Fraunhofer IKTS

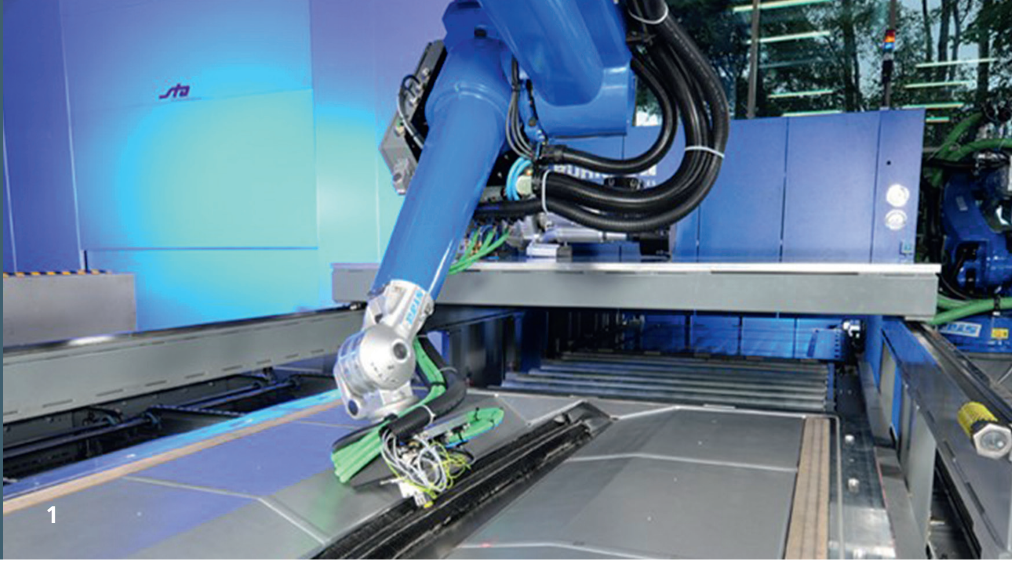
FRAUNHOFER INSTITUTE FOR CERAMIC TECHNOLOGIES AND SYSTEMS IKTS

INDUSTRIAL SOLUTIONS

NON-DESTRUCTIVE TESTING

TITELBILD *Robot-based eddy current testing system for components with complex shapes.*

1 *Linking and quality assurance robot at the German Aerospace Center in Stade with EddyCus® technology for fiber orientation detection (source: DLR Stade).*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NON-DESTRUCTIVE TESTING: A SYSTEMS APPROACH

Industry 4.0 and big data methods will lead to a paradigm shift in the application of non-destructive components testing and materials diagnostics methods. These methods are an essential source of valuable data. New sensor concepts, robot-assisted measurements, cloud-based data acquisition, and data evaluation using AI methods are driving this transformation and expanding the application range of new and well-established NDT methods.

Backed by several decades of experience, Fraunhofer IKTS and its Materials Diagnostics Division are positioned to cope with these challenges. IKTS concepts established in ceramics development – covering complete value chains and realizing material and process innovations at the system level – can also be transferred to materials diagnostics.

Non-destructive components testing (NDT) and materials diagnostics will be performed over the entire product life cycle, from development to testing or monitoring in production and use. For this, Fraunhofer IKTS draws on traditional methods such as ultrasonic, eddy current, and x-ray inspection as well as acoustic diagnostics, combining or supplementing these techniques with new methods such as laser speckle photometry or optical coherence tomography. By linking the data acquired during testing with a dynamic simulation model of the part or system, it is possible to predict the service life or performance with the help of the "digital twin".

Fraunhofer IKTS is part of the globally leading Dresden Materials Research Cluster and cooperates with the Dresden Microelectronics Network as well as various established mechanical engineering companies.

Capabilities

The range of capabilities at Fraunhofer IKTS goes far beyond that of a classic provider of NDT testing services. The traditional strength of the institute – handling noisy signals – is reflected at the hardware level by adapted sensors and in-house electronics with excellent signal-to-noise ratios as well as by an in-house software library and use of state-of-the-art machine learning methods. The mathematical know-how of the institute and research partners fuels the algorithm development process and forms the basis of sensor data fusion concepts.

Sensor development activities profit from the main Fraunhofer IKTS materials systems and technology offering, which includes thin-film, thick-film, and multilayer technologies as well as printed electronics and ceramic sensors for use in harsh operating conditions. In the profile lines of nanoanalytics and robust electronics, knowledge related to failure models is acquired and applied in reliable sensor solutions. Interference-free optical data transmission and data compression by preprocessing in the sensor round out the profile.

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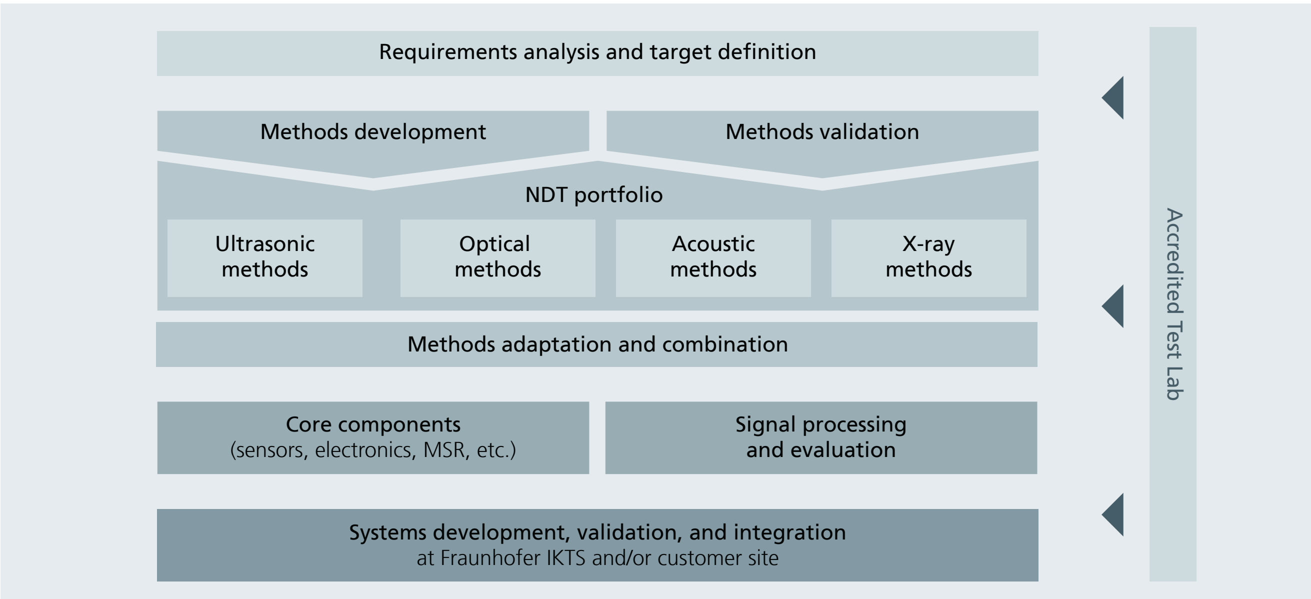
With these core technological capabilities – combined with a systematic approach and driven by a creative team of scientists, technicians, and engineers – established methods can be advanced and new non-destructive testing methods can be qualified.

