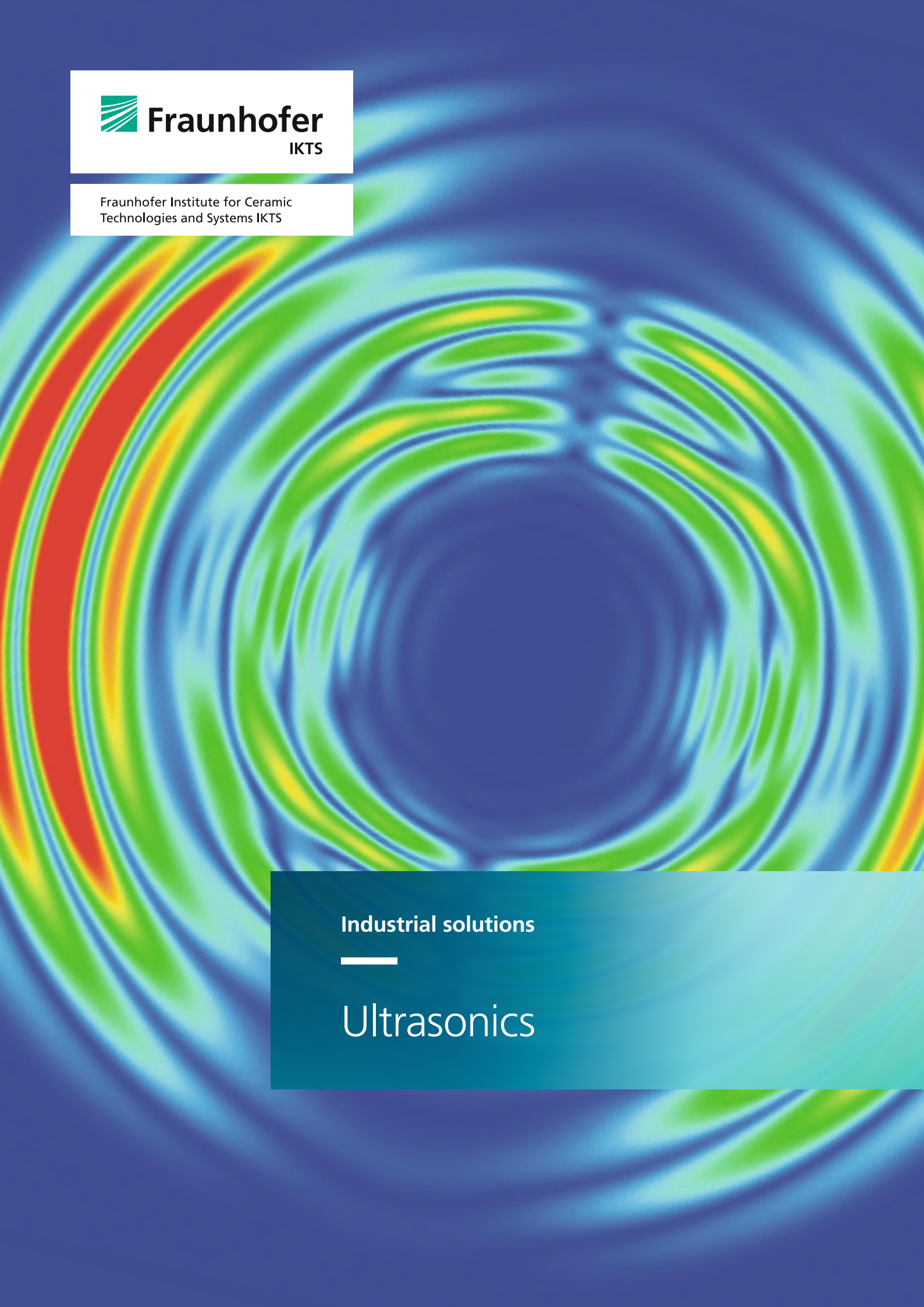


Fraunhofer IKTS

Fraunhofer Institute for Ceramic Technologies and Systems IKTS

Industrial solutions

Ultrasonics

Table of contents

Cover image: Wave field of a PZT fiber transducer.

