMR eddy current sensor and all received signals were recorded. The smallest reference flaw with a depth of 0.4 mm was still clearly detected as depicted in Figure 2.

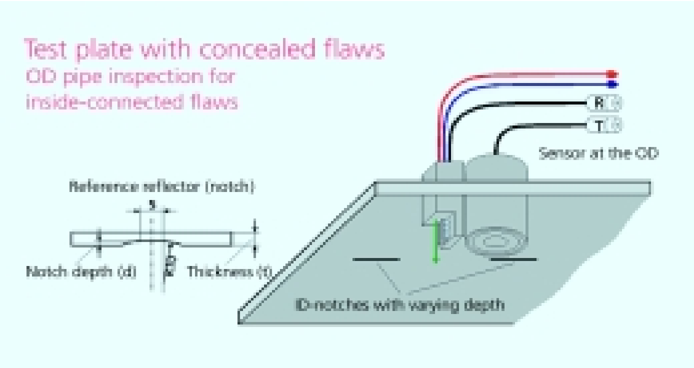

Figure 1: Inspection of a stainless steel plate - reference reflectors (ID-notches) with varying depth

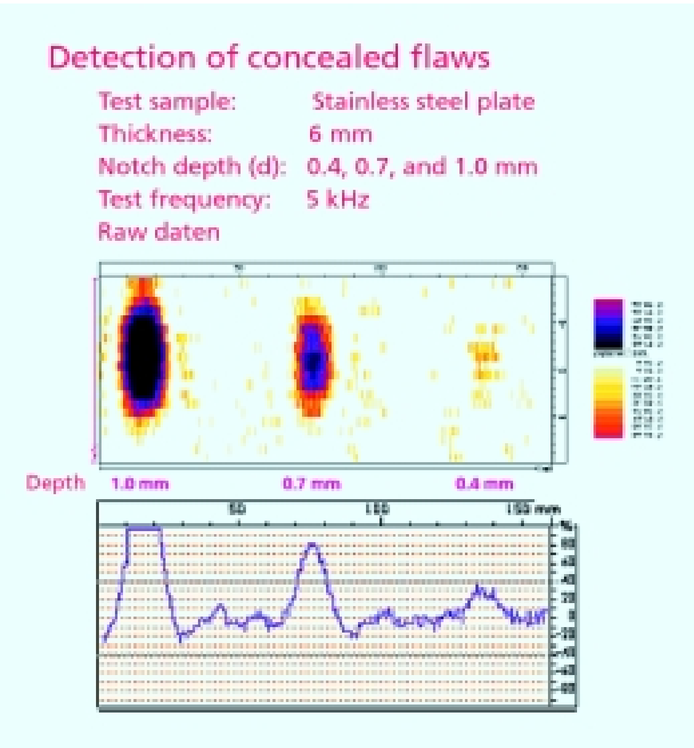

Figure 2: C-Scan and A-Scan presentation of the Eddy Current raw data

Experimental testing on plates with wall-thickness above 6.0 mm confirmed that the smallest detectable flaw size can be derived from the ratio of d/t ~ 0.1 for a wall thickness of over 10.0 mm. Current sensor designs, however, limit the smallest detectable flaw size to 10% of the wall thickness in materials having only small variations in magnetic permeability

To optimize the eddy current sensor sensitivity for concealed flaws, IZFP performs numerical investigations with three-dimensional FEM modeling.

Sponsor

The project is sponsored by the German Federal Ministry for Education and Research.

Keywords

Stainless Steel
Austenite
Giant Magneto-Resistance
Eddy Current Testing
Eddy Current Sensors

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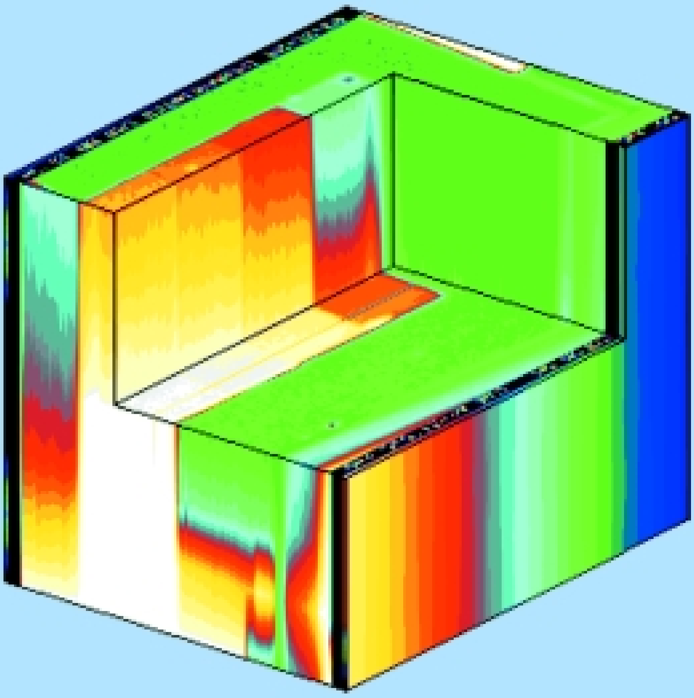
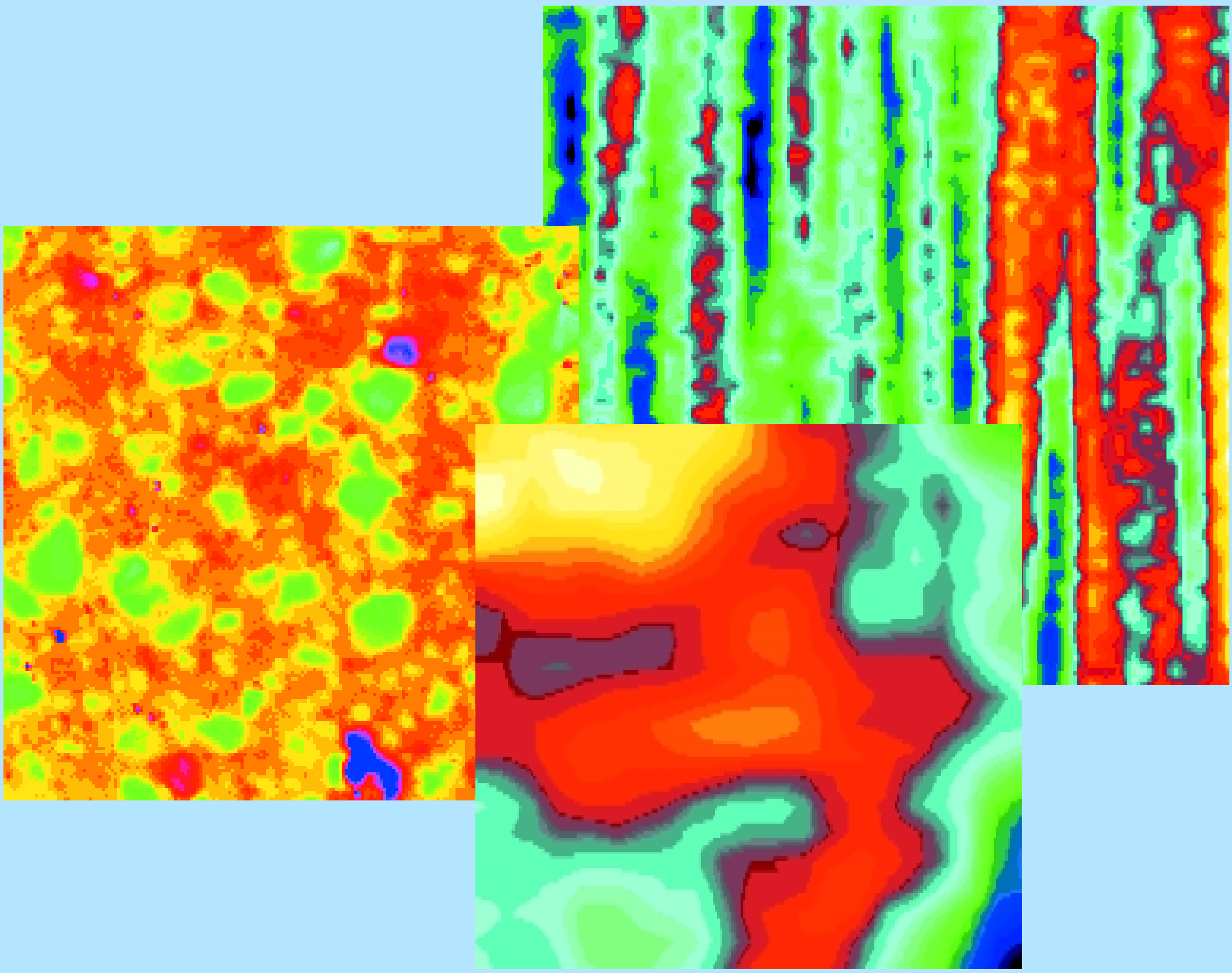
Characterization of Materials, and Layers





Nondestructive (Non-Contact) Characterization of Layers, and Layer-Systems

Problem and Task

Many of the so-called »new materials« that have been available for industrial applications in the last few years are composed of one or several layers or layer systems. Nondestructive characterization of these materials - including non-conductive, conductive, and semi-conductive layers and coatings - has a tremendous influence in the ceramics, plastics, and coatings industries. The procedures used for the monitoring of the manufacturing process should not only be nondestructive but also non-contact.

Due to these requirements, the microwave processes are very attractive, especially the free soundfield process. Using these processes, the sample is irradiated or penetrated by microwaves and the amplitude (or in some cases the phase) of the reflecting and/or transmitted waves are evaluated. The required output is relatively small (mWatt range) and therefore the sample's material is not altered.

Results

The Fraunhofer-Institute for Nondestructive Testing (IZFP) performed several studies to determine the potential of the microwave process for the nondestructive characterization of these materials. The system used was based on a commercial vector network analyzer (to measure the amplitude and phase) in a frequency range between 75 GHz and 100 GHz. This system delivers both frequency and time domain data. A linear relationship often exists between the microwave's measurement quantities and the nominal material variable for microwave transmissions performed on relatively non-complex test samples, e.g., a single layer. The example in Figure 1 demonstrates this relationship using a piece of polyurethane foam with varying porosity (density). The calculation index was determined from the microwave's transit time in the sample. Similar linear relationships also apply for ceramic layers and boards for both conductive and semi-conductive layers. The conductive layer must be thinner than

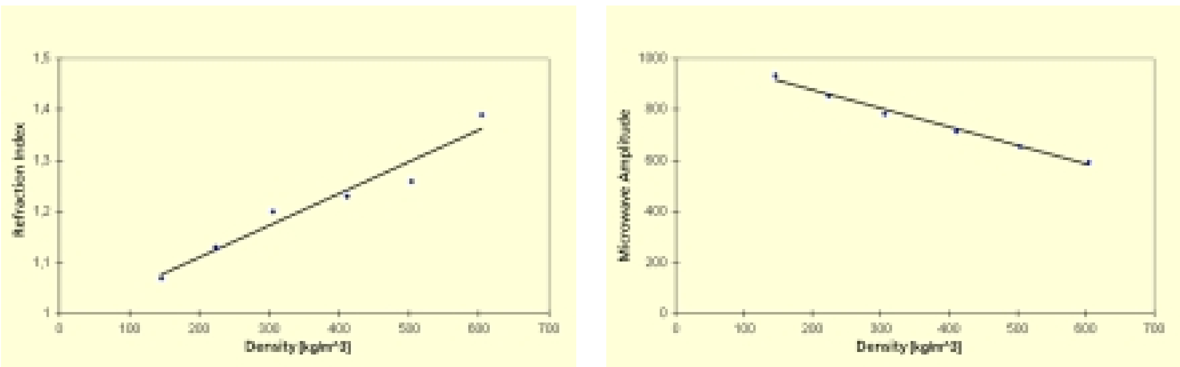


Figure 1: Microwave transmission through Polyurethane foam of varying thickness

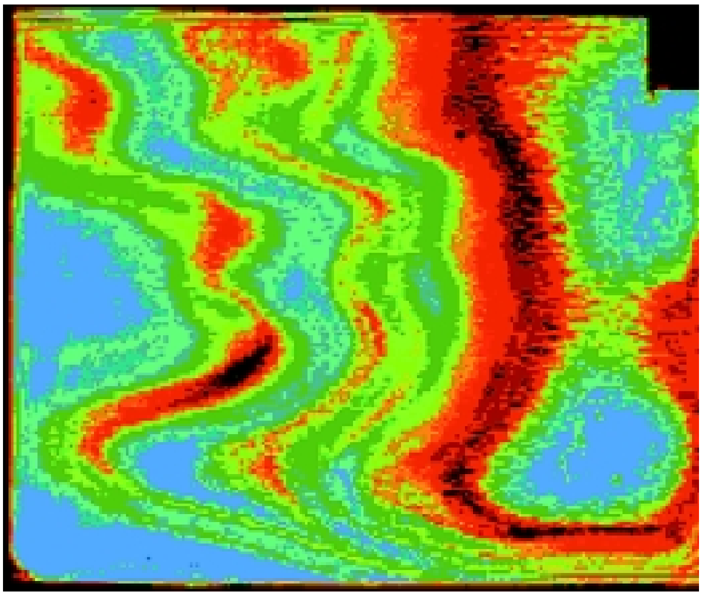


Figure 2: Reflected microwave image of zircon oxide coated steel sample scanned in two directions with a testing frequency of 87.5 GHz

the penetration depth of the microwave to prevent total microwave reflection. This limits the process to metal-based layer thicknesses in the range of a few 10 nanometers. The thickness of many metal-based layers, for example the thermal-protection silver layer on window glass, is within this range, permitting nondestructive layer characterization using microwaves.

To display the characteristic of a layer in a two-dimensional image the sample is scanned in two directions. Figure 2 displays such an image of a zircon-oxide layer sprayed onto a steel substrate. The color-coded variations of the reflected amplitude indicate variations in the zircon-oxide layer structure.