Services offered

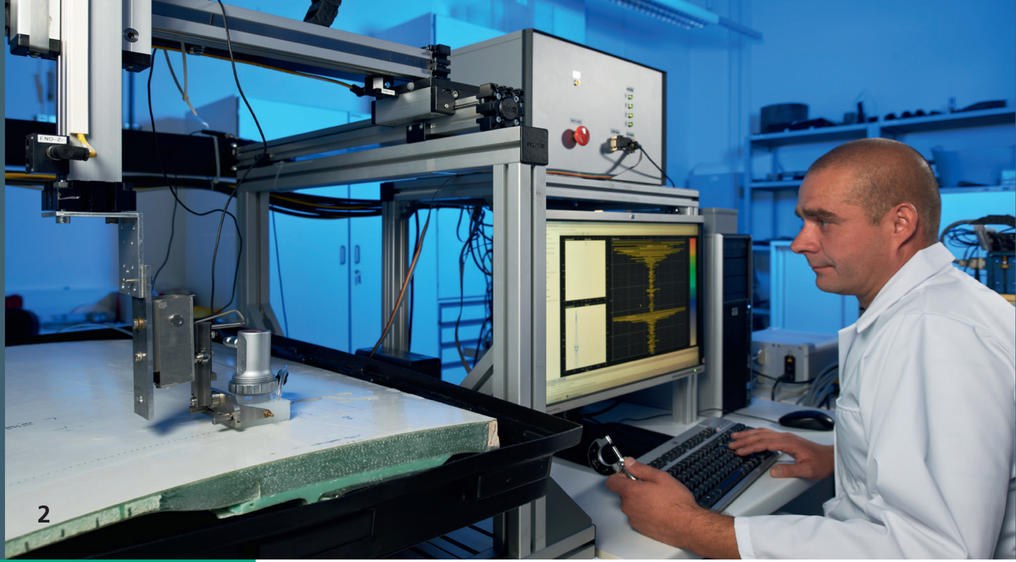
For customers of Fraunhofer IKTS, various contract and cooperation modes are available to accommodate the given task and in-house capabilities. Projects range from simple service provision and improvement of specific aspects of a method or customer components to complete system development.

Each project begins with a clear problem analysis and a feasibility demonstration. Feasibility studies in the early phase of development reduce the financial risk and provide a stable basis for all further project steps. The result is a CE-certified system and approval of the testing process by the Accredited Test Lab. IKTS can work flexibly with the client to coordinate individual development and implementation steps.

Successful hardware developments are commercialized via industrial collaborations and can be licensed by industry customers for their applications.



1 *Roller bearings with printed and laser-sintered sensors for strain and structure-borne sound measurements, realized within a Fraunhofer project (source: Fraunhofer ILT).*



ACCREDITED TEST LAB

FASTER IMPLEMENTATION OF NEW TEST METHODS

To perform valid and reproducible non-destructive tests, know-how and experience are very important. A multiplicity of national and international standards, which can differ depending on the industry, sets the boundary conditions for use of established and new methods. Especially in the optimization of existing and development of new methods and systems, the latest regulations must be complied with and new methods or device systems developed accordingly.

The test lab has been granted flexible-scope accreditation status in accordance with DIN EN ISO/IEC 17025 by the Deutsche Akkreditierungsstelle (DAkkS). This status makes it possible to validate ultrasonic and eddy current testing methods developed in-house and apply them like standard methods to the customer's task. It thus provides a decisive advantage over conventional standardization processes by enabling faster implementation of time- and cost-efficient testing methods.

The Accredited Test Lab also offers conventional non-destructive testing of metals, nonmetals, ceramics, and composites using standard methods. Capabilities range from single components testing to testing of large parts volumes in multishift operations and development of customized semi-automatic testing systems for handling special tasks.

Testing capabilities at Fraunhofer IKTS

- Materials: steel, austenite, titanium alloys, non-ferrous metals, polymers, ceramic composite materials, polymer composites, rock, concrete, and natural fiber materials
- Material-to-material connections: welded joints, sandwich/layers, semi-finished products, riveted and bolted joints, bonded joints, and solder joints
- Geometries: voluminous bodies, complex geometries, flat sheet metal, etc.
- Part sizes: from a few millimeters to several meters, depending on the given task
- Defect patterns: cracks, pores, delamination, geometry defects, inclusions, etc.
- Testing methods: ultrasonic, eddy current, magnetic particle, penetrant, visual, hardness, thermography, and x-ray CT testing and x-ray laminography

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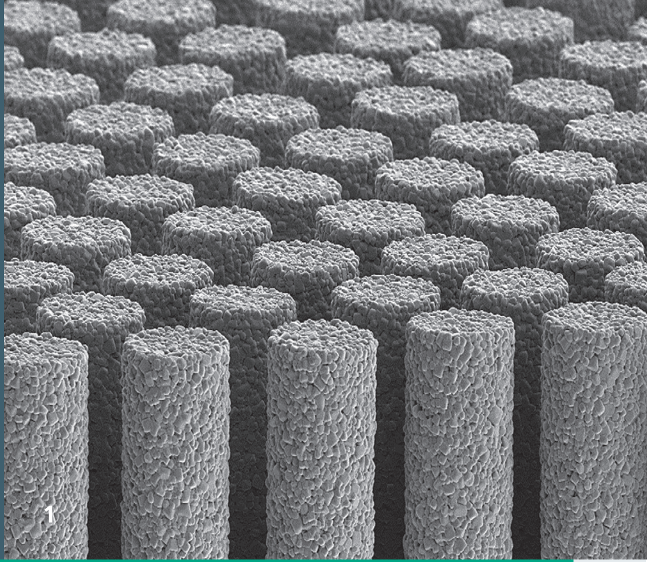
DAkkS
Deutsche
Akkreditierungsstelle
D-PL-11140-10-00

2 *Validation of a new testing method at the Accredited Test Lab.*



ULTRASONIC METHODS

Ultrasonic methods are some of the most frequently used methods for non-destructive testing. Fraunhofer IKTS combines years of experience in materials testing with unique capabilities in the field of ultrasonic technologies. As a developer of industrial ultrasonic testing systems, Fraunhofer IKTS offers sensors, testing electronics, software, simulation and modeling services, and an accredited test lab for validation and verification of ultrasonic methods – which truly makes it a one-stop shop for ultrasonics.

Ultrasonic sensors

At the heart of every testing system are the sensors. Fraunhofer IKTS develops sensors optimally adapted to the given geometries, materials, and acoustic parameters.

Technical details

- High-performance ultrasonic transducers for use on fiber-reinforced composites (high- and low-frequency, focused/unfocused, single-element or segmented)
- Dice-and-fill composites
- Soft-mold composites for frequencies of 5–30 MHz with max. transducer dimensions of 10 x 10 mm
- Screen-printed ultrasonic transducers for mass-produced compact sensor systems with 5–30 MHz and max. transducer dimensions of 100 x 100 mm
- Focused ultrasonic phased array probes
- High-sensitivity phased array probes
- High-frequency probes (100–250 MHz)
- High-temperature probes (up to 200 °C)
- Acoustic emission sensors

Ultrasonic electronics

To get the full potential out of the sensors, Fraunhofer IKTS offers the PCUS® *pro* series of powerful modular electronics. The portfolio extends from simple manual ultrasonic testers to fully automated ultrasonic testing systems.