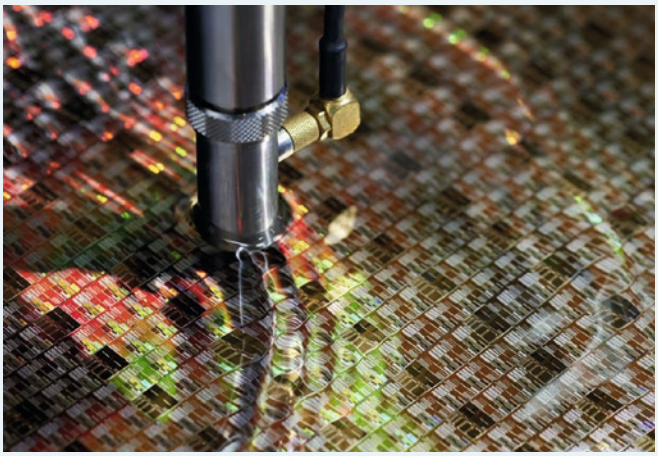
“One Stop Shop” for ultrasonic technology

Ultrasonic technology is one of the most common non-destructive testing (NDT) methods used in industry. The Fraunhofer Institute for Ceramic Technologies and Systems IKTS combines long years of experience in materials testing with unique know-how in the field of ultrasonic technologies. As an NDT specialist, the institute is therefore able to develop new and more efficient ultrasonic testing methods. IKTS oversees the development of client-specific ultrasonic testing systems across the complete value chain, from simulation and modeling down to system integration, including the development of probes, sensors and high-performance testing electronics.

Fraunhofer IKTS has been researching ultrasonic testing since the 1960s, when it was still part of the Central Institute for Nuclear Research in Dresden-Rossendorf. Today, the largest ceramics research institution in Europe creates smart solutions for non-destructive materials testing – from piezoelectric ceramics to certified ultrasonic testing systems.

Sensors are at the heart of any testing system. Fraunhofer IKTS supplies its own developed sensors for special applications. They can be adapted optimally to fit various geometries, materials and acoustic parameters. Client-specific testing systems are equipped with modular and very powerful electronics (PCUS® *pro* device family) as well as flexible software (PCUS® *pro* Lab).

IKTS strives constantly to optimize and develop further testing systems and test procedures. This is done with simulation technologies, which are also used to seek out new approaches to measuring. Scientific consulting in basic aspects of non-destructive testing with ultrasonic technology, and the implementation and supervision of entire R&E projects, complete our portfolio.



A wafer being scanned by an ultrasonic probe.

Ultrasonic methods and technologies for NDT, materials diagnostics and materials characterization

- Development of methods
- Probes and sensors
- Electronics
- Software
- Simulation and modeling
- Accredited NDT for ultrasonic testing
- Ultrasonic testing systems

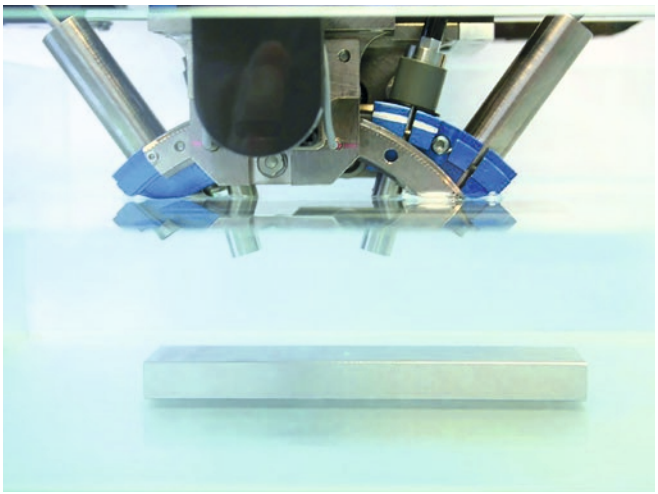
Development of methods

New manufacturing processes, ever more complex components and increased expectations of quality mean that companies are faced with questions that conventional approaches to ultrasonic technology cannot solve. The NDT specialists at Fraunhofer IKTS develop new and effective testing methods for industrial ultrasonic applications "out of the box". These applications can be completed with customized measuring and analysis technology as required.

Characterization of boundary layers

In order to improve material properties, such as vibration resistance, stiffness, resilience and fatigue strength, the boundaries of components under heavy strain, such as camshafts, gears, bending and pressing tools or engine components, are often modified with regard to their mechanic and thermal parameters. This can be achieved by shot blasting metals in order to modify their microstructure (strain hardening) or to introduce surface compression stress. Surface hardening is another option. However, these modifications frequently result in unwanted side effects, such as surface degradation from micro cracks.