For multiple layers, a comparison of the experimental results to the theoretical calculations is indispensable. IZFP has developed a model that allows the calculation of the frequency and time domain of the transmission and reflection behavior of several layers that are irradiated vertically with planar electromagnetic waves. The input parameters are as follows: layer thickness, (complex) dielectric constants, magnetic permeability, and electrical conductivity. The model was developed for five layers, but is expandable for additional layers. Figure 3 shows the excellent agreement of experiment and theory using an example of the layer combination of air, rubber (6.3 mm thick), and metal. The time domain signal shows the reflections of the microwaves at material interface, equivalent to an ultrasonic A-scan presentation. Multi-layer systems can therefore be characterized with microwaves by adjusting the theoretical curves to the measurement values using the appropriate algorithms.

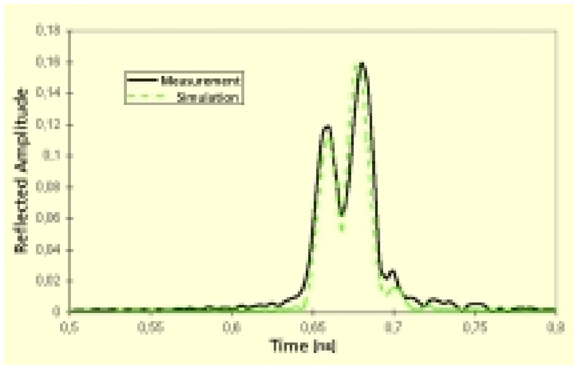
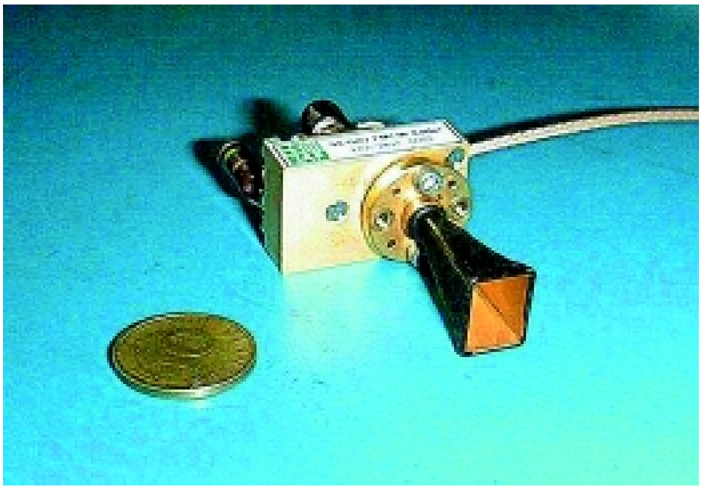


Figure 3: Comparison of the actual testing signal and modeled signal on a multi-layer sample, reflections in the time-domain

Applications

The presented results were achieved using a complex network analysis system, which, due to its size and high cost, could only be applied to a limited number of industrial applications. However, over the past few years, microwave components and radar systems have increasingly entered industrial, public, and private areas, based on the increasing availability of highly integrated and, when purchased in large quantities, low cost components.

Significant advancements can be found in the telecommunications and automotive (distance radar) industries. For example, a highly integrated, frequency modulated, continuous-dash radar module (FMCW-radar, Figure 4) was developed by the Fraunhofer-Institute for Applied Solid-State Physics (IAF), in Freiburg. Initially, the module was developed for distance and velocity measurements, but it incorporates many major characteristics of a network analysis system while remaining significantly less expensive. Currently, IZFP in cooperation with several other Fraunhofer Institutes is building a module for measurement and testing based on the FMCW module to be utilized in custom NDT solutions for a wide variety of testing applications.



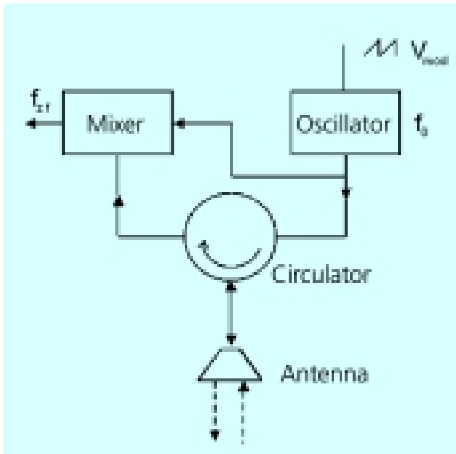


Figure 4: 94 GHz FMCW Radar Sensor

Keywords

Non-Contact Nondestructive Material Testing and Characterization
Coatings
Imaging Methods
Microwave Methods
Layer-Systems

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High-Resolution Characterization of Thin Ferro-Magnetic Coatings and Layers

Problem

Ferromagnetic materials are highly important for recording data of all types and are used e.g., in thin coatings of data carriers or in read/write heads. Currently, high-density storage (≥ bit/mm²) and concurrent high data transfer rates (approx. 25 Mbits/sec) can only be attained using magnetic recording systems. Magnetic recording still has decisive advantages and development potential compared to alternative recording methods. Magnetic recording systems are also simple and inexpensive to develop and overwriting of the data does not pose a problem.

Recent developments in thin-layer technology specifically relate to improvements in magneto-resistive sensors. The new sensors will take advantage of the giant magneto-resistive (GMR) or colossal magneto-resistive (CMR) effects. These effects can also be used for the development of magneto-electronic MRAM memory. Shorter access times, non-volatile data memory, and a simple system structure are the main advantages when compared to semi-conductor memory.

New nondestructive techniques may greatly enhance the characterizations of structure and quality of magnetic coatings. What is needed is a testing technique that allows in situ nondestructive determinations of magnetic and mechanical parameters using mid- to high-level resolution of location, imaging of internal stress, and investigation of the re-magnetization processes.

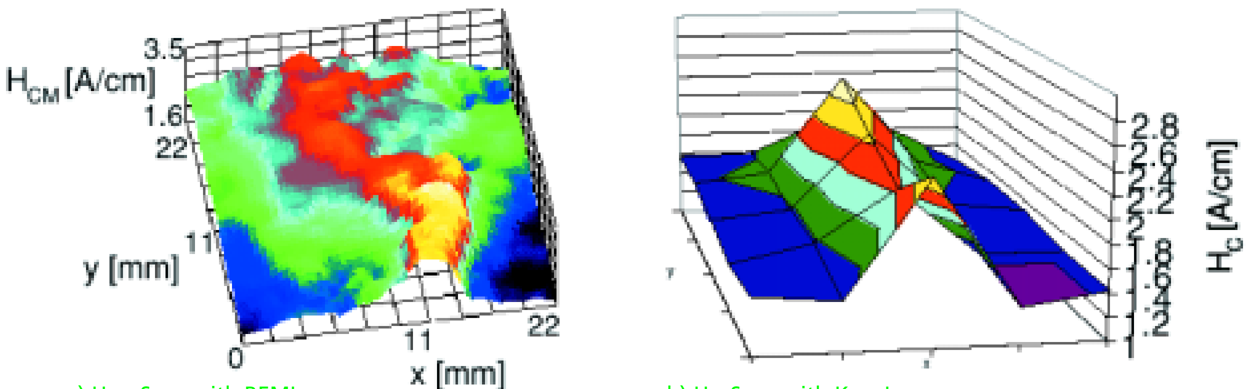
Approach

The understanding of the correlation between structure and quality of the material is a decisive prerequisite for the efficiency improvement of magnetic recording systems with respect to memory density, bandwidth, and data transfer rate.

One objective of the project presented here was to clarify the correlation between mechanical (structure, state of stresses, and hardness) and magnetic characteristics for a series of selected thin ferro-magnetic coatings used in digital recording systems.

Results

The high-density memory required in ferro-magnetic thin coatings can only be achieved by controlling the homogeneous magnetic characteristics and minimal residual stress. Investigations done on tempered and un-tempered coatings showed evidence that local variations in soft magnetic characteristics can be verified quickly and nondestructively using the Barkhausen Noise and Eddy Current Microscope (BEMI). Figure 1a shows an example of the H_{CM} area-scan of a magnetic dual coating (NiFe/NiFeX) with a non-magnetic layer in the center. For comparison, Figure 1b shows the H_c values determined for the same scanned area (5 x 5 data points), demonstrating a qualitatively good correspondence.



a) H_{CM} -Scan with BEMI

b) H_c -Scan with Kerr Looper

Figure 1: Area Scans on NiFe/NiFeX Multi-Coating System

The determination of the residual stress state of the coating using nondestructive methods continues to be important for purposeful development and optimization of ferro magnetic layers used in read/write heads. Residual stress (intrinsic stress) occurs due to non-optimal process conditions, undesirable phase transformation, and/or lack of elastic matching to the substrate, and it has a negative effect on the signal-to-noise ratio and sensitivity of the read/write heads. As a result of non-suitable elastic matching between the substrate and the ferro magnetic coating, the workability of the read/write heads cannot be guaranteed.

IZFP's X-ray diffractometer, located at the branch office in Dresden, permits measurement of several internal stress values on a single sample with an X-ray beam diameter approximately 100 mm. Figure 2 shows the location-related distribution of the radiographically determined residual stress of a tempered sendust sample having a coating thickness of 2 mm. Figure 2b shows the location-related distribution of the Barkhausen Noise amplitude for the same area (2 x 2 mm); 40 by 40 data points were taken at increments of 100 mm. The total time to acquire the data was approximately 30 minutes. Only 5 x 5 radiographic measurement points were taken since a single radiography point takes approximately 5 hours; points in between were interpolated.

Each of the two images shows almost identical structures. In addition, the internal stress values and the M_{MAX} values have a comparatively high gradient in the investigated area (310 MPa and 2.26 – 3.84 V). This demonstrates that it is possible to use the BEMI for a fast, qualitative, locally resolved, and (appropriate radiography calibration provided) quantitative determination of the internal stress distribution of soft magnetic thin coating.

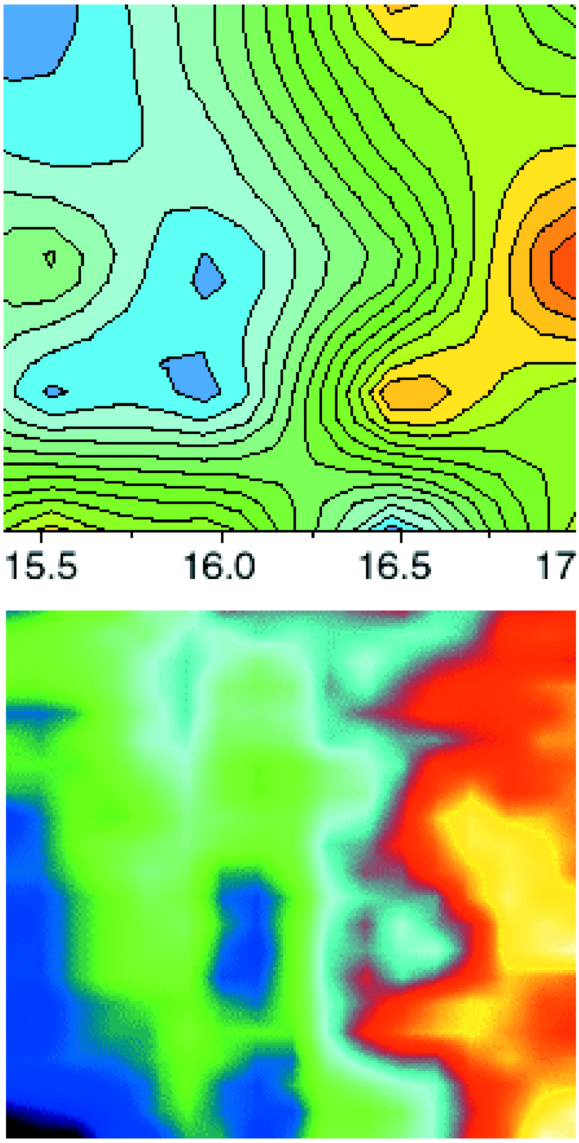


Figure 2

Magnetic structures can also be displayed using the photo-thermal modulated flux-field technique (PMS) described in the 1996 IZFP Annual Report. These investigations were conducted on amorphous metal alloys with a thickness ranging from 25 to 40 mm. These samples were made using the melt-spinning process. A liquid alloy was poured onto a wheel rotating at a high speed, resulting in rapid solidification of the material into long thin strips. This alloy $(Co_{70}(Si+B)_{23}Mn_5(Fe+Mo)_2$ has an extremely low magnetostrictive saturation level resulting in a relatively low residual stress distribution to permit the formation of relatively large magnetic structures.

The PMS technique utilizes a modulated laser beam to locally heat the test sample and then records the resulting local magnetization variations of the outer surrounding flux-field. A domain structure is displayed without an outer flux-field as seen in Figure 3.

With increasing external static magnetic fields, the domain structure is destroyed and replaced by another structure, probably due to deviations in the ideal amorphous condition of the material (Figure 4). This new structure is always oriented vertically to the outer field.

Roughly the same area was also imaged using optical microscopy, eddy current microscopy, and Barkhausen Noise microscopy as displayed in Figure 4, bottom.

The optical image shows the surface topography: elongated structures along the strip axis and rounded mounds and depressions; the latter are also observed in the eddy current image. This might be due to the lift-off effect of the sensor, which is particularly influential for high-resolution eddy current measurements. Structures, similar to those found in the PMS image, typical for strong flux-fields, are also noticed in the Barkhausen Noise image.

Contrary to the PMS technique, the BEMI periodically generates and destroys the domain structure; the amount of the outer flux-field has a high median value. Therefore only the structures that could be seen with the PMS technique for high fields were seen. Only a few but intensive noise events were observed for large domain dimensions, which were also noticed experimentally.

Sponsor

The investigations were sponsored by the Federal Ministry for Education and Research. The results were obtained in cooperation with Exabyte Magnetics, Germany, and IBM, Germany.