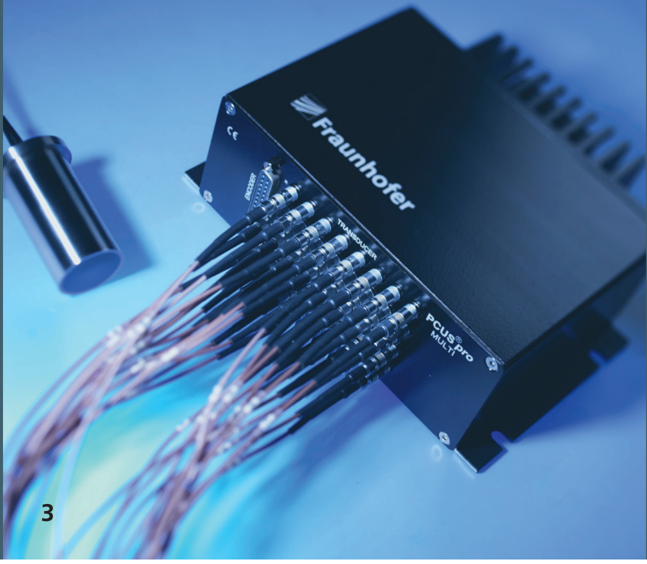
Technical details

- Modular and customizable
- Compact and energy-efficient
- Meets respectively relevant parts of ultrasonics standard DIN EN 12668
- Suitable for single oscillators as well as single- and multi-channel testing electronics up to arrays (up to 128:128)

Ultrasonic software

Software has become fundamental to the development of testing systems for industrial application. It must be innovative and quickly available without compromising flexibility to allow future changes and extensions. PCUS® *pro* Lab is a modular software suite that quickly and flexibly creates solutions for the given testing task. The software supports parameterization for actuator and sensor control, visualization, and evaluation. Data organization and management take place in the flexibly adaptable revision system. In addition, the suite can be fully integrated into existing manufacturing concepts within the scope of Industry 4.0.

1 *Microshaping of fine-scaled piezoceramics for high-frequency ultrasonic transducers.*
2 *Acoustic emission sensor for active and passive structure monitoring.*



Technical details

- Intuitive operation via a modern, accessible, and easily adaptable user interface
- Professional implementation of customer-specific requirements through a modular parameterization, test procedure, and analysis concept
- Mapping of complex test requirements to any geometries
- Real-time display of volume images during data acquisition

Simulation and modeling

Nowadays simulation techniques are essential for optimizing ultrasonic testing systems and developing new measurement methods. They enable the physical plausibility of a method to be tested and the best possible measurement and probe parameters to be determined even before the first measurement setup is actually realized. This saves time and money in the development and leads to testing systems with clearly improved performance parameters.

Technical details

- Numerical ultrasonic solver (EFIT) developed in-house
- Wave physics simulation
- Consideration of diffraction, interference, mode conversion, multiple scattering, etc.
- Isotropic and anisotropic, homogeneous and heterogeneous materials
- Solids and liquid media
- 2D and 3D models
- Time signals, wavefield snapshots, video animations

Services offered

- Development of customer-specific sensors
- Measurement and characterization of probes
- Development of software for special applications up to complete testing systems conforming to DIN EN 12668
- Development of testing electronics for simple manual testing systems up to automated ultrasonic testing systems
- Development of user-specific simulation tools
- Scientific consulting with simulation-supported feasibility and optimization studies
- Interpretation of results
- Demonstration and training

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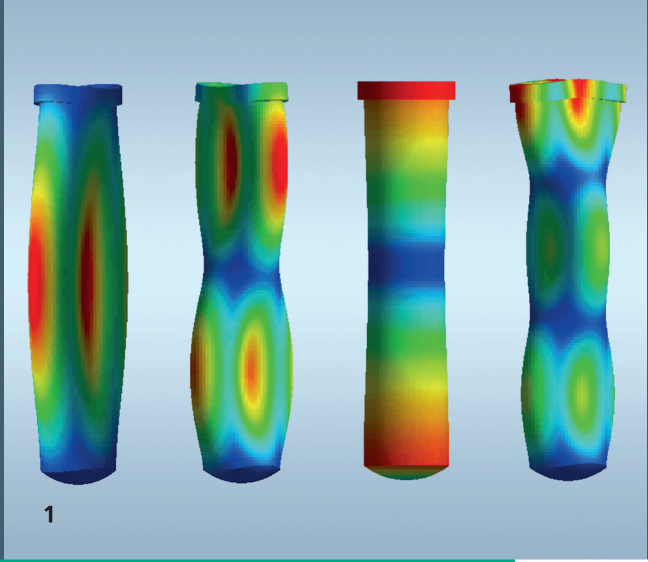
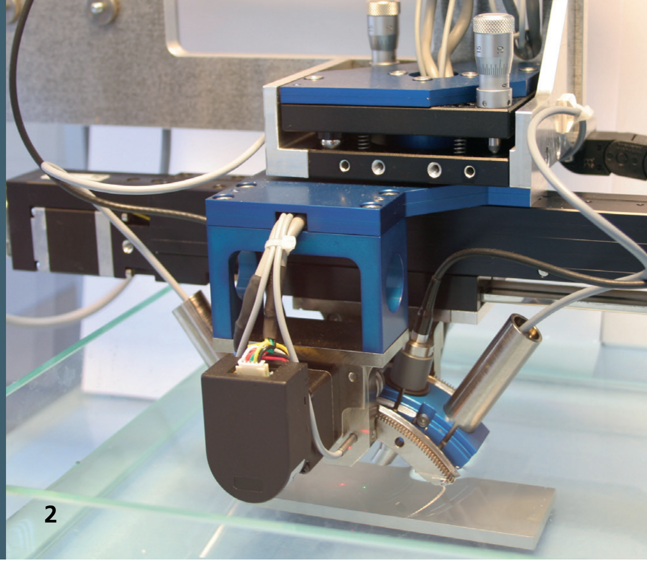
3 *PCUS® pro Multi for automated ultrasonic testing.*
4 *Mobile testing system for wheel set shafts with longitudinal bores using electronics and software from Fraunhofer IKTS (source: Arxes-Tolina).*





SPECIAL ELASTODYNAMIC METHODS

Like ultrasonic methods, acoustic methods utilize elastodynamic interactions in an object to yield information about the condition of the object. This is frequently connected with acoustic signal radiation. Acoustic resonance testing is a well-known and widely applied method for detection of cracks in parts such as ceramic utensils.

Scientists at IKTS supplement this initially purely empirical approach with experimental and theoretical model-based vibration analysis. Special elastodynamic methods cover a wide range of methods from the scalar acoustic waves until several 100 MHz linear and nonlinear bulk elastic waves. Thus, mechanical stresses can be determined from the relationship between the velocity of elastic wave propagation and mechanical stress. Focused very-high-frequency ultrasonics enables volume imaging with microscopic resolution (scanning acoustic microscopy, or “SAM” for short) to be performed on opaque objects.

If the application requires it, the methodology is modified to solve the given problems. One example of this is SAM tomography, which delivers a spatial representation similar to that provided by x-ray CT for tasks that are difficult for ultrasonics. Another recent development is imaging of surface microstructures via grazing elastic waves that are optically scanned.