In any case, the non-destructive testing of a material condition will always be of interest. V waves help to obtain the desired information. These ultrasonic waves are brought onto the surface of the component and penetrate it to varying levels of depth, depending on their frequency.



HUGO III system by Fraunhofer IKTS for the swift and non-destructive characterization of hardened and shot-blasted metals.

The frequency-dependent sonic velocity (dispersion) provides information on the depth gradient of the examined properties. The acoustoelastic effect – the interdependency of the velocity of propagation and the elastic stresses – makes it possible to determine an internal stress (depth) gradient. The laser-optical determination of the Rayleigh wave dispersion has become a well-established and very accurate method for the non-destructive characterization of boundary layers. However, it is a highly complex and mechanically not very robust process.

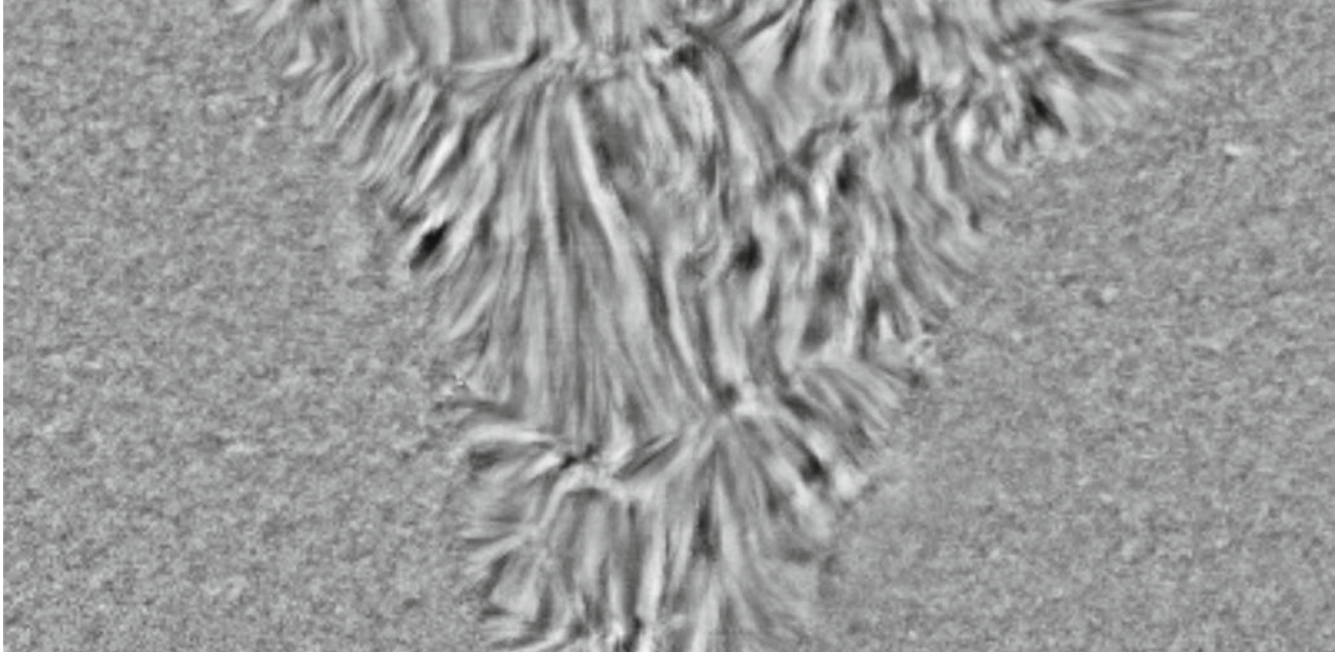
Therefore, Fraunhofer IKTS was looking for an alternative for the characterization of internal stress in shot-blasted metals. Using the "High Resolution Ultrasound Goniometer" (HUGO), which was developed at the institute, the spectrum of the signal, reflected through immersion technology, is visualized through the angle, which allows generating a dispersion curve.

This approach enabled the researchers of Fraunhofer IKTS, in several projects for clients, to characterize the internal stress condition of hardened and shot-blasted metals quickly and without destroying the materials. Furthermore, the testing device can be used to determine layer thickness and surface degradation.