Keywords

Resolution, high-resolution, lateral
Barkhausen Noise Microscope
Thin coatings
Residual Stress Measurement
Coating Characterization
Sensor Technology, miniaturization
Flux-fields, Photo-thermal modulated
Eddy Current Microscope

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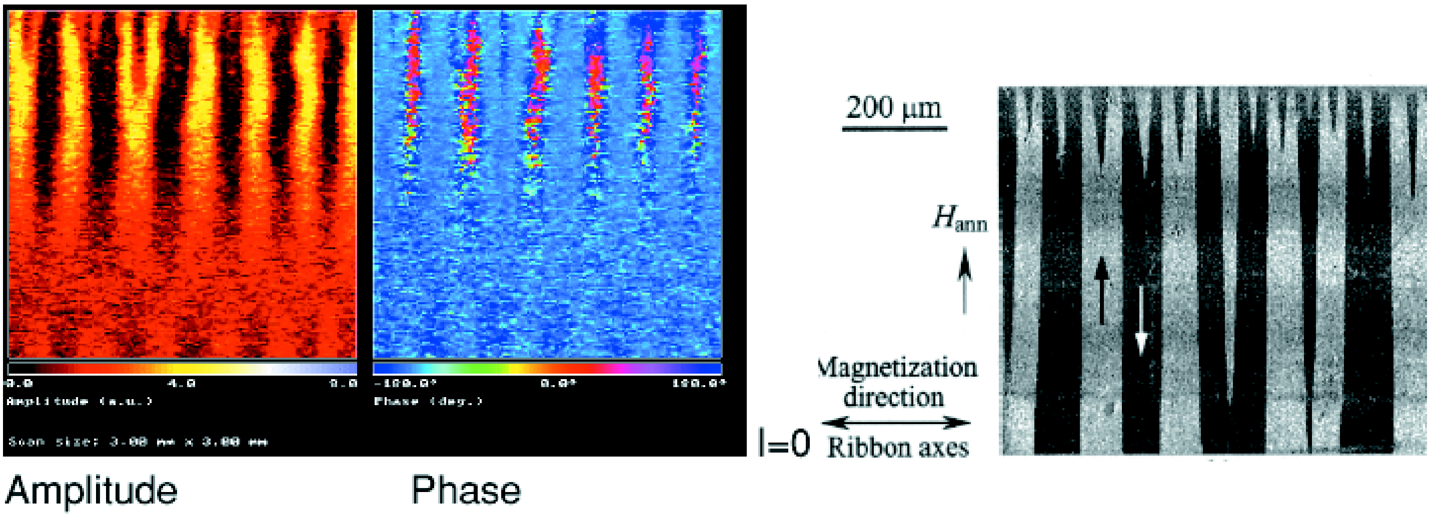


Figure 3:
Left: PMS image of signal amplitude (left) and single phase (right) of met glass, 3 mm x 3 mm section.
Rhigt: Magneto optical image of a simular alloy (A. Hubert, R. Schäfer: »Magnetic Domains«, Springer, Berlin 1998)

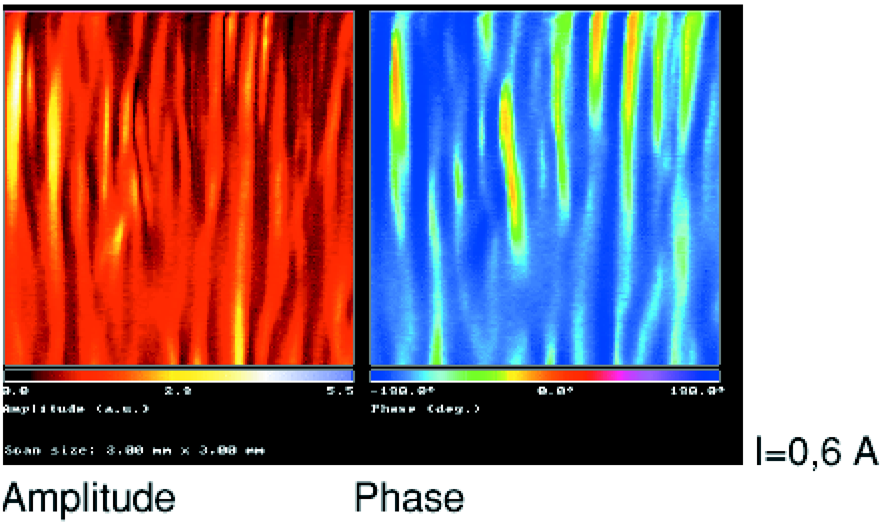
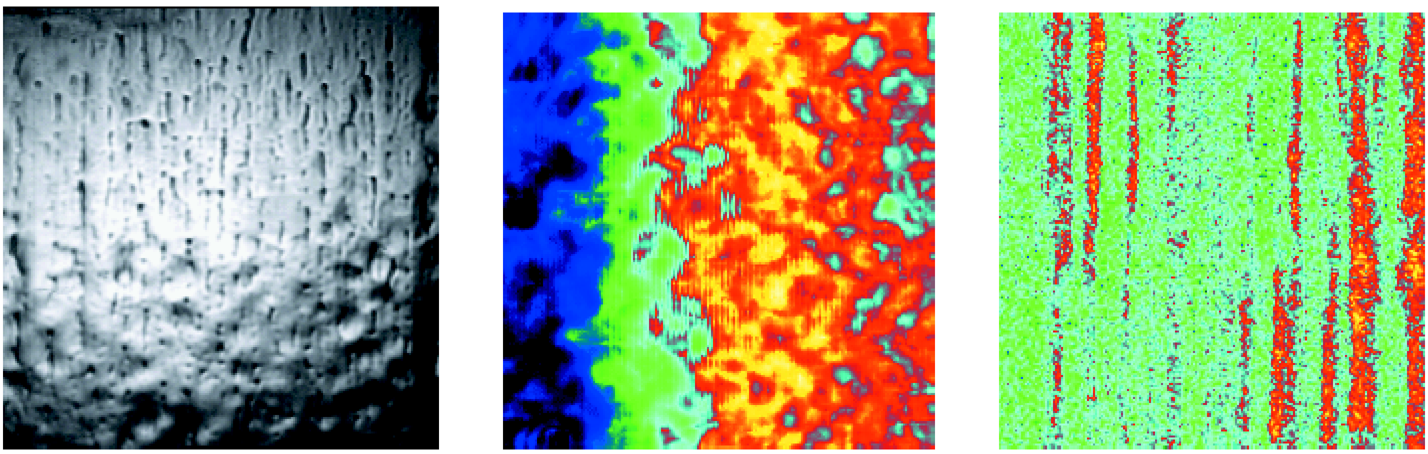


Figure 4:

Left: PMS image under outer static magnetic field

Bottom
Left: Optical image
Center: Eddy current image at 2 MHz
Right: Barkhausen Noise image, integrated amplitude
Image sectiom 3 mm x 3 mm



Characterization of Corrosion and Oxidation Proof Coatings on Turbine Blades

Problem

The design of modern stationary and aircraft turbines strives for low emission rates and high efficiency at high gas temperatures, causing extreme stresses for the turbine blades. Metal oxidation and corrosion-protective coatings prevent premature material damage and aging.

Approach

Nondestructive testing techniques were to be developed to inspect the protective coating of turbine blades for delamination and remaining thickness in a joint project of European manufacturers of stationary and aircraft turbines. Specific problems for the testing process consisted of the minimal thickness of the coating-layers and, at the same time, the surface roughness and contour of the blades. It was decided that what was needed was a high-speed pulsed-thermography testing system with improved time resolution in comparison to existing systems. Thermal waves and high-frequency ultrasound would serve as reference techniques. It was hoped that the results would provide for improvements in manufacturing quality control and for monitoring and repair of coated components in practical applications.

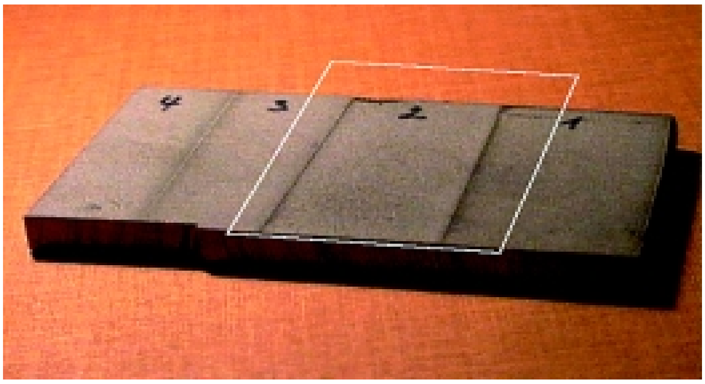


Figure 1: MCrAlY coated sample with varying coating thickness.

Results

A high-speed thermography system featuring an array camera and image frequencies up to 1100 images/sec was developed and combined with the necessary software (refer to 1997 IZFP Annual Report). Initial investigations using this system were performed on flat Ni-base alloy samples with MCrAlY coatings at coating-thicknesses between 10 and 150 µm (see Figure 1).

Due to the favorable thermal conductivity and the low thickness of the coating the typical diffusion times were within a few milli-seconds (msec.). A semiconductor-controlled rectifier (thyristor) was used to switch a flash with a 600 µs pulse for the fast heating of the sample surface. Figure 2 displays results of the experiments.

A 40 mm by 40 mm square area (white marking in Figure 1) with three different coating thicknesses (116 µm, 90 µm, and 37 µm) is shown in Figure 2 at different times, prior to and following the excitation flash. »Hot spots« due to the roughness of the coating are visible immediately following the excitation (b). The contrast indicating coating thickness variations is clearly visible after 2 to 5 ms (c), where this contrast is nearly gone after 20 ms (d). These experimental results were supported by semi-analytical model calculations in which the known Green Function (delta-shaped heating) was compared to the measurement response of the flash light intensity curve (Figure 3). Here too, the temperature contrast between all three layers was greatest after 2 to 3 msec.

The results of the thermal measurements were verified using (high-frequency) ultrasound at frequencies between 50 and 100 MHz. Figure 4 depicts the cross section of a MCrAlY coated sample (B-scan presentation), where the coating thickness is obtained from the distance between the interface signal of layer-substrate (top red line) and the signal from coating surface (bottom red line). The white marking shows the area of the sample as seen in Figure 2.

The ultrasonic technique requires flat samples and access from the substrate side because of the coating roughness. Therefore, the ultrasonic method is only practical as a reference method. This new thermography method, because of its non-contact application, high-speed data acquisition, and the ability to be used on contoured (curved) surfaces, has great potential for practical industry applications such as turbine blade inspections.

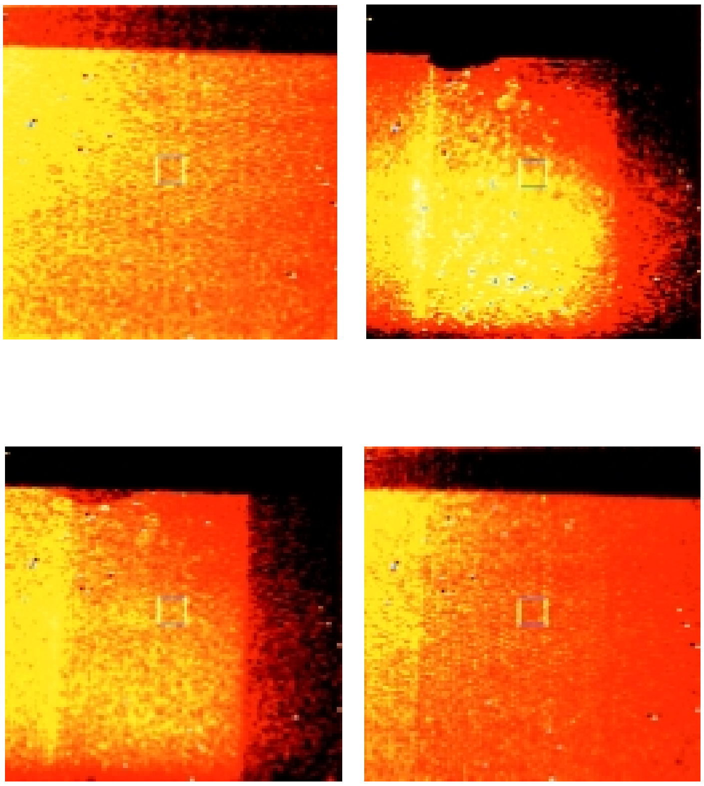


Figure 2: Thermography images of a sample with varying coating thickness prior and after the excitation flash.

Project Description

European Joint-Project COST 501
Project Sponsor
Federal Ministry for Education and Research, administered by The German Center for Aviation and Aerospace (DLR)

Keywords

High-Speed Thermography
Corrosion-Proof Coatings

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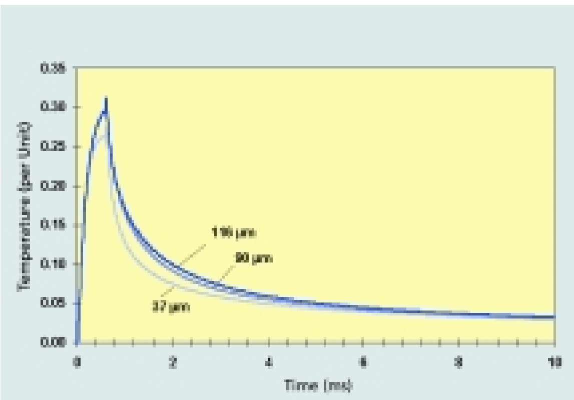

Figure 3: Computed thermal response curves of MCrAIY coating with three different thicknesses.