The available standard equipment does not always permit use of novel methods. When necessary, IKTS scientists can develop suitable equipment and make it available to customers.

Application fields

- Fast whole-part defect analysis
- Determination of surface gradients in mechanical properties and stress states
- Verification of layer adhesion, inhomogeneities, and cracks

Services offered

- Methods development and adaptation for individual test conditions
- Development and validation of adapted measurement systems
- Service provision and consulting

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1 *Simulated vibration behavior of ceramic tubes for battery applications.*
2 *Ultrasonic goniometer HUGO measuring surface property gradients.*

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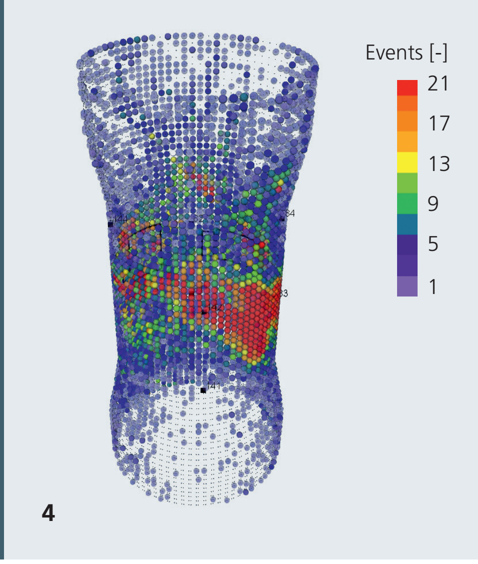

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ACOUSTIC EMISSION ANALYSIS

Fraunhofer IKTS provides acoustic emission analysis for damage detection of structural components during fatigue tests or under operational load by fast and reliable localization of sound emitting regions, e.g., due to crack growth. The position of the damage can be determined by the travel time of ultrasonic waves from damage to the sensors of the network. Furthermore, detailed signal processing allows the evaluation and the classification of the damage. The results from acoustic emission analysis offer detailed information which can be used for the focused application of conventional NDT methods and allows better load control during structural testing.

Acoustic emission testing is well suited for static and dynamic tests on fiber composite parts. These materials produce strong acoustic emissions when fiber breaks and delamination occur. In dynamic fatigue tests, the high level of noise from the surroundings and the acoustic properties of the composite materials might decrease the detectability and therefore lead to challenges. To face them and to ensure a wider applicability of acoustic emission, IKTS offers an acoustic measurement system with high measurement dynamics and sophisticated damage evaluation and localization algorithms. The system also supports the storage and the evaluation of complete waveforms. If used during fatigue testing, the distributions of acoustic emission parameters supply information about the structural state and allow to adjust the load conditions if needed.

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Technical details

- High variability of acoustic emission measurement system due to modular structure of 4-channel sensor nodes
- Adaptation of in-house hardware and software to the given measurement task

Application fields

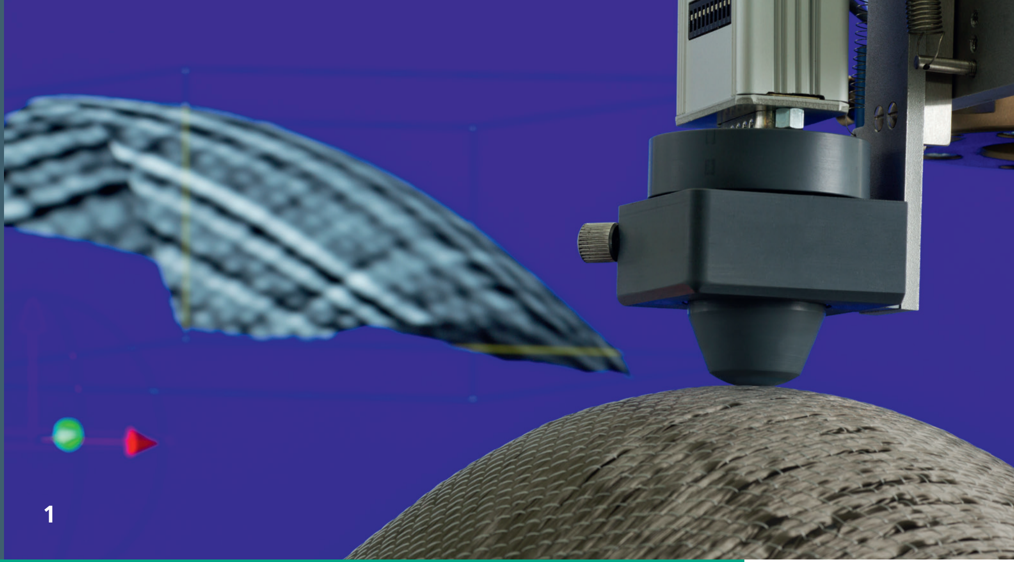
- Development of light-weight structures
- Integrity testing of light-weight structures under specific loading and environmental conditions

Services offered

- Accompanying measurements for static and dynamic structural fatigue tests (from coupons to large structures)
- Supply of measuring equipment
- Specific system and sensor design
- On-site installation of measurement systems
- Support in evaluation of recorded signals
- Employment of high-resolution NDT methods after location of defects and customer-specific development of acoustic measurement systems

3 *Monitoring of structural damage in thermally loaded parts via acoustic emission and high-temperature strain measurement.*

4 *3D acoustic emission location plot for creep damage localization.*



ELECTROMAGNETIC METHODS

HIGH-FREQUENCY EDDY CURRENT METHODS

The eddy current method is an electromagnetic technique for non-destructive testing of metals and non-conductive or weakly conducting materials such as plastics or ceramics. It has become a key technology for quality assurance, especially in the field of light-weight construction – for all areas from the aerospace and automotive industries to energy technology – because of its high speed, operation without a coupling medium, no requirements regarding radiation protection, and ease of integration into industrial manufacturing processes.

The so-called high-frequency eddy current technique and imaging impedance spectroscopy in the frequency range of 100 kHz to 100 MHz used to analyze weakly conducting material classes such as carbon fibers and carbon fiber composites were developed at Fraunhofer IKTS. Methods know-how covers the entire production chain – from simulation and sensors, manipulation, and electronics to device construction. Customer requirements are consistently converted to adapted measurement and testing solutions.

The EddyCus® device plattform from Fraunhofer IKTS meets the growing requirements of the light-weight construction industry and can also cater to the needs for eddy current-based techniques for quality assurance in other areas.

Technical details

- Frequency range: up to 100 MHz
- Special sensors for fiber composite materials
- Eddy current system for individual system integration (integration kit)
- 2D and 2.5D eddy current scanning systems
- Robot-based eddy current systems for freeform parts

Application fields

- Characterization of fiber layers and material properties of carbon fiber composites
- Testing of ceramics and metals
- Monitoring of hardening reactions in epoxy resins

Services offered

- Development and setup of customer-specific testing systems, including sensors, hardware, software, and manipulator technology

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1 *Development of eddy current sensors for special applications, e.g., composite materials.*

2

MICROMAGNETIC BARKHAUSEN NOISE

The micromagnetic Barkhausen noise technique is a surface characterization method that can only be used on ferromagnetic materials. The Barkhausen effect represents the interaction between an induced electromagnetic field and the component microstructure. It is especially useful for detecting stress and fatigue, but it can also be used for detecting residual austenite and cementite. Barkhausen noise is also the only non-destructive method other than x-ray diffraction that can be used to determine internal stresses independently of the microstructure.