Representation of volume images

High-frequency ultrasonic immersion technology, also called ultrasonic microscopy or scanning acoustic microscopy (SAM), makes it possible to represent volume images. This method is ideal for objects with small defects (scatterers), but rather imprecise when it comes to detecting sloping, planar inhomogeneities, such as cracks.

The newly developed measuring technique and analysis software for ultrasonic microscopy by Fraunhofer IKTS solves this problem. SAM tomography does a lot more for objects with an even coupling area than conventional ultrasonic microscopy, since it can correctly detect and represent sloped planar defects as well.



Grain structure of an austenitic weld seam, visualized through GIUM (Grazing Incidence Ultrasound Microscopy).

Measuring ultrasonic wave propagation

Optimizing ultrasonic testing methods requires extensive knowledge about how ultrasonic waves propagate. Numerical simulation, which is used as a tool for this purpose, often fails to offer benefits if the tasks are more complex, for instance if input parameters are missing or imprecise. In such cases, experimental methods are indispensable in order to information.

The researchers of IKTS can look back on many years of experience in measuring ultrasonic wave fields using various methods. The laser vibrometric measurement of ultrasonic wave propagation on surfaces or cross-sections has emerged as a particularly suitable approach. This method is completely free from retroactive effects and delivers snapshots and videos of the wave propagation. It is particularly suited to fiber reinforced materials or materials that are elastically highly anisotropic, such as austenitic weld seams. Furthermore, it is possible to gain relevant insight into ultrasonic wave propagation even for defect-based interactions.

Determination of microstructures

An ultrasonic wave propagating along a surface does not just carry information on the varying elastic macroscopic properties. It also contains information on the microstructure of the examined object. The researchers of Fraunhofer IKTS have managed to make the microstructure visible by performing laser vibrometric measurements of grazing ultrasonic waves.

This new type of elastodynamic near-field microscopy, also called “grazing incidence ultrasound microscopy” (GIUM), represents an alternative to metallographic methods for grain structure analyses; it also does away with etching. Also, in contrast to electron backscatter diffraction (EBSD), GIUM does without a vacuum and allows for much larger samples.

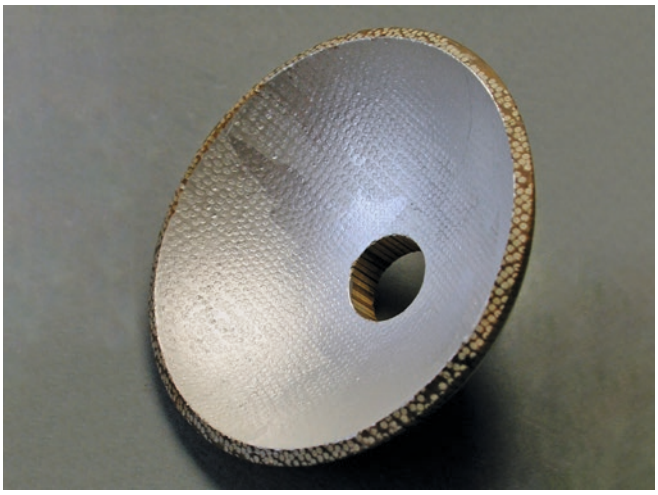
Service portfolio

Fraunhofer IKTS provides innovative solutions for industrial tasks using ultrasonic methods. Furthermore, other NDT methods are available; they pass through all or some of the following steps, depending on the problem to be solved:

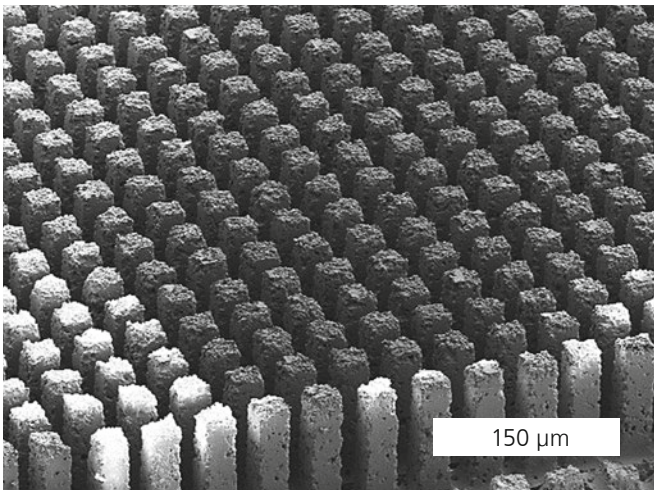
- Analysis of the problem
- Search for known solutions or approaches
- Modelling of the facts and situation
- Experimental investigation
- Demonstration of feasibility
- Development/adaptation of sensors and/or electronics
- Development of software
- Measurements as a service or supply of a testing system