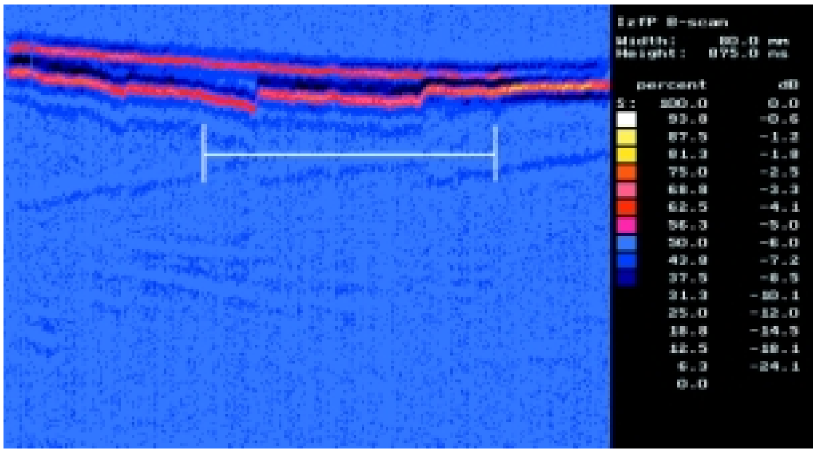

Figure 4: High-frequency ultrasound B-scan presentation of the MCrAIY coated sample.

Testing Systems

Ultrasonic Testing of High-Speed Train (Bullet Train) Wheel Sets

Problem

Continuous improvements in track-bound vehicles, particularly high-speed trains (bullet trains) such as the ICE or the TVG, require continual developments in the associated safety technology. This new safety technology presents a challenge for nondestructive testing (NDT).

To assure the safety of railroad vehicles, the inspection of railroad wheels and wheel sets is required after manufacturing and during service at predetermined intervals. During a major scheduled inspection of the vehicle, the entire wheel set (rim, disk, hub, and axle) and all accessories are dismantled and inspected for material flaws and mechanical alterations. Relevant inspection procedures are established in the codes and standards of the railroad industry.

Until now, the disassembled wheel sets have been inspected by manual ultrasonic methods, where only the wheel rims were tested in two scan directions. The time for these inspections typically exceeds one hour, followed by manual documentation of the test results.

Figure 1: Wheel set testing station »AURA« at the Nürnberg maintenance facility (Deutsche Bahn)

IZFP Approach

These manual ultrasonic inspection methods are very time-consuming and subject to limited reproducibility of the test results. The IZFP approach was to design a fully automated inspection technique for railroad wheels and wheel sets.

A fully automated inspection technique must be capable of meeting the following requirements:

- Minute flaws must be safely and reproducibly detected in the earliest stage at the surface and within the volume of the wheel. The acquired data must permit analysis to determine type, size, and location of the detected flaw.
- All existing flaws must be detected even if parts of the wheel surface are inaccessible for the transducers.
- Inspection times must be short, with a minimum of system operators, to lower inspection costs.

Figure 2: Wheel set testing station »AURA« at the Munich maintenance facility (Deutsche Bahn)

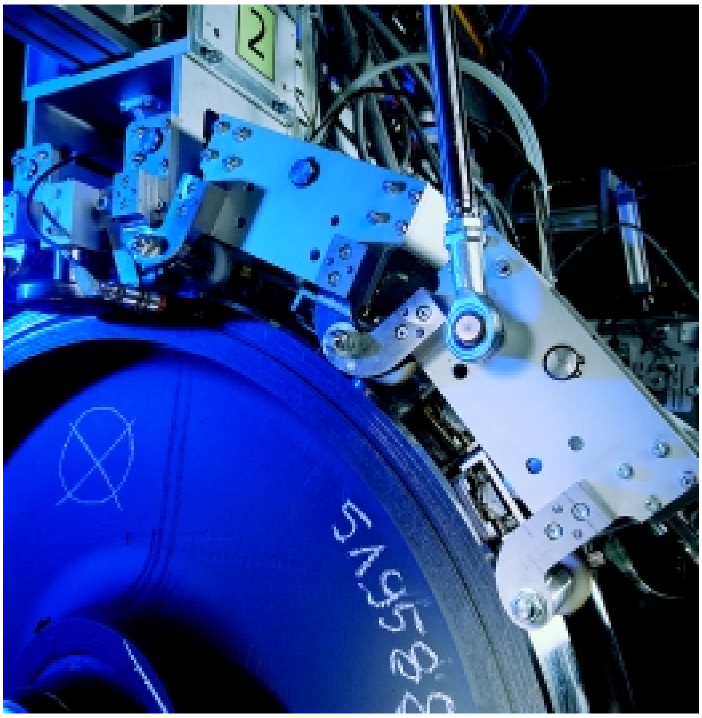

Figure 3: Detailed view of the transducer carrier

Sponsored Project

The AURA inspection station was specified, designed, and commissioned in close cooperation by two Fraunhofer-Institutes (IZFP & TEG) and the Deutsche Bahn AG.

The Research and Technology Center Kirchmöser (a subsidiary of the Deutsche Bahn AG) specified the system concept including the relevant inspection techniques. Based on this detailed specification, IZFP developed the ultrasonic hardware and software (including documentation components) and described the abilities of the inspection techniques employed by the system. TEG designed and manufactured the ultrasonic transducer carriers. The wheel set feeding system was designed and manufactured by small and mid-size company.

Under the management of IZFP, the project was guided by the most current knowledge available concerning NDT inspection techniques and manipulation technologies. In February 1999, a fully automated wheel set testing station, AURA, was installed at the Nürnberg maintenance facility of the Deutsche Bahn AG, where it underwent rigorous internal performance testing.

Results

In cooperation with the Deutsche Bahn AG, and the Fraunhofer Technology Development Group (TEG), the Fraunhofer-Institute Nondestructive Testing (IZFP), has developed a fully automated wheel set testing station (see Figure 1).

The wheel sets are inspected for flaws in the wheel rim and disk. This technique is designed to detect crack-like flaws initiating at the surface and embedded flaws contained in the volume of the rim and disk. The testing station accepts wheel sets with diameters ranging from 780mm to 1200mm (30" to 47"). The inspection of a complete wheel set takes approximately eight minutes.

The inspection is performed using a 28-channel ultrasonic instrument (PCUS 40) integrated into a rugged industrial computer (PC). This system belongs to IZFP's family of ultrasonic pulser/receiver boards, which are integrated into industrial type PC's providing versatile ultrasonic systems when combined with appropriate software. Operation and control of the instrument is provided through the menu-driven user interface running under Windows© NT 4.0.

Twenty-six conventional ultrasonic transducers and two EMAT transducers are used for the inspection of the wheel rim and disk. The spring-loaded transducer carrier contains all transducers and constantly maintains the correct contact to the scanning surface.

The inspection of the wheels is accomplished by using the following ultrasonic wave modes:

- Longitudinal waves, normal incidence (piezo-electric)
- Shear waves, angle beam (piezo-electric)
- Shear waves, parallel polarized to the disk (EMAT)

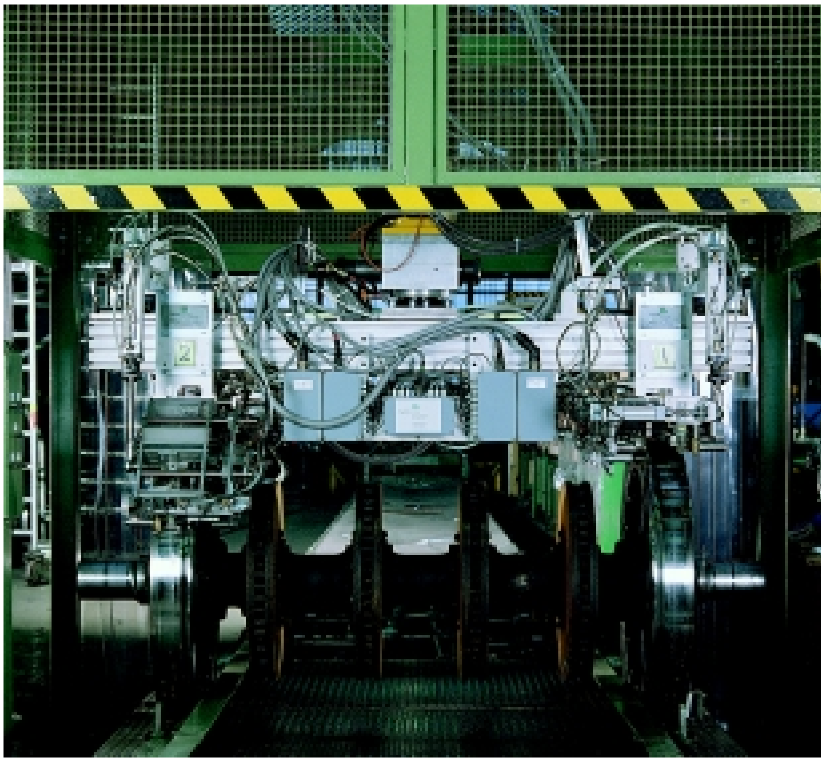

Figure 4: Wheel set with reference reflectors

Figure 3 displays the transducer carrier, which is pneumatically positioned and maintained on the inspection surface.

During inspection, the wheel is revolved one turn. After completion of the first turn, the transducer carrier is rotated by 180°, and then the inspection is repeated in the opposite scanning direction to complete ultrasonic coverage of the required areas.

A wheel set with reference reflectors of known type, size, and location was used for the calibration of the ultrasonic instrument. The system verification/calibration was performed at the beginning and end of each shift (approximately 8 hours), to verify setup and sensitivity of the entire inspection system. Figure 4 depicts a wheel set with reference reflectors placed into all relevant inspection areas of the wheel rim and disk.

The advantages of the AURA inspection system can be summarized as follows:

- Short inspection times
- Automated feed of the wheel sets
- No magnetic particle testing (MT) required
- Simple system control by user-oriented software
- System service and maintenance is supported by integrated system self-tests
- Remote system diagnostics
- Immediate documentation of inspection results
- Post-processing and analysis of A-scan, B-scan, and C-scan images
- Easy assembly of quality assured reports and documents
- Quick status information of acceptable stock through integrated data management software
- Highly flexible selection of pre-programmed inspection functions
- Pre-programmable inspection parameters
- CAD display of inspection functions and parameters
- Self-test and documentation of the inspection system according to relevant codes and standards

The AURA inspection system is equipped with the latest computer technology. All mechanical, hydraulic, and pneumatic functions are sequenced automatically. The ultrasonic data are acquired relative to the test sequence to permit reproducibility of the data. All inspection and analysis data can be stored to a database to allow continuous monitoring of individual wheel quality (histograms).

Keywords

Automated Inspection Techniques
EMAT
Railroad Wheel Set Inspection
Ultrasonic

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Development on an Intelligent System for the Characterization of Surfaces Based on a Digital Signal Processor

Problem

Rolling of thin sheets of metal in hot wide strip mills leads to excessive wear of the rollers during the production process, which results in an increase in surface roughness of the rolled sheets. In normal situations, the rollers have a smooth, almost mirror-like surface. As service times increase, this leads to the formation of unwanted surface structures on the rollers and thus increased surface roughness. Often the roughness is limited to specific, stripe shaped areas and not to the whole surface. These zones cover the entire circumference of the roller and become plainly separated from the neighboring smooth regions. In extreme cases, a layer of material several micrometers thick can separate from the roller surface, this is called »pealing roughness«. Usually pealing roughness occurs locally, and does not encompass the whole roller.

Obviously, the roughening of the roller surface during the rolling process has a direct impact on the surface quality of the rolled product. For example, thin sheet metal for the automotive industry requires a surface literally free of any roughness because roughness impairs the adhesion of the enamel coating. »Pealing roughness« predetermines that damage will occur to the final product. Often, due to extreme roller roughness, impurities and contaminants can be entrapped and rolled into the sub-surface of the hot plate. Initially these impurities remain undetected, but when the hot plate is rolled into thin sheets these areas of impurities break open and result in the characteristic surface flaws. In many cases, large sections of thin sheets are affected, and this can result in great economic loss for the mill. Due to missing and/or late feedback information, corrective actions at the flaw-causing process site (i.e., the hot strip rollers) are not possible.

The amount of surface roughness is not only determined by the service time of the rollers but also by the processing parameters, and is therefore constantly subject to process parameter variations. It is often impossible to detect roller damages at the end of the rolling process (when a roller is removed) because a roller with »pealing roughness« can cure itself during the rolling process – making it nearly impossible to trace the cause of the flaws. Damage mechanisms and origin can be identified and appropriate corrective actions can be taken in a timely manner utilizing on-line monitoring of the surface condition during the fabrication process.

Solution and Approach

An intelligent test system was developed at IZFP to determine the surface condition of the rollers by using the diffused-light technique. To optimize the utilization/cost ratio, a modular system was designed, permitting different data acquisition modules to be mounted on a basic board. The SPBB (Signal Processing Basic Board) presented in Figure 1 is the central element of the system, and it has a DSP (Digital Signal Processor) that operates several standard interfaces and controls the (plug-in) data acquisition modules. Using a DSP with a processing capacity of 40 MIPS (Mega Instructions Per Second) and 120 MFLOPS (Mega Floating Point Operations) enables applications that require high capacity calculations and real-time capabilities. Comprehensive communication capabilities permit using the module as a stand-alone data acquisition system, or in operation with an external host computer. The module was designed with small dimensions for use in limited space, as is often required for hot wide strip mill applications.