Barriers to use of this method in practice can mainly be attributed to the large size and inflexibility of the sensors, the extreme sensitivity of the testing systems to parasitic effects, and the extensive calibration. Fraunhofer IKTS has developed smaller, more compact, and more robust test equipment to overcome these barriers. The technology is now less sensitive to environmental effects. In addition, special sensors allow for wider use and the calibration requirements can be considerably reduced through a complex algorithm.

Technical details

- Application with standard sensors or, alternatively, with multi-axis sensors or current excitation
- Transfer of raw data (integral, maximum, mean value, coercive field strength, etc.)
- Alternative transfer of calibrated materials properties (hardness, stress, retained austenite, cementite, etc.)
- Measurement services as well as conceptual design and set-up of customized test equipment and/or sensors

Application fields

- Outdoor deployment in rugged environmental conditions with laboratory instruments and robust manual test equipment
- Materials characterization during the manufacturing process
- Evaluation of stress state in large-scale industrial plants and buildings

Services offered

- Development of customized sensors and test equipment
- Rental of testing systems
- Training
- Testing services

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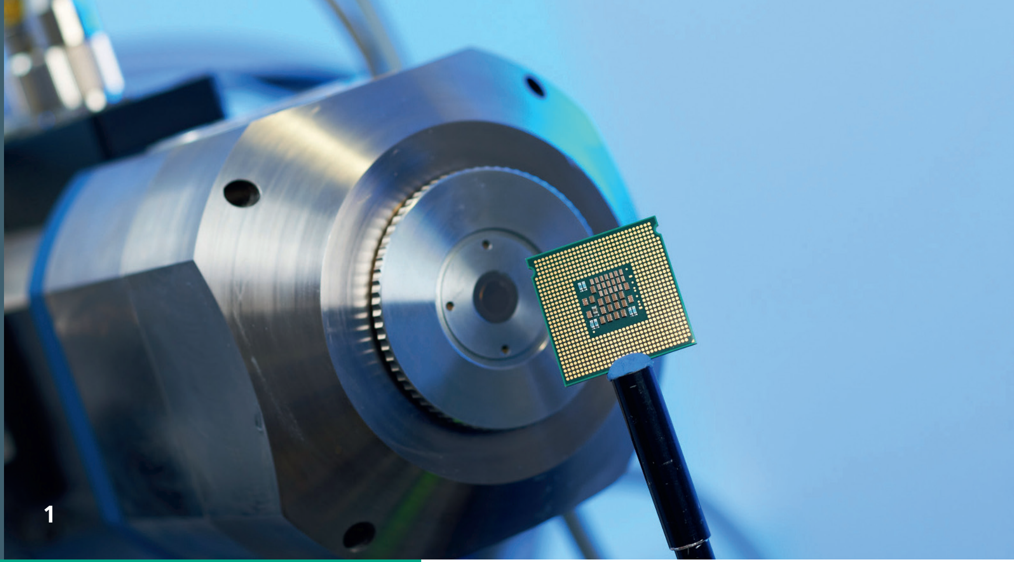
2 *Testing weld seams on frame structures by means of micromagnetic Barkhausen noise.*



MICRO-COMPUTED TOMOGRAPHY

Industrial micro-computed tomography (micro-CT) is an established method of analysis for technical and scientific applications and is increasingly established in the investigation of artistic and cultural goods. It is ideal for visualizing air inclusions, cracks, and other material inhomogeneities in objects of any shape. Micro-CT enables non-destructive three-dimensional examination of objects with a high spatial resolution.

Fraunhofer IKTS has a micro-CT system that can be adapted to customer requirements. This makes it possible to investigate objects ranging from miniature electronic components to large art objects and fossils.

Technical details

- 225 kV microfocus x-ray tube
- 2048 x 2048 pixel area detector
- Spatial resolution: max. 1 µm
- Specimen size: max. 60 cm (greatest extension)
- Specimen weight: max. 6 kg

Application fields

- Materials and product development for electronics industry and medical technology
- Examination of mass-produced parts
- Examination of archaeological finds and art objects

HIGH-RESOLUTION CT LAMINOGRAPHY

High-resolution computed laminography (HRCL) is a new x-ray tomography method that was developed at Fraunhofer IKTS. With it, small regions of especially large-area and planar circuit substrates can be investigated non-destructively at a high resolution. With a modified measurement setup and an optimized reconstruction algorithm, the challenges associated with high-resolution investigation of circuit boards with size restrictions by micro-CT were eliminated. Now, for example, control boards for automotive or power electronics and embedded systems can be analyzed non-destructively without any need for sample preparation.

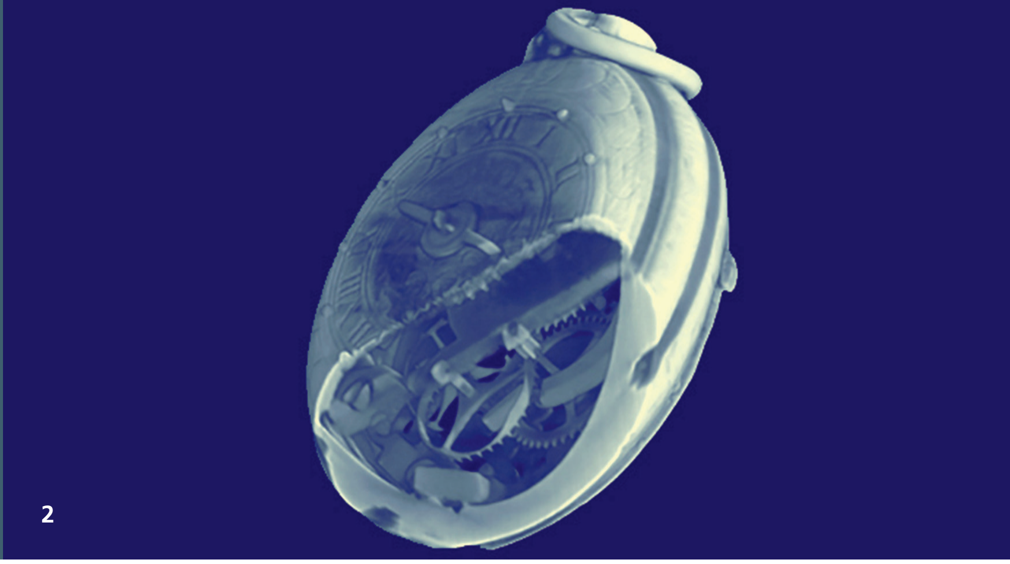
Technical details

- 225 kV microfocus x-ray tube
- 2048 x 2048 pixel area detector
- Spatial resolution: max. 900 nm
- Specimen size: max. 60 cm (greatest extension), larger for examination of subareas
- Sample weight: max. 6 kg

Application fields

- Fast visualization of cracks in bond pads for electronic components on substrates
- Examination of systems embedded in CFRP plates

1 *Examination of an electronic assembly using high-resolution x-ray laminography.*



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X-RAY DIFFRACTION

Fraunhofer IKTS utilizes the x-ray diffraction (XRD) method to determine the compositions of material mixtures. In this method, an incident x-ray beam is diffracted by ordered structures such as crystals or quasi-crystals and the diffraction intensity distribution is measured.