Ultrasonic transducers

Ultrasonic transducers are the most important component of ultrasonic probes. Using its material and manufacturing know-how, Fraunhofer IKTS provides unique solutions for specific transducers as well as innovative testing applications.



Focusing ultrasonic transducer based on a piezo fiber composite.



Sawed piezoceramic for the production of 1-3-piezocomposites.

Piezo fiber composites

The combination of piezoceramic elements and polymers enables a wide range of high-performance ultrasonic transducers. For efficient production, both the piezoceramic components used and the piezoelectric composites derived from them are tailored to individual applications.

At Fraunhofer IKTS, piezoceramic fibers are manufactured using a spinning process. This provides a powerful technology for the production of fibrous piezoceramic components, which can be integrated into so-called 1-3-piezocomposites in regular or arbitrary distribution. The ultrasonic transducers can thus be adapted to the specific requirements:

- High frequency/low frequency
- Focused/non-focused
- Single element/segmented

Resonance frequency	40 kHz to 8 MHz
Coupling coefficient	0.60
Acoustic impedance	15 to 25 MRayl
Fiber diameter	100 to 800 µm
Max. transducer dimension	60 x 60 mm

Dice-and-fill composites

1-3-piezo composites are mainly manufactured using dice-and-fill technology. Vertical cuts are introduced into a sintered and polarized piezoceramic block. The resulting grooves are filled with a polymer and the bottom body and excess polymer are removed by grinding. The piezoceramic rods have a rectangular cross-section. Compared with standard all-ceramics, 1-3-piezocomposites offer the following advantages:

- Lower acoustic impedance Z_a
- Higher coupling coefficient k_t
- Higher bandwidth B
- Lower mechanical quality factor Q_m

The piezoceramic material is selected according to the requirements. For highly sensitive ultrasonic transducers, monocrystalline materials such as PMN-PT are particularly suitable.

Resonance frequency	1 to 15 MHz
Coupling coefficient	0.68 (ceramic), 0.75 (single crystal)
Acoustic impedance	18 to 22 MRayl
Min. element size	50 µm
Min. gap	20 µm
Max. transducer dimension	60 x 60 mm

Soft-mold composites

The production of high-frequency ultrasonic transducers for frequency ranges greater than 10 MHz is very challenging due to the possible groove width and brittleness of the piezoceramic carrier material. With the soft-mold process, Fraunhofer IKTS has developed a technology with which even smaller distance sizes and a free design of the piezoceramic rods can now be realized.

In the soft-mold process, Fraunhofer IKTS uses original molds that are structured using microsystem techniques, such as reactive ion etching of silicon wafers. Polymer molds are taken from these and then filled with a ceramic slurry. After drying, demolding and sintering, fine-scale piezoceramic arrays are produced, which can be filled with a polymer and sanded to the desired thickness.

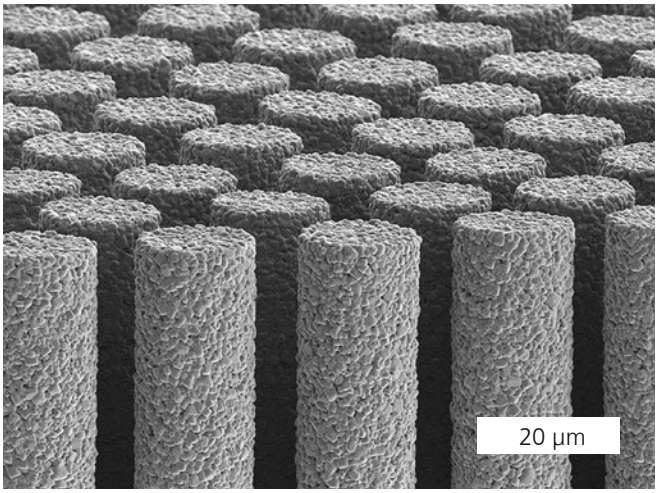
Resonance frequency	5 to 40 MHz
Coupling coefficient	0.60
Acoustic impedance	10 to 20 MRayl
Min. element size	15 µm
Min. gap	5 µm
Max. transducer dimension	10 x 10 mm