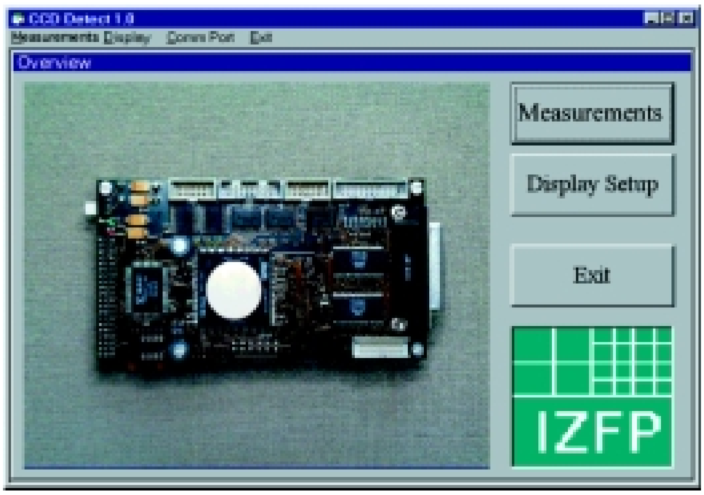

Figure 1: Main menu and image of the SPBB processing module

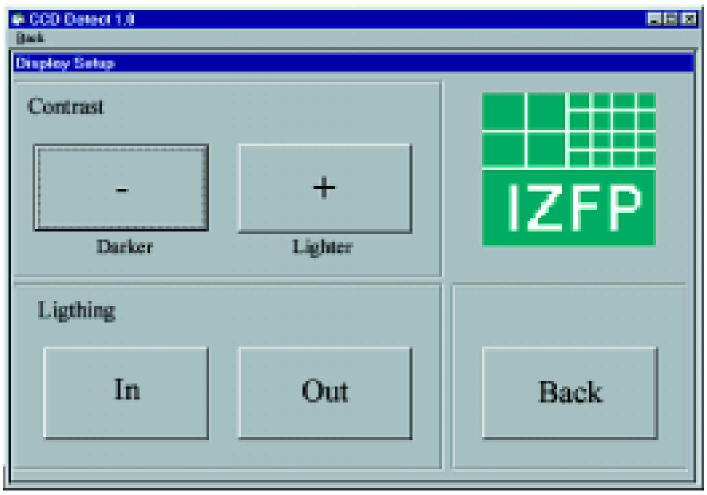

Figure 2: Display configuration menu

The CAM (CCD Array Module) data acquisition module developed for the roughness testing system combines the hardware components necessary for the diffused-light technique. The module includes the output control and monitoring elements for the laser diode, the A/D converter for the conversion of the analog data, the interface to the CCD-sensor, and the expansion interface for the SPBB base module integration.

The functionality of the roughness testing system, composed of the SPBB and the CAM module, CCD sensor and laser diode, was tested and validated during operation. The system was then integrated into a laboratory setup for testing and verification of the methodology and quality of the calculation algorithms.

A technically straightforward and user-friendly operation interface was developed for the roughness testing system. To control the system functions and for the display of the recorded data, a graphical user-interface was implemented for PCs. The host program and the SPBB module communicate via a RS232 interface so that the roughness testing system can be connected to any commercially available IBM-compatible standard PC.

Custom-developed protocols are used for communication with the PC. These protocols consist of an instruction (header) and a data block and permit simultaneous transmission of data packages and control commands. The header block generally contains information about the transmitter of the data package, destination, number of the data words to be transmitted, and a command section.

Figure 2 illustrates the display setup menu and Figure 3 shows the data acquisition menu. A graphical display shows the intensity values of the individual CCD elements. The Single Data or Continuous Data control buttons start either a single or continuous data acquisition for the display of the CCD-intensity values on the screen after completion of data acquisition.

The computed Sn-value is displayed in the corresponding Sn-Value box. The time of illumination and the laser-diode power are adjusted in the parameter menu using sliders, as shown in Figure 4. The Test Laser button initiates the measurement of the power requirement of the laser-diode. This value is compared to a limit value, which (when exceeded) triggers the display of an error condition on the monitor.

The flexible modular design allows effortless integration of additional functions and application-specific data acquisition modules. It is planned to develop a flat array CCD that, in combination with special evaluation software, computes optical texture characteristics using signal-processing algorithms.

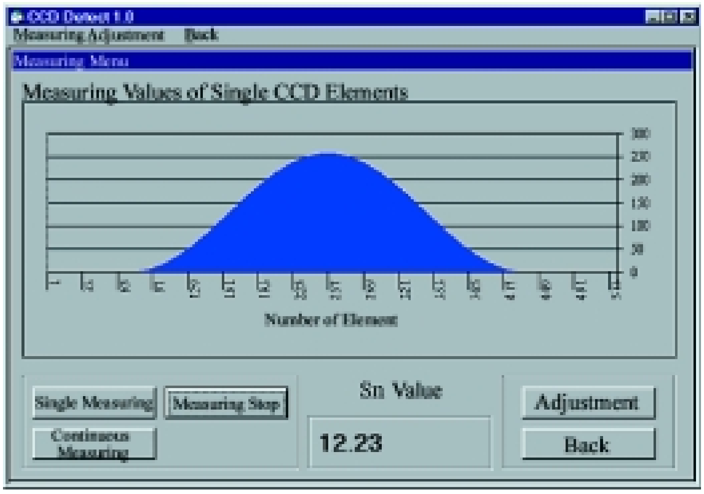

Figure 3: Data acquisition menu

Project Sponsor

The module was developed as part of a joint project with SARCLAD, Great Britain.

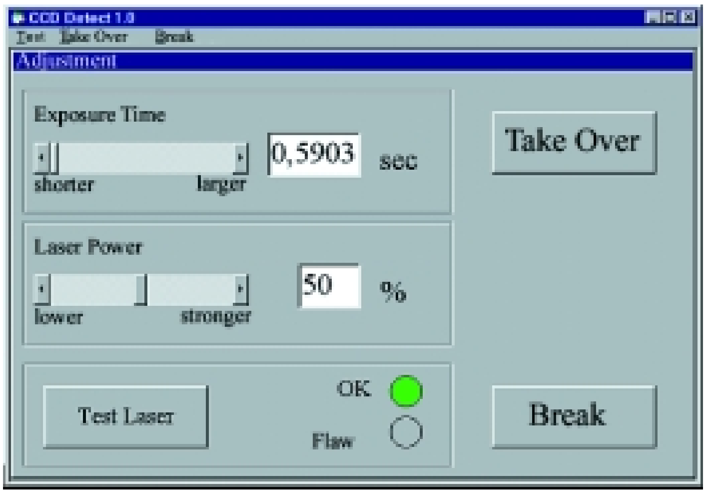

Figure 4: Test parameter menu

Keywords

Basic Board
Digital Signal Processor (DSP)
Thin Sheets
Data Acquisition Plug-in Module
M-Module
Modular Concept
Texture Characteristics
Hot Wide Strip Mill

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Quantitative Flaw Detection of Aluminum Materials and Components

Arrangements for A Quantitative Description of Flaws

One of the most well known ultrasonic techniques for flaw testing is based on the evaluation of amplitudes using the DGS (Distance-Gain-Size) method. The method enables the characterization of e.g., crack-like flaws in such a way that the pulse received from the ultrasonic search unit is displayed at the same height on the screen as a disc-shaped flaw with a diameter »D« and perpendicular to the sound beam. In reality, the reflected amplitude is also determined by the reflector's configuration and parameters such as flaw orientation, roughness of the reflecting surface, and signal accumulation or dispersion (as seen in porosity clusters). Using the DGS evaluation method requires extensive engineering experience to avoid erroneous assessments. Sufficient information relevant to the component safety cannot be provided by ultrasonic testing solely based on the evaluation of amplitude heights. Arrangements for a quantitative detection of flaws must include time-of-flight information, improved search unit technology for the acquisition of high-frequency data, computer-aided tomography, and CAD modules for a locally accurate implementation and presentation of the flaws and the simulation of certain testing situations.

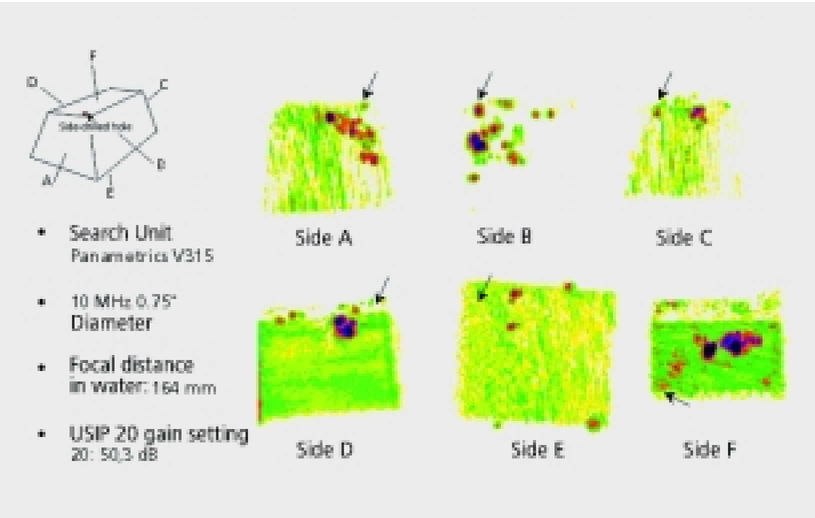

Figure1: Example of a high-resolution (ultrasonic) focus inspection for inclusions in aluminum – Top View

Focusing Technique

The accuracy of flaw detection results depends on the beam spread (divergence) of the transducer, the depth location of the flaw, and the flaw properties. If the flaw orientation is generally parallel to the inspection surface, a straight beam transducer (longitudinal wave modes) technique is used for the inspection. If the flaw orientation is primarily vertical (perpendicular) to the scanning surface, then an angle beam search unit using shear wave modes is used.

The necessity of determining the size of even the smallest imperfection requires the use of high testing frequencies, e.g. 10 MHz, and a focused sound beam. Figure 1 shows the flaw distribution in the upper half of an approximately 45 mm wide and 50 mm long asymmetric test sample. The tests were performed from each of the six sides of the sample (marked A through F). Figure 2 shows an additional application variation whereby the testing of a laser weld seam is done using 45° shear wave modes and a test frequency of 10 MHz.

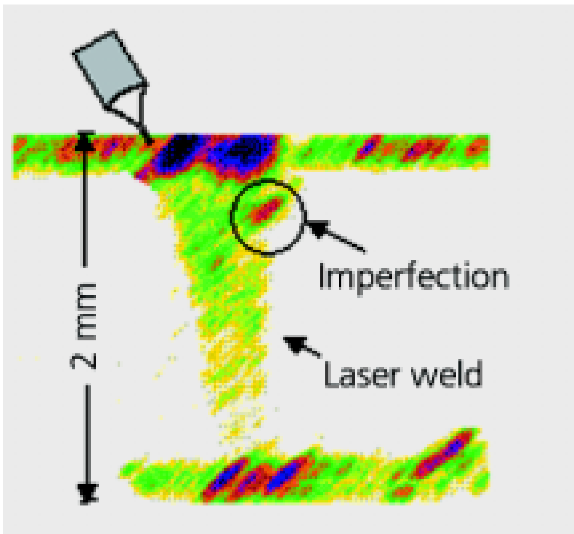

Figure 2: High-resolution (ultrasonic) focus image of a laser weld containing a flaw

Airborne Ultrasound and Generation of Plate Waves

Ultrasonic testing using submerged focused transducers is widely in use. However, this technique cannot be applied if the surface of the test piece cannot be exposed to oil or water and therefore cannot be submerged. For such situations, the air-coupled (airborne) ultrasonic inspection technique in addition to the electro-magnetic acoustic transducer (EMAT) technique provides testing alternatives. The major disadvantage of the air-coupled ultrasound technique is the loss of more than 150 dB of signal during transfer into the test material; however, this can be compensated for with the appropriate electronic instrument components and a suitable test setup. A good solution is the application of plate waves, e.g., for the detection of delamination of different material layers. It is important to note that in these situations the test object is usually accessible from only one side. Therefore, a plate wave with a frequency of 270 kHz is generated and the transmitter and receiver are positioned opposite each other on the accessible side of the sample (pitch-catch arrangement). Attaching the transducer arrangement to a scanner and raster scanning the test sample provides a B-scan image of the inspected area as depicted in Figure 3.

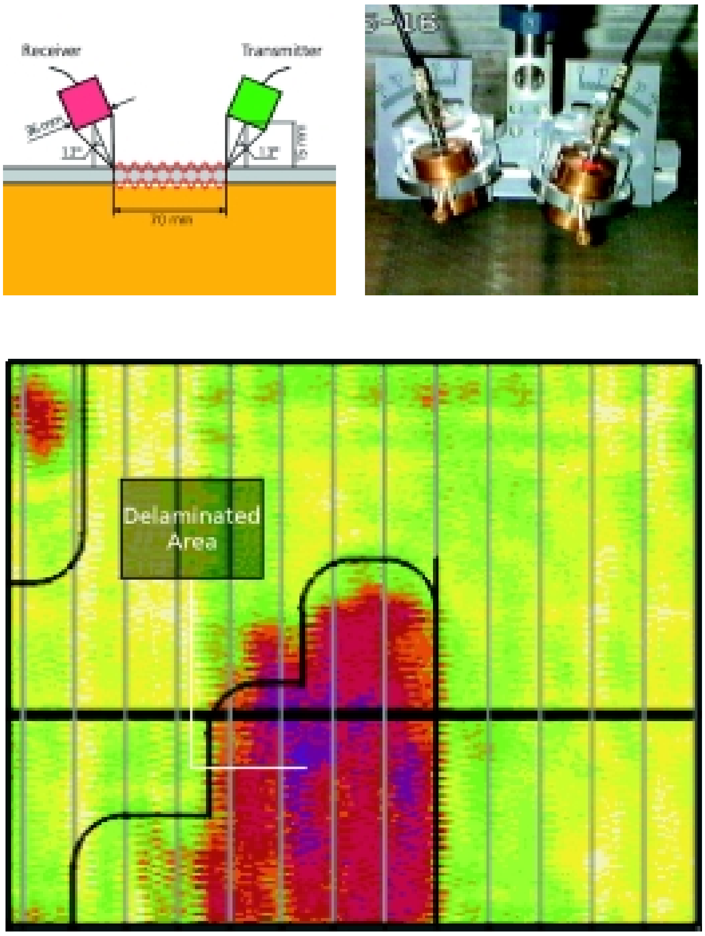

Figure 3: Non-contact testing for delamination using air-coupled ultrasound. Principle, setup, and C-Scan presentation.