Fraunhofer IKTS also uses XRD to determine internal stresses via the sin2ψ method. Here, the specimen is tilted by a certain angle ψ (psi) to a reflection. Measurements are performed at various points, which at least include the extremes (edges, corners, and middle), to yield the distribution of internal stresses in the specimen. Texturing affects the results obtained by numerous methods. Using the sin2ψ method reliable values are determined, if the layer to be investigated is not textured. For this reason, the pole figures are obtained for at least two different reflections at various points on the test object. The internal stress can then be derived from the determined peak positions.

Application fields

- Determination of compositions of material mixtures and internal stresses within the scope of materials and product development
- Root cause studies for part defects

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X-RAY LINE DETECTOR

X-ray line detectors are usually used to examine continuous streams of products or to avoid undesired scattering when the object size only permits linewise illumination. The L100 line detector developed at Fraunhofer IKTS is made using customer-specific ASICs and thus enables low-cost fabrication and diverse configurations – with no size restrictions. The novel detector also works with direct conversion. This yields higher resolutions and speeds than are obtained with conventional detectors. Thanks to the single-photon counting mode, the x-ray photon energies can also be evaluated. This enables "dual energy" applications, in which differentiation is made between materials in terms of composition.

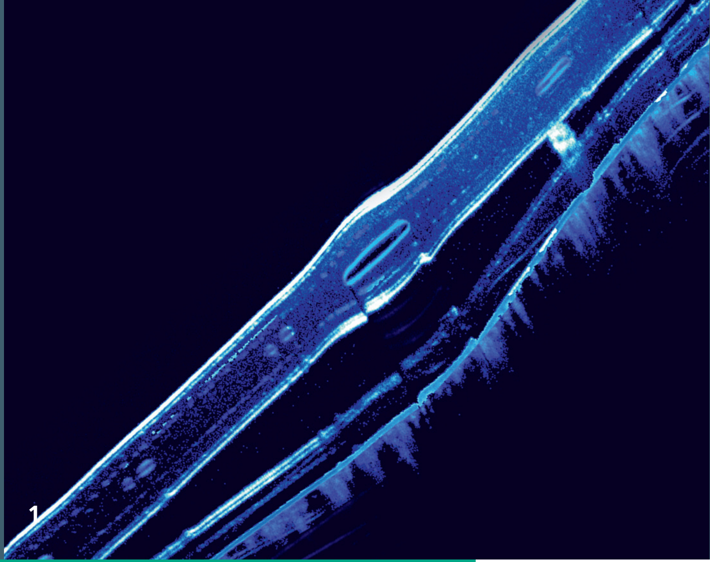
Technical details

- Line length: 102.4 mm
- Resolution: 100 µm
- Energy range: 30–200 keV and 2–40 keV
- Scan speed: up to 50 m/s

Application fields

In-line quality assurance and materials classification for:
- Food and pharmaceutical industries
- Small parts/semi-finished product manufacturing

2 *X-ray CT of a single-handed pocket watch, manufactured around 1600 (exhibit item on display at Staatliche Kunstsammlungen Dresden).*



OPTICAL METHODS

OPTICAL COHERENCE TOMOGRAPHY

At Fraunhofer IKTS, optical coherence tomography (OCT) is used for three-dimensional detection and imaging of structures in various materials such as ceramics, plastics, glasses, glass fiber-reinforced plastics, and biological materials. The noninvasive tomographic imaging method enables visualization of the surface topographies and internal structures in scattering media. For this, the object to be investigated is irradiated with a low-coherence near-infrared light source and the scattered light is processed by a spectroscopic method.

OCT allows testing to be done in real time without direct contact with the specimen. Another advantage of OCT is its high measurement speed, which enables bulk specimens to be investigated in a matter of seconds. These advantages qualify it as an efficient, low-cost method for in-line defect detection (e.g., seal seam inspection) as well as for foreign object detection in bulk materials in various branches of industry. The measurement method can be adapted to diverse applications and optimized for specific requirements.

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Technical details

- 3D imaging method for semi-transparent materials
- Measurement area: 40 x 40 cm
- Resolution: < 10 µm
- High penetration depth: 1–3 mm
- High axial resolution: 0.5–15 µm
- Non-invasive, non-contact measurement method
- No ionizing radiation
- More than 30 cross-sectional images per second

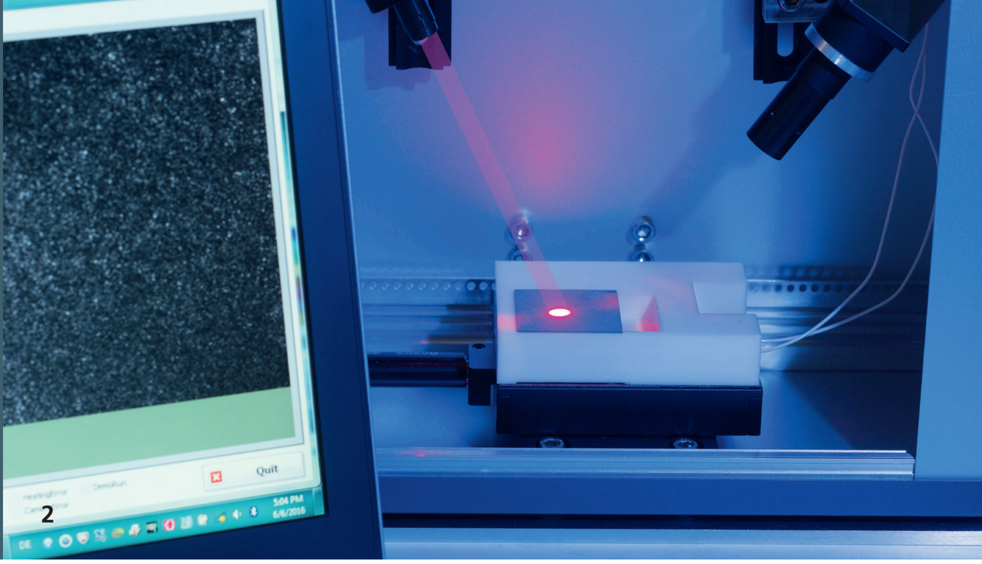
Application fields

Product testing and process monitoring for:
- Plastics and packaging industry
- Ceramics industry
- Electronics industry
- Additive manufacturing methods
- Food industry
- Roll-to-roll processes

Services offered

- Static and dynamic layer thickness measurement
- Three-dimensional structure visualization (surface and internal structure)
- Development of customized testing systems
- Improvement of measurement algorithms and image analysis
- Integration into existing systems

1 *OCT cross-sectional image of a weld seam with air and particle inclusions.*



LASER SPECKLE PHOTOMETRY

Time-resolved laser speckle photometry (LSP) is a new method that was developed at Fraunhofer IKTS to characterize part surfaces. It is based on evaluation of the temporal changes in speckle patterns formed due to mechanical or thermal excitation of the test objects. Excitation can originate from the process itself (e.g., heat generated by welding) or through deliberate input (e.g., of heat or mechanical stresses) during testing.