Screen-printed ultrasonic transducers

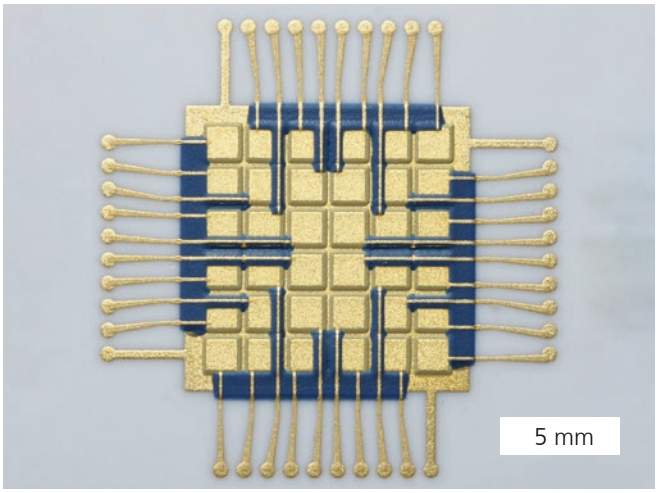
Fraunhofer IKTS supplies special ultrasonic transducers manufactured by screen printing. Structured PZT thick layers with a typical thickness of 30 to 150 µm can be easily applied to common electronic substrates such as Al_2O_3, LTCC (low temperature cofired ceramics), silicon and selected steel grades. Compact devices with piezoelectric function and electronics are manufactured in series at the wafer level. These meet all requirements regarding miniaturization and integration. By structuring piezoceramic thick film and electrode arrays, it is possible to design ultrasonic transducers as phased arrays.

Screen printing technology can also be used on cylindrical substrates.

Resonance frequency	5 to 35 MHz
Coupling coefficient	-
Acoustic impedance	-
Min. element size	70 µm
Min. gap	50 µm
Max. transducer dimension	100 x 100 mm



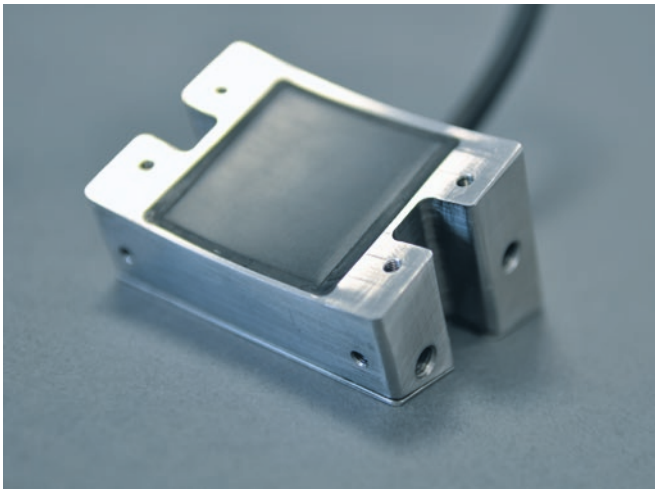
Sintered piezoceramic rods for the production of 1-3 piezocomposites.



2D ultrasonic transducer on Al_2O_3 substrate.

Ultrasonic probes and sensors

Ultrasonic probes are used in many industries for non-destructive testing. They enable precise determination of the location of faults and thus a reliable quality and reliability assessment. IKTS offers a wide range of probes with different frequencies, configurations, connections and cable types.



Mechanically focusing phased-array probe.

Focused phased-array probes

Fraunhofer IKTS manufactures special probes for ultrasonic applications on curved components, pipes and holes. The curved phased-array probe focuses the sound field geometrically, improving the sound transmission into the test object.

Transient oscillator probes

The measurement with a transient oscillator probe, combined with the analysis of the running time between two subsequent back echoes, enables great precision without systematic errors. Fraunhofer IKTS supplies transient oscillator probes for immersion technology, for instance with a water tightness of up to 2 m water column and up to 9 m cable length.