Inspection of Aluminum Container Joints

The tightness of aluminum food containers must be warranted after automated filling with food and subsequent sealing with the aluminum cover. A 100% inspection of the seal, integrated into the filling and sealing process, is encumbered by several aggravating conditions, such as the entire inspection time per can is approximately 1 second, of which about 250 msec are available for ultrasonic testing. The ultrasonic inspection must be performed without couplant agents, except possibly light moistening.

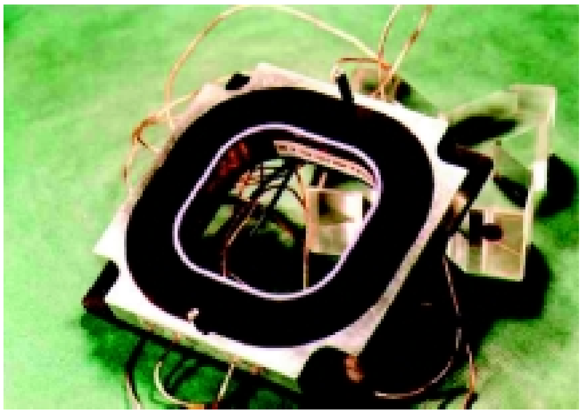

Figure 4: 400-channel ring array; the light-colored inside ring contains the piezo-electric transducers, the dark ring covers the cabling

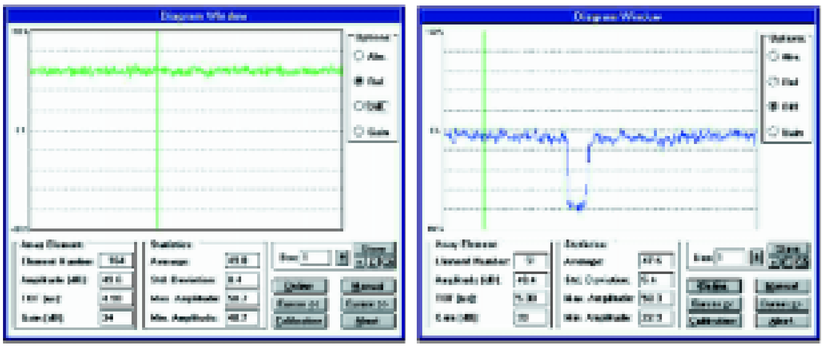

Figure 5: Typical signal-train of 400 individual transducer elements during the inspection of aluminum container seal welds

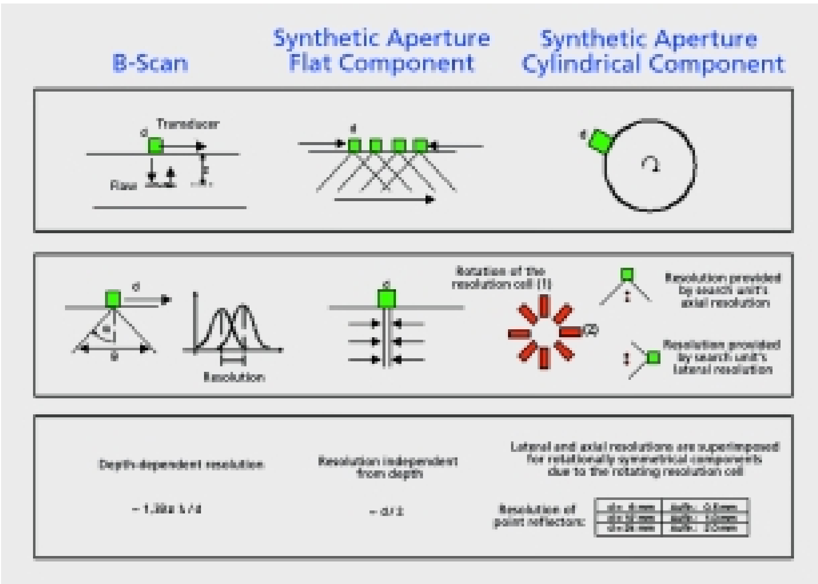

Figure 6: Image quality enhancements due to improvements of the lateral resolution using Synthetic Aperture Techniques

For the inspection of aluminum container joints, IZFP utilized ultrasonic through-transmission with two square ring arrays. The test object was placed between the ring arrays during one cycle. Each ring array consisted of 400 individual transducers, which were made of four straight and four curved transducer segments (see Figure 4). The container to be tested was placed in the receiver array shown here. The testing frequency was 7 MHz with an individual transducer element size of 2 x 0.63 mm^2. Individual elements of the transmitter and receiver arrays were parallel connected to reduce the number of RF-cables from 800 to 180.

The entire inspection system was designed as a modular setup with a decentralized, networked system, whose sub-units could exchange data via quick, serial interfaces. The digitalization and processing modules utilized digital signal processors (DSP), which were optimized for the highest computation capacity. The user menu allowed the setup of the inspection system parameters, the management and evaluation of test data, and the display of the inspection results. An automatic calibration function allowed the harmonization of the amplitude sensitivity of the 400 receiver transducers. The signals could be evaluated for location, amplitude height, etc., using cursor functions. The through-transmission amplitudes and the corresponding statistical values could be exported to spreadsheet programs such as Microsoft® Excel.

Extensive testing of the system was done in the laboratory and at a processing plant. The influence of various flaw conditions, e.g., contamination of the seal seam, insufficient processing temperature during sealing, and cover mismatch were investigated in addition to testing the reproducibility of the acoustical coupling conditions, search unit sensitivity, and the mechanical loading capacity. Figure 5 shows an example of the 400 through-transmission signal amplitudes of a perfect seam. The required short cycle-times of the inspection system could only be accomplished with the development of a multi-channel ultrasonic testing system.

Pipe Weld and Piping System Inspections using Ultrasonic Tomography and CAD Imaging of Pipe Segments

AutoSketch©, AutoCAD®, and other computer-aided-drafting programs make it possible to generate a two- or three-dimensional image of a component with respect to significant cutting planes on a personal computer. However, including and displaying the results of a thermography, radiography, or ultrasonic inspection image are not possible.

Raster scanning on components using ultrasonic search unit(s) enables the display of side view (B-scan, D-scan) and/or top view (C-scan) presentations. Without further signal processing, the image quality is reduced due to insufficient lateral resolution since the sound beam is divergent and with increasing depths the resolution of neighboring reflectors decreases. Through post-processing of the acquired data, the beam spread (divergence) influence can be removed if the principle of the synthetic aperture focusing technique (SAFT) is applied. As a result, a depth-independent resolution directly related to the size of the search unit is much better for practical applications than using half-width value of the search unit diameter. Applying SAFT to rotationally symmetrical components results in even more improved values, as shown in Figure 6. The advantages of depth-insensitive imaging quality are especially evident when inspecting heavy wall components.

A »3-D Ray-SAFT« program, running under Windows NT, was developed at IZFP. The program enables the reconstruction of the ultrasonic data using the synthetic aperture focusing technique algorithms and the transformation of the reconstructed data for visualization in a CAD environment. In general, the displayed image corresponds to the coordinate planes to show the extent of the flaw parallel to the surface (C-scan image, z = 466mm), or in the two side view images (B-image for y = 48 mm and D-scan image, x = 34mm) to determine the orientation the flaw and the flaw size. Various tools for image processing are available. Figure 7 shows isolated slag-inclusions located at the weld-to-base material interface and in the weld material.

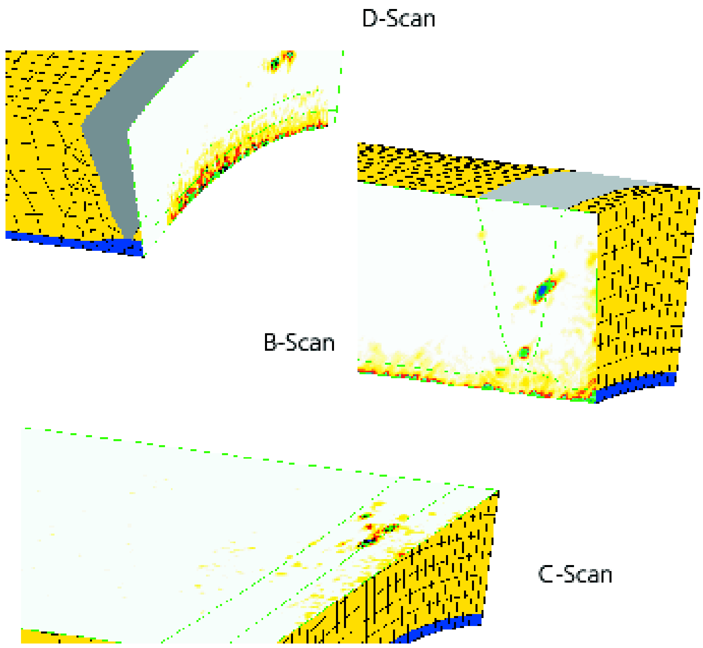

Figure 7: Presentation of a SAFT reconstruction image with two side views and top view to determine exact location and size of slag-inclusions in a weld

Keywords

CAD Module
Digital Signal Processor (DSP)
Focal Inspection
Airborne Ultrasound
Quantitative NDT
Pipeline Inspection
Simulation

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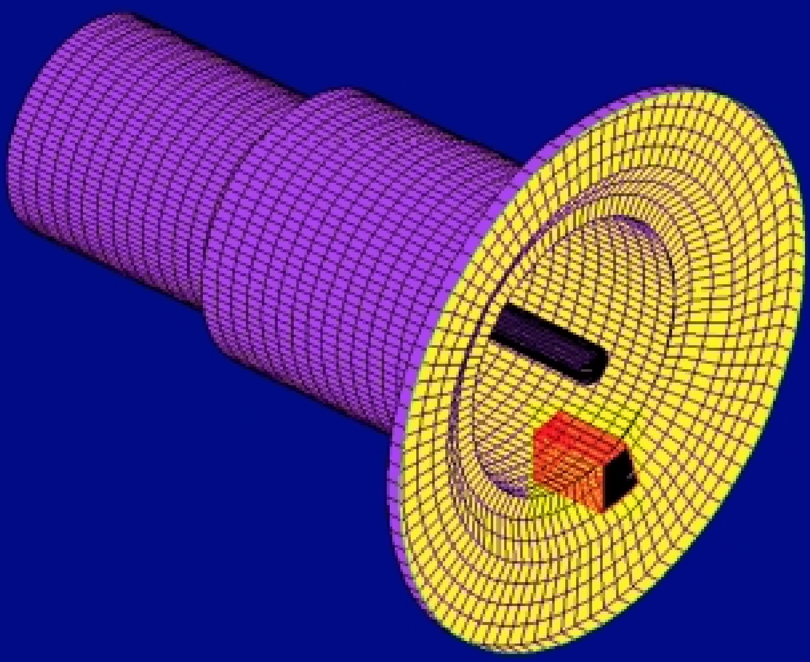
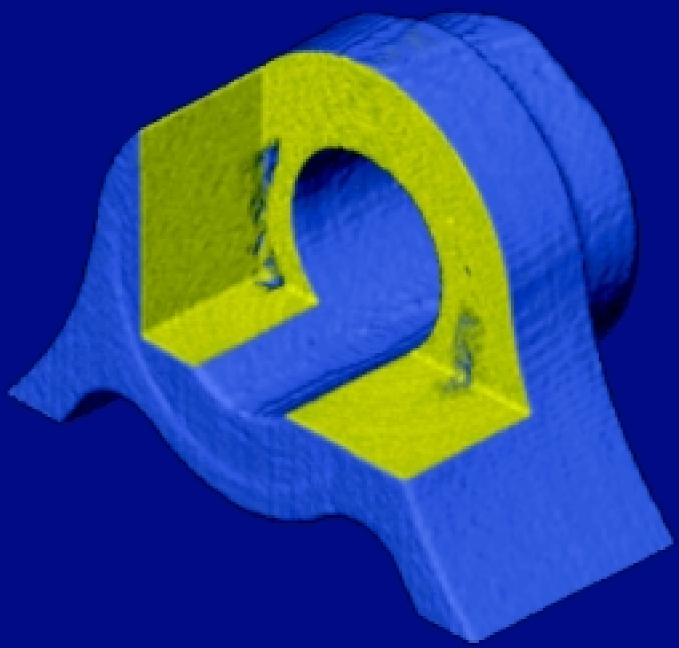
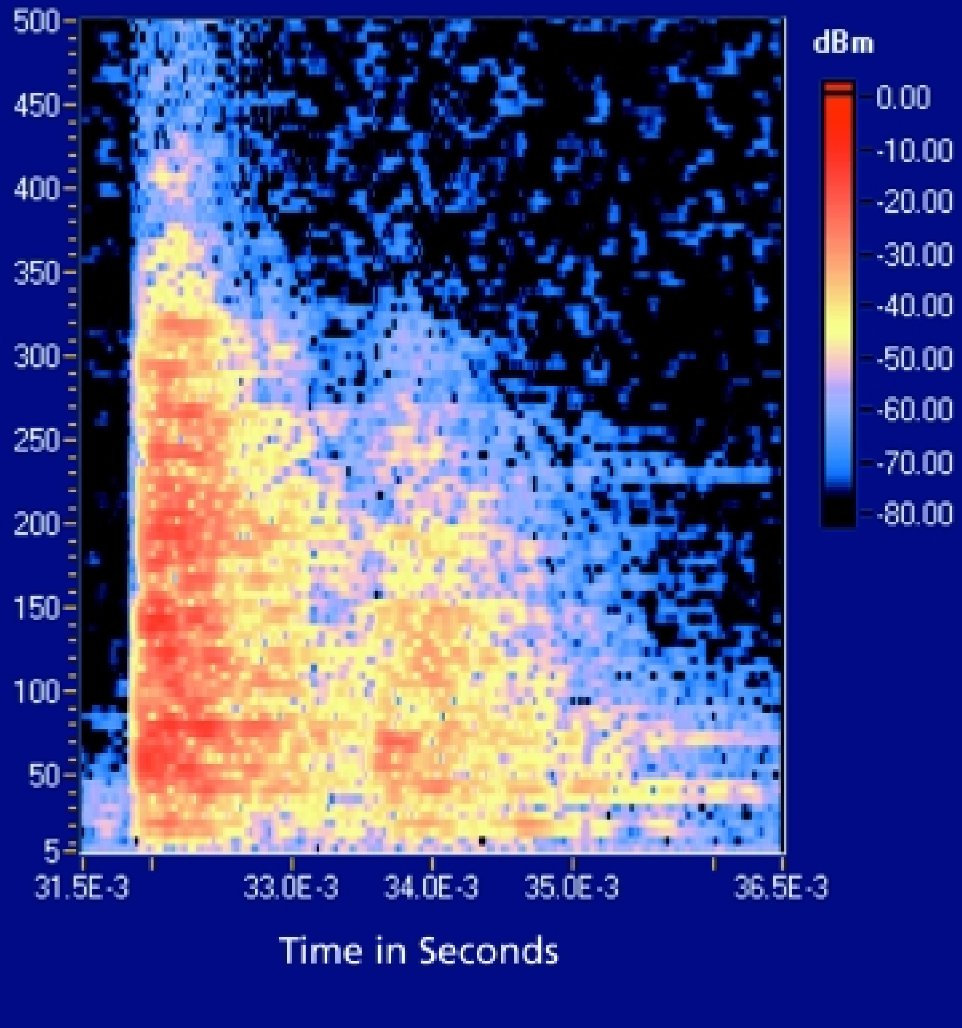
Applications







Micrometer-Resolution Diffractometer for Nondestructive Material Characterization of Micro-Electronic Components

Problem

Components for microelectronics and opto-electronics are usually manufactured using epitaxial growth to layer different coatings onto a semiconductor substrate. The crystalline quality of the total structure, which determines not only the quality but also the life expectancy of the component, is significantly dependent on the quality of the wafer used as the substrate. Silicone is the dominant substrate used in the microelectronics industry, whereas InP and GaAs are primarily used in the opto-electronic industry. In addition, the development of new materials such as SiC and GaN are showing promise.