The non-contact method is characterized by a simple, robust design and low costs compared with those of competing measurement methods. The extremely short measurement times predestine it for in-line use in industrial production and for in-situ measurements within the scope of maintenance and repair work.

Laser speckle photometry is highly sensitive to out-of-plane and in-plane displacements. Compared with other techniques that concentrate on the distortion of the overall speckle patterns or of the fringes, laser speckle photometry measures the spatial and temporal dynamics of the speckles produced by changes in intensity of each pixel in the camera sensor. The interaction between the speckle dynamics and the specimen condition can be described by a correlation function. A customer-specific correlation model based on reference values, process conditions, and material characteristics is used to determine properties such as porosity, stresses, and defects.

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Technical details

- Can be used on all non-reflecting materials
- Test chamber size: no restrictions, homogeneous illumination of areas of up to 100 x 100 mm, larger areas are examined by scanning
- Lateral resolution: 10 µm (metals) to 100 µm (ceramics)
- Measurement speed: 20 measurements/second, 30 images/minute

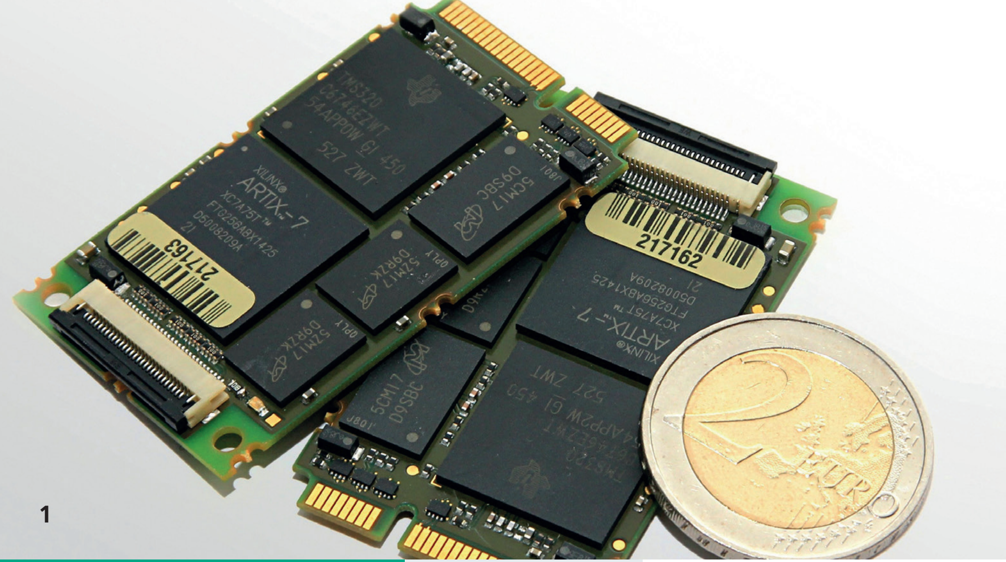
Application fields

- Process monitoring of rapid manufacturing processes, e.g., in-line materials characterization in additive manufacturing processes
- Structure monitoring (stresses and defects)
- In-line monitoring of biotechnological processes

Services offered

- Development of customized LSP-based testing systems
- On-site measurement services
- Measurement of electronic component geometries
- Contract research

2 *Automated in-line testing system based on laser speckle photometry.*



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ADVANCED NDT

In the scope of Industry 4.0-related testing, a huge volume of process data is accumulated from different sources and must be analyzed. Suitable methods can be applied to obtain further information from already determined or additionally measured parameters. Fraunhofer IKTS optimizes established and new NDT methods to show customers how they can use this valuable information.

Pattern recognition

With pattern recognition, test objects can be classified by means of their measurement signals, for example, through actively or passively acquired acoustic signals, images, or other parameters such as temperature values. The main focus of pattern recognition is on giving these data a meaning, for example, "The gear is defect-free" or "The valve has reached 80 % of its lifetime".

Fraunhofer IKTS has a wealth of experience in the field of pattern recognition. Developed algorithms have already been successfully tested and used in numerous applications, e.g., in mechanical engineering, automotive, glass, paper, textile, and watch- and clockmaking industries. In addition to a PC-based solution, an autonomous, modular device for mobile measurements has been developed for connection of various sensors or microphones.

Technical details

- Independent of testing method as well as sensor measurement principle and type
- Combination of different sensor data possible

Application fields

- OK/NOK analysis
- Service life prediction
- Detection of cracks, inclusions, and impact damage
- Wear monitoring
- Condition monitoring of parts, machines, and plants
- Monitoring of production processes

Machine learning

Machine learning, as a subarea of artificial intelligence, is the process of learning from an existing, usually large set of data. This process does not occur by "rote learning", but by recognition of patterns and regularities in known examples, the training data. In the training process, generalized models are built and can be used to classify new, unobserved data.

Fraunhofer IKTS uses special machine learning processes such as deep learning for training of deep neural networks (DNNs), the expectation maximization (EM) algorithm for hidden Markov models (HMMs), or convex optimization for support vector machines (SVMs). Special training software enables easy learning of new models, e.g., for additional series of the same part or comparable parts.

Services offered

- Recognition and training software
- Hardware modules
- Data analysis and evaluation
- Customer-specific development of complete systems

1 *Hardware module for pattern recognition.*

NDT assistance systems

Another focus of Industry 4.0 is on assistance systems intended to support humans in dealing with technology. Fraunhofer IKTS is developing a cognitive user interface for the control of testing systems. This cognitive UI enables a natural dialog between the user and the testing system. Thus, the user does not have to have any prior knowledge or learn any special commands. The interface independently adapts to the tester's way of working and the testing tasks. It also learns the individual user's behavior and can be controlled via various communication options (e.g., voice, touch, and gestures). This can, for instance, help testers operate test equipment when access to the test specimen is impeded or environmental conditions pose a complication (e.g., radioactively contaminated surroundings).

The cognitive user interface developed at Fraunhofer IKTS has the advantage of being autonomous. It requires neither an Internet connection nor a radio network. In addition, the hardware module does not use any resources from the test equipment. For absolute data security, data are only kept on the device and are, by default, not transferred to external servers or clouds from third-party providers. This also makes the interface suitable for confidential and local applications involving sensitive data.

Technical details

- Can be used without radio network or Internet connection
- No transmission of user speech input to third-party servers
- Enables non-contact "hands and eyes free" communications

Application fields

- Maintenance, repair and operation (MRO) in:
  - Large-scale technical infrastructures
  - Aerospace
  - Industrial and plant engineering
- Human-machine interaction
- Control of equipment and plants

Services offered

- Recognition software
- Hardware
- Training software
- Customer-specific development