Highly sensitive phased-array probes

For ultrasonic applications at spot welds in strongly anisotropic materials, especially in the automotive industry, Fraunhofer IKTS develops highly sensitive PMN-phased-array probes. Sensitivity is up to 10 dB higher than in probes based on PZT-based composites. In addition, relative bandwidth improves by approximately 20 percent.

Cylindric probes

For ducts in heat exchangers or smaller tubes, IKTS offers special probes manufactured through the rotary printing of thick-film piezoceramic polymer composite pastes onto cylindrical carrier materials. These can be designed as arrays or as line-focused probes. This opens up new potential for the ultrasonic testing of small inner diameters (10 to 30 mm).

Probes	Focused phased-array probes	Transient oscillator probes
Number of elements	16 to 64	1
Sensor material	Composite	Composite
Connection	Hypertronics or Olympus	LEMO or as per client's request
Cable	Coaxial cable	Coaxial cable
Operating frequency	2 to 15 MHz	2 to 15 MHz
Element diameter	Line arrays as per client's request	3 to 50 mm
Max. temperature	40 °C	40 °C
Housing	Stainless steel	Stainless steel
Membrane	-	-
Adaptation medium	As per client's request	As per client's request

Acoustic emission probe.

High-temperature probes.

High-frequency probes

Based on an aluminum nitride thin-film oscillator, Fraunhofer IKTS manufactures probes using a frequency of 100 to 250 MHz. These high-frequency probes are used for ultrasonic microscopy as a focusing or non-focusing version.

Acoustic emission probes

Active and passive structural monitoring of e. g. steel tubes, steam lines, large tank bottoms or bridge structures is realized using acoustic emission probes for the typical frequency range of 100 to 700 kHz, depending on the client's wishes and the required temperature stability.

High-temperature probes

Fraunhofer IKTS supplies suitable specialist probes for measuring construction components, liquid media and test specimens from steel, nonferrous metals, aluminum with alloys, plastics, ceramics and glass. The probes can be used for the most varied applications in temperatures of up to 200 °C. They are designed and manufactured for testing in surface-mount or immersion technology.

Probes	Highly sensitive phased-array probes	Cylindric probes	High-frequency probes	Acoustic emission probes	High-temperature probes
Number of elements	16	16	1	1	1
Sensor material	Composite (monocrystal)	PZT thick film	AIN thin film	Piezoceramic polymer composite	Piezoceramic polymer composite
Connection	Hypertronics or as per client's request	Hypertronics or as per client's request	UHF, Microdot	LEMO	LEMO
Cable	Coaxial cable	Coaxial cable	-	Teflon coaxial cable	Teflon coaxial cable
Operating frequency	2 to 10 MHz	10 MHz	100 to 250 MHz	100 to 600 kHz	1 to 10 MHz
Element diameter	Line arrays as per client's request	Linie arrays	2 to 5 mm	3 mm	3 to 12 mm
Max. temperature	40 °C	60 °C	60 °C	150 °C	200 °C
Housing	Stainless steel	Stainless steel	Stainless steel	Stainless steel	Stainless steel
Membrane	-	-	-	Steel membrane	Ceramic tip
Adaptation medium	As per client's request	As per client's request	Quartz	-	-

Electronics

Powerful modular electronics and software make it possible to get the maximum performance out of a sensor. With its PCUS® *pro* device family, Fraunhofer IKTS offers ultrasonic electronics that are suited for use in manual ultrasonic testing, as well as automated ultrasonic testing systems.

All PCUS® *pro* devices are compact and energy-efficient and comply with the respective relevant parts of the ultrasonic standard ISO 22232-1 or ISO 18563-1. The modular structure allows for adaptation of the equipment to suit the testing task at hand, all with only a moderate development effort. Connecting any number of PCUS® *pro* devices to a PC, laptop or tablet is easy with USB. The compact design allows for sensor-adjacent applications.

PCUS® *pro* Single

PCUS® *pro* Single is an ultrasonic front end for manual or automated tests with a conventional probe (single or double element). The cost-effective solution turns any PC or laptop running a Windows operating system into a full-featured ultrasonic testing system.

Product details

- Compact electronics for manual and mechanized ultrasonic testing with a single channel
- Energy supply and data transfer via USB 2.0
- Optional external encoder interface for four axes
- For IE/SE probes within the frequency