The development of improved manufacturing technologies determines the need of suitable methods for complete nondestructive characterization of the wafer quality, especially in respect to the crystalline characteristics of matrix distortion, twisting, defect arrangement, mosaicism, etc.

Objective

X-ray refraction methods are well suited for the characterization of crystalline properties of a sample because the wavelength of the rays used is in the size range of the distances between the atoms of the crystal lattice. The half-width value of the rocking curves is used as a quality indicator for crystalline perfection. Changes in the relative position of the Bragg-points and the sample position provide valuable information on the bending and lattice distortion of the wafer. The highest possible local resolution is desired for detailed characterization.

X-ray machines specifically designed for the characterization of substrate wafers are commercially available, currently with a resolution of 1 mm^2. The local resolution is achieved by reducing the beam cross-section using a mechanical aperture and scanning of the wafer surface. This allows a macroscopic quality control but does not allow the correlation of the quality parameter to the cause of the imperfections, the microscopic defective crystal structure. To achieve this objective, the local resolution must be increased by at least two orders of magnitude without increasing the processing time.

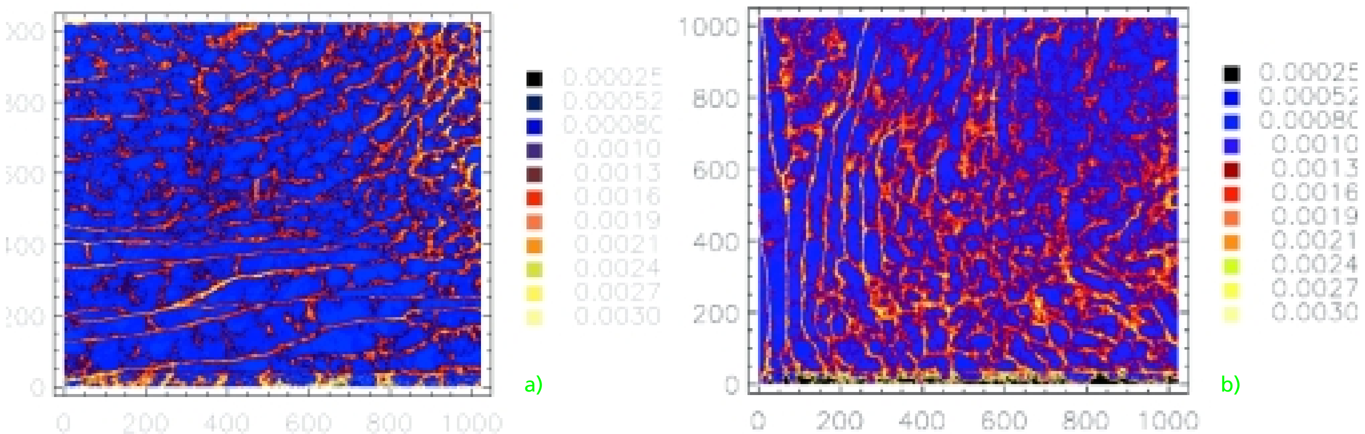
Solution

An IZFP work group stationed at the European Synchrotron (ESRF) in Grenoble, France, has developed a new technique for a micrometer-resolution diffractometer. In contrast to conventional methods, which depend on the reduction of the beam width, this technique utilizes the full beam width featuring a highly parallel beam. The local resolution is achieved using a high-resolution X-ray camera.

The measurements were unparalleled using this new principle, a combination of diffractometry and topography. The refracted intensity is recorded for all points of the inspected area simultaneously, i.e., the rocking-curves for all points are measured simultaneously by rotating the sample. This greatly increases the speed of the process in comparison to the initial techniques used. The result shows the measurements of rocking-curve maps with an angular resolution of £10^{-4} and a significantly improved local resolution in the range of 1 µm.

The technique possesses a high degree of flexibility: the wavelength of the rays, the diffraction geometry, the crystallographic reflection used, and

Figure 1: Micrometer-resolution diffractometry on a GaAs-LEC wafer: Section of a half-width value map at two different locations. (Color-coding in degrees C°)



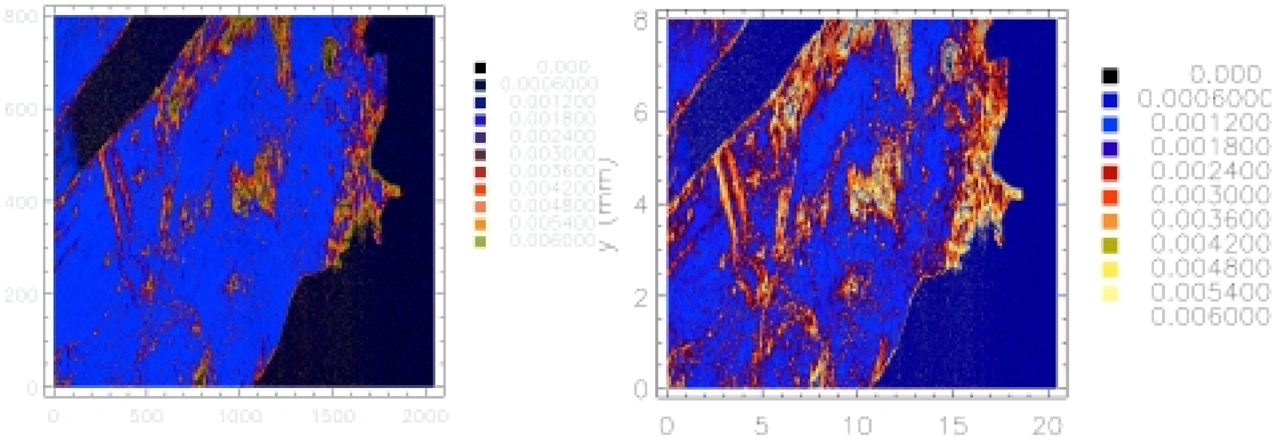


Figure 2: Half-width value maps of a SiC sample.
(Color-coding in degrees C°)

the desired local resolution are individually variable and can therefore be adapted to the characteristics of individual samples. In this way, using high-energy radiation allows the reduction of the natural half-width value of a perfect crystal lattice by one order of magnitude, which permits the measured half-width value to primarily reflect the realistic structural characteristics of the sample.

Results

A custom-developed software package permits the gathering of numerous information from the acquired data. Of special significance as a gage for the local quality of the crystal lattice are the wafer curvature and the half-width value of the rocking-curves. This information provides a clear picture of the crystal growth process, which offers further information about the perfection of the periodic order of the atoms in the lattice at micrometer-resolution. The characteristics of dislocation-networks, covering the entire sample, and disoriented crystallites can now be effortlessly identified.

Figure 1 shows examples of a half-width value map of a GaAs-LEC wafer at two different sample positions. Dislocation-networks cause locally enlarged half-width values in comparison to the undisturbed regions with high crystal perfection. The network structure varies with variations in sample position.

Figure 2 displays two half-width value maps of a SiC sample. Areas of different crystallographic phases are discernible; only the areas with a cubic crystal structure add to the refraction-intensity of the map. Map (a) shows local defects; in contrast, map (b) shows local defects correlated to areas of varying crystal orientation.

Project Description

The project was executed in cooperation with the European Synchrotron Radiation Facility (ESRF) in Grenoble, France
Project Sponsor
Saarland Ministry for Education, Culture, and Science.

Keywords

Semiconductor Wafer
Crystal Defects, Crystal Quality
Local-Resolution Diffracted Radiography

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New Tomography Concepts Provide Highest Local Resolution for Imaging of Objects with Minimal Density Variation

Problem

Conventional radiography is used to determine local material distribution in objects that can absorb the radiation. This occurs by measuring the transmitted radiation following absorption by the object. The irradiation of the object from different directions provides a three-dimensional image of the object when combined with the appropriate reconstruction algorithms, and this is called Absorption Tomography.

Nondestructive testing using absorption tomography currently faces two major problems:

1. Imaging of objects having minimal or no absorption contrast – specifically, very light materials and/or objects in a matrix of similar densities (for example: Al_2Ox in Al).
2. Imaging of objects with a localized resolution of less than 8×10^3 µm³.

Mission

The increased use and importance of light materials, such as metal foams, aluminum materials, plastics, and composite materials, have required the achievement of improved resolutions up to 1 µm³ in objects with minimal density differences using X-ray radioscopy and tomography, by utilizing the instrumental capabilities of the European Synchrotron in Grenoble, France.

Solution:

This requirement lead to a methodical expansion with respect to phase-sensitive radiography and tomography, and thus to a qualitative expansion of the potential application opportunities. The method is primarily based on the high spatial coherence of X-rays provided by the third generation synchrotron sources. In this simple manner, the limitations of radiography for absorption radiography/tomography can be eliminated, which permits the display of so-called phase images, i.e., diffraction-images based on the phase shift of the high-energy radiation penetrating the object. High quality phase-contrast images clearly display variations in radiation intensity.

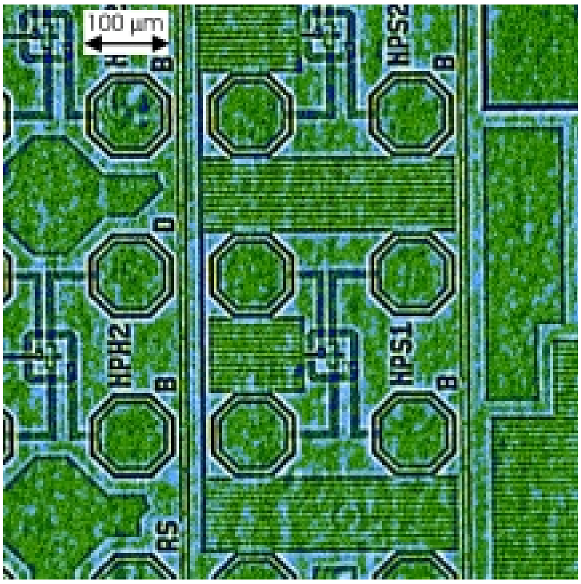

Figure 1: Section of a phase-contrast image of an integrated circuit

The method is based on a local variation of the »optical« path length. The physical basis of the imaging procedure lies in the Fresnel effect, which is the diffraction of the radiation as it bends within an object. As a result, an adequate description of the waveform is achieved in comparison to conventional radiography. The waveform of conventional radiography is based on the determination of the amplitude modulation of the transmitted wave when passing through an object (e.g., due to the varying

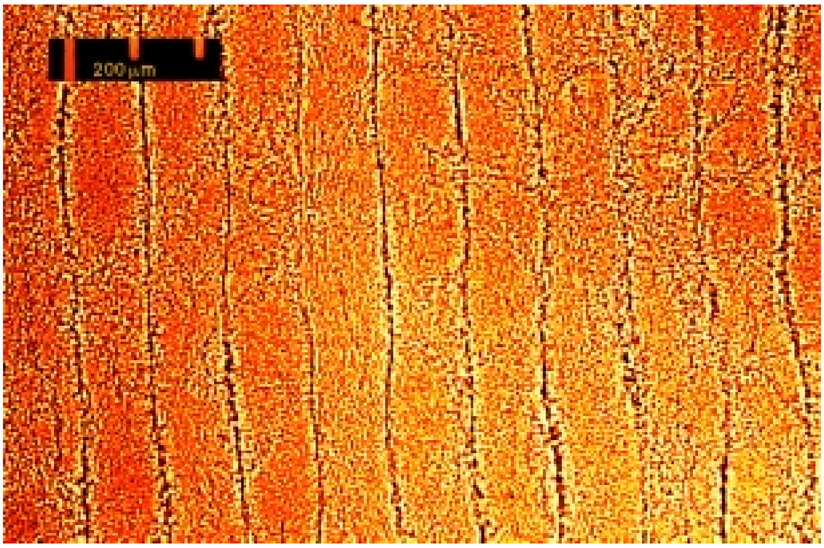

Figure 2: Phase-contrast image of a carbon fiber material disc

absorption qualities of the different materials in the object being penetrated). On the other hand, phase-sensitive radiography is based on the shifting of the phases of the refracted waves.