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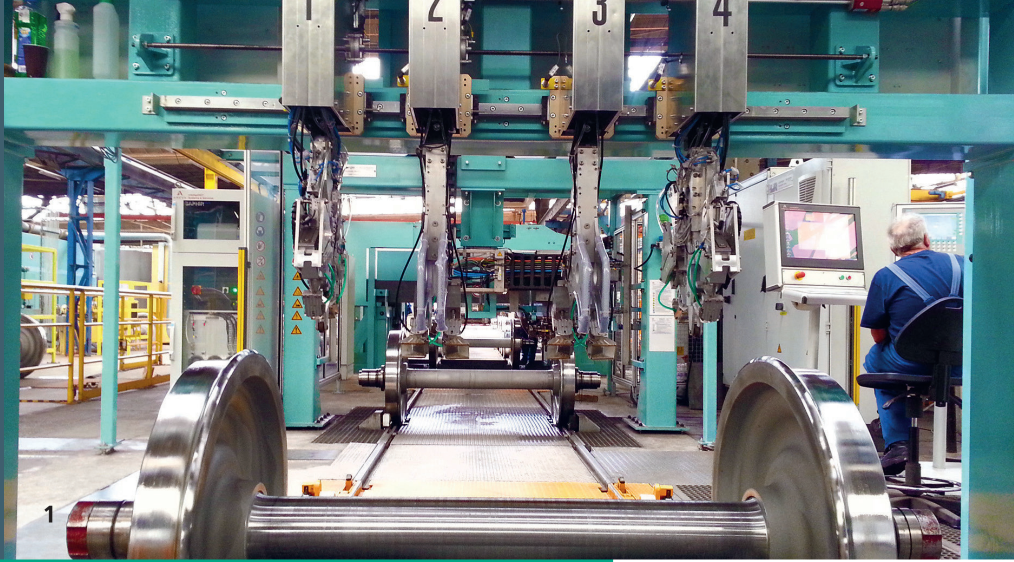
2 *Robot-assisted measurement and AI-based data analysis extend the range of applications for NDT methods.*



1

APPLICATION EXAMPLES

ULTRASONIC BIPLANAR ARRAYS

In ultrasonics, different sensor types based on single-element or array technology are used. Specifically for array technologies, hardware solutions with numerous synchronized channels are required; these solutions become increasingly expensive as the number of channels increases. Linear arrays are usually used in practice, but they are not sufficient in some cases. In such cases, matrix arrays represent an alternative, which, however, is very difficult to implement: an 8x8 matrix array alone requires 64-channel electronics.

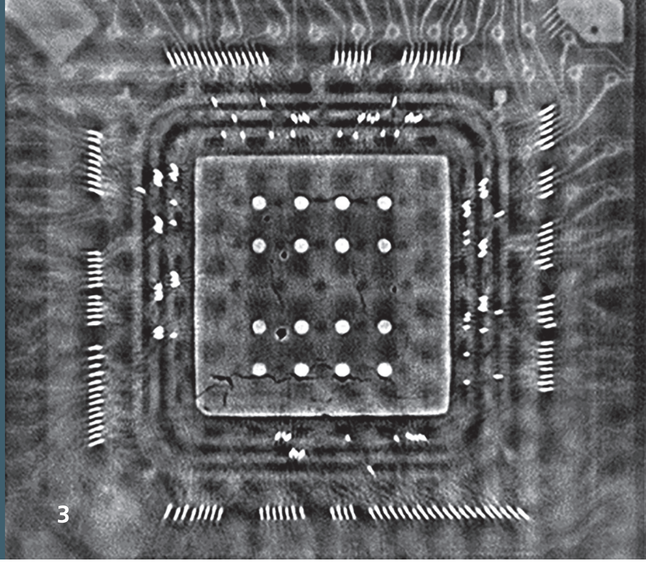
Development of so-called biplanar arrays at Fraunhofer IKTS aims at reproducing the performance of a matrix array using two combined linear arrays aligned orthogonally to each other. Through appropriate switching of the connected electronics, various points in the two-dimensional space under the array can be activated to reproduce the imaging characteristics of a matrix array. The decisive advantage of this design is that it enables an 8x8 array to be reproduced with just 16 channels.

ULTRASONIC SYSTEMS FOR RAIL VEHICLES

Highly loaded train and railroad car components such as axles and wheels need to be inspected regularly. Together with partners from industry, Fraunhofer IKTS is developing the software and electronics for ultrasonic testing systems. The software design enables intuitive operation by inspection personnel as well as mistake-proof inspection. Engineering standards are fully met. The powerful PCUS® *pro* electronics guarantee rapid testing and flexible parameterization due to the high data rates and the parallel FPGA design.

This work has led, for example, to the development of a hollow-shaft testing system for high-speed trains. With seven different single-element probes, the component can be inspected quickly and safely. In addition, a solid-shaft testing system for freight trains was developed using an ultrasonic phased array as a basis. The two systems have been used successfully both by Deutsche Bahn and outside Germany for a few years now.

1 *Phased-array testing system for wheel set solid shafts with electronics and software from Fraunhofer IKTS (source: Arxes-Tolina).*



EDDYCUS® ROBOT

Carbon fiber composites are shaped into complex geometries early on in the production process. For this reason, the EddyCus® Robot for testing of carbon fiber preforms was developed on the basis of the high-frequency eddy current technology with 2D or 2.5D scanning systems for flat test specimens.

The path plan for the robot-based testing system can be generated according to the CAD data. However, in case the data are not available or are subject to strong fluctuations due to the manufacturing process, the EddyCus® Robot provides an alternative system. Here, an unknown part is digitized with a structured-light scanning camera through parametric path planning on the reconstructed surface. The sensor is then guided over the part surface orthogonally to the surface. At the end of the process, the sensor measurement results and the path data are combined to form a C scan.

The EddyCus® Robot is currently being used, for example, at Bayerische Motoren Werke AG for the detection of fiber, layer, and other internal defects.

X-RAY LAMINOGRAPHY SYSTEM

Inclusions in soldering points or small cracks can occur in the production of electronic devices. With conventional x-ray computed tomography, three-dimensional datasets representing the internal structure of a part can be generated. The resolution of the individual voxels strongly depends on the overall size of the test object. Hence, for large flat structures such as PCBs, only a limited resolution can be obtained.

To increase the resolution, Fraunhofer IKTS developed the so-called x-ray laminography method. Through a very specific arrangement of x-ray tube, detector, and object, a high-resolution 3D dataset can be generated especially for small subareas of flat component assemblies. In this way, cracks in bond pads for mounting electronic components on substrates can be quickly visualized in a non-destructive manner without the need for preparation.

The method is typically used in electronics fabrication, but use in quality assurance of embedded systems in CFRP structures is gaining momentum.

2 *EddyCus® robot for inspection of freeform-based components using high-frequency eddy current technology.*
3 *X-ray laminography image of a ball grid array with crack.*

FRAUNHOFER IKTS IN PROFILE

The Fraunhofer Institute for Ceramic Technologies and Systems IKTS conducts applied research on high-performance ceramics. The institute's three sites in Dresden (Saxony) and Hermsdorf (Thuringia) represent Europe's largest R&D institution dedicated to ceramics.

As a research and technology service provider, Fraunhofer IKTS develops modern ceramic high-performance materials, customized industrial manufacturing processes and creates prototype components and systems in complete production lines from laboratory to pilot-plant scale. Furthermore, the institute has expertise in diagnostics and testing of materials and processes. Test procedures in the fields of acoustics, electromagnetics, optics and microscopy contribute substantially to the quality assurance of products and plants.

The institute operates in eight market-oriented business divisions to demonstrate and qualify ceramic technologies and components as well as non-destructive test methods for new industries, product concepts and markets within and beyond the established fields of application. Industries addressed include ceramic materials and processes, mechanical and automotive engineering, electronics and microsystems, energy, environmental and process engineering, bio- and medical technology, optics as well as materials and process analysis.

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Industrial Solutions
Non-Destructive Testing

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