Basically, two techniques are utilized: 1) the so-called object-edge technique, which displays every interior object boundary between areas of different diffraction indices as an intensified and clear image; and 2), the holographic technique, which shows a diffracted presentation of a very distorted image of the whole object but allows the combination of images that appear at different distances behind the object, using appropriate algorithms to determine the phases of the transmitted wave forms, and therefore the density distribution in the sample.

Phase-sensitive radiography and phase-sensitive tomography have advantages with respect to absorption radiography/tomography especially if the absorption contrast is minimal. Low absorption-contrast occurs primarily in light materials, generally thin objects, and objects having minimal local differences of mass density and/or atomic number. The extremely small radiation source (0.12 mm x 0.03 mm) and the long distance (150 m) between the source and the sample results in a broad homogeneous cross section (14 mm x 40 mm) of the ray with high coherence and low divergence (0.1 – 1 micro radian). For the first time, samples can be imaged using a ray cross-section of comparable size as a whole and in one pass with a resolution currently up to 1μm^3 for absorption-contrast and phase-contrast presentation.

In contrast to all other radiation tomography methods such as absorption tomography and diffraction tomography based on low-angle scattering phenomena, the described method is based on the experimental determination of amplitudes and phases of the transmitted waveforms. The method also allows the reconstruction of objects that are »invisible« for X-rays without prior knowledge of the structure.

Results

Investigations were conducted on metal foams, composite materials, fiber materials, semi-conductor materials, and components such as wafers, high capacity laser, integrated circuits, flip chips, etc.

Figure 1 shows a section of a phase-contrast image of an integrated circuit (IC). The intensity of the light/dark contrast of the band pattern is a measurement of the thickness of the metallic strip (aluminum) and the covered layers. The latter are not visible using a light microscope, and absorption radioscopy does not show a contrast here.

Figure 2 depicts a phase-contrast image of a carbon fiber laminate section. The carbon fibers, arranged in layers of approximately 10 µm thickness and about 110 µm apart, are clearly visible in the phase-contrast image. The length, distribution, and orientation of the fibers relative to the disc axis were exactly determined.
Figures 3 and 4 present three-dimensional (3D) reconstructions and the corresponding images of the micro-tomography of industrial aluminum and zinc foams (absorption mode). The diameters of the foam pores are close to the mm-range in both samples. In contrast, the walls of the pores of the zinc sample are only about 10 to 20 µm thick. Additional pores were observed in the walls and especially in the branches.

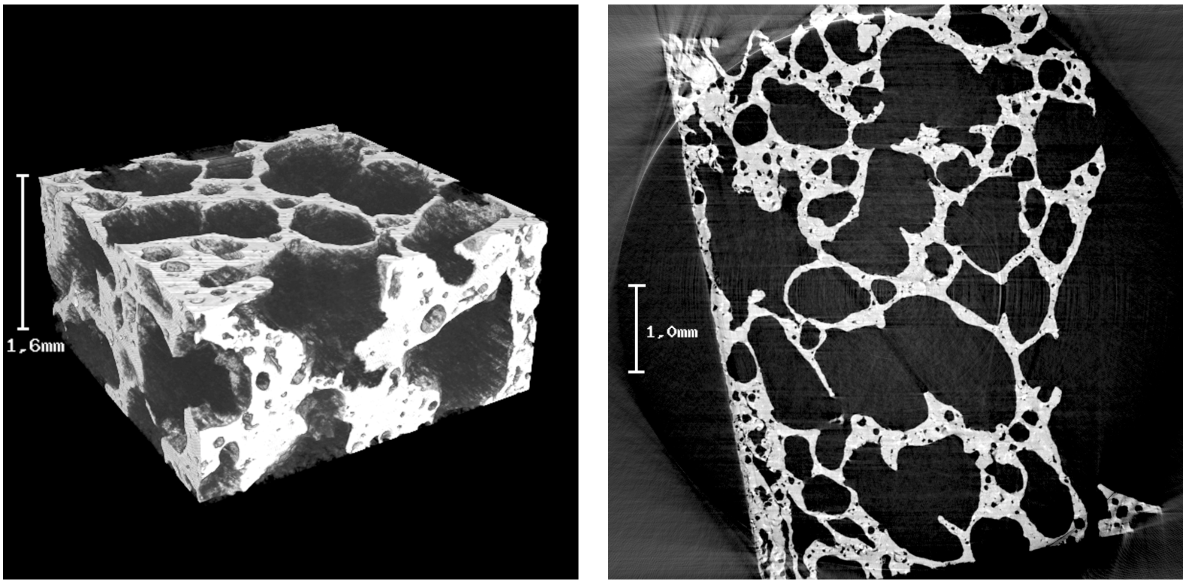

Figure 3: Three-dimensional (3D) reconstruction (left) and cross-section of a micro-tomography image (right) of an aluminum-foam sample, provided by the Fraunhofer-Institute for Applied Material Research

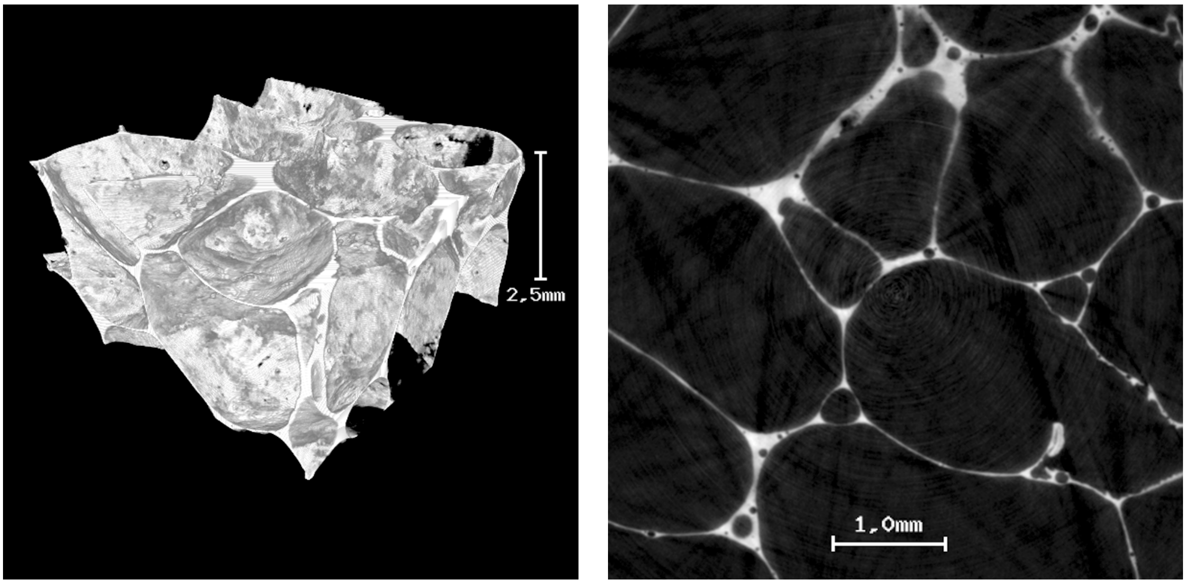

Figure 4: Three-dimensional (3D) reconstruction (left) and cross-section of a micro-tomography image (right) of a zinc-foam sample, provided by the Fraunhofer-Institute for Applied Material Research

Keywords

Fiber Materials
Composite Materials
Foamed Materials
Micro-Electronic Circuits
Micro-Tomography
Radiography
Cooperating Partner
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Industrial Computed-Tomography

Introduction

Nondestructive testing of coarse structures with radiography is typically accomplished using one of two methods: a) conventional radiography; or b) tomography methods, e.g. computed-tomography (CT) and laminography.

In conventional radiography, all details of a three-dimensional (3D) object are projected onto two-dimensional (2D) recording media such as X-ray film or fluoroscopic/fluorescence screens, thus superimposing and/or masking multiple information in radiation direction. However, tomography methods permit the display of inside structures (attenuation coefficients) of the test object without eclipsing information.

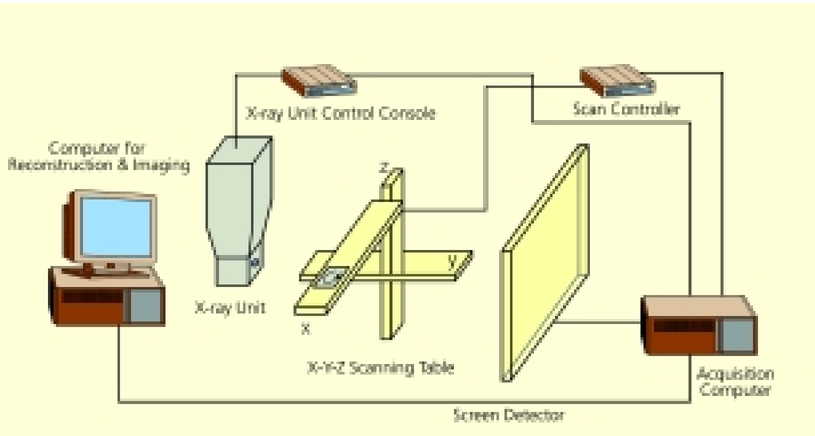

Figure 1: 3D-CT System setup diagram

The much more detailed information available with tomography methods enable a much more precise view of the inside of an object, which is of particular importance and value in the design and testing phase of various commercial products from large investment cement castings to the micro-structures of electronic components. Until recently, tomography methods were not used for industrial applications due to enormous data acquisition and post-processing time, and thus have only been in use at laboratories. The introduction of new, flat X-ray sensors drastically reduced the time for the volumetric inspection by replacing hitherto common 2D-CT with the so-called Volume-CT (or 3D-CT). In addition, rapid improvements in computer processing power and parallel processing of algorithms have reduced the time for data reconstruction to industry-acceptable levels. Based on these developments, the Fraunhofer-Institute Nondestructive Testing (IZFP) in Saarbrücken and Fraunhofer-Institute Integrated Circuits (IIS-A) in Erlangen initiated a joint-venture department for X-ray techniques to develop a system for fast industrial 3D-CT.

System Overview

For several years, both Fraunhofer Institutes were intensely involved in X-ray and radiography imaging, sensor techniques, and CT. Since the beginning of 1998, the new joint-venture department for X-ray Techniques has worked on the industrial application of Volume-CT (3D-CT). Contrary to medical applications, the test object can be rotated in the conical X-ray over the entire circumference. This permits a substantial simplification of the object manipulation devices and thus significantly reduces overall costs. The details of the test object are projected onto the X-ray detector from every angular position. With 3D-CT, the object's volume is reconstructed from the initial area-projection using reconstruction algorithms such as the modified Feldkamp algorithm.

Figure 1 shows a typical setup diagram of a 3D-CT system. The system consists of an X-ray source, X-ray detector, and a computer for data reconstruction. The reconstruction data are processed, displayed, and analyzed by an industrial-type multi-processor Pentium® PC. This technology can be applied in the following areas:

- Inspection of micro-mechanical components
- Inspection of plastic and aluminum cast parts
- Reverse engineering
- Material development

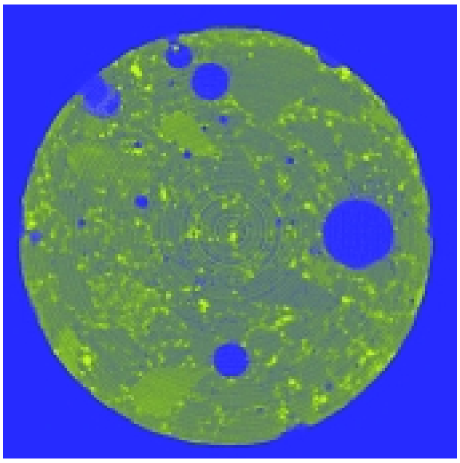

Figure 2: 2D-Section of a concrete sample using 2D-CT

Volume Computed-Tomography

To demonstrate the Volume-CT technique, a small concrete cylinder (7 mm in diameter) is used for volumetric reconstruction (sample provided by IBMB of the Technical University Braunschweig). Figure 2 illustrates a radial plane reconstructed perpendicular to the cylinder axis using conventional 2D-CT.

To image the complete volume of the cylinder, 2D-CT has to process a large number of sections in the volume, which requires a long of time. However, the 3D-CT process requires only a complete (360°) rotation of the object during data acquisition to reconstruct the entire volume in a significantly shorter time. The data are acquired using a screen detector (not a line detector as for 2D-CT), which reduced data acquisition and reconstruction time on the above sample by a factor of 100. A volume of 512 cubic pixels can be acquired and reconstructed by the fully optimized reconstruction algorithm within five minutes.

The resulting image of a volumetric scan is presented in Figure 3.

Once the three-dimensional reconstruction process is completed, the test object can be displayed in freely selectable perspectives, as shown in Figure 4.

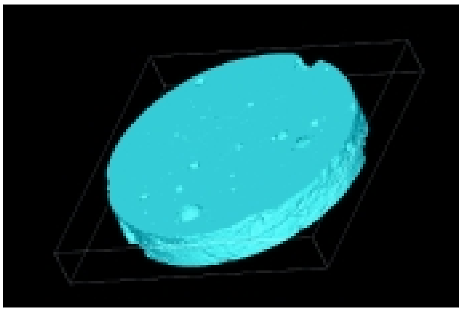

Figure 3: 3D-CT Volumetric image of a concrete sample

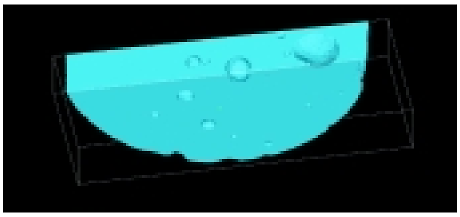

Figure 4: 3D-CT Volumetric section of a concrete sample

Keywords

2-D Computed-tomography
3-D Computed-tomography
Radiography
X-ray Techniques
Volumetric Reconstruction
Microstructures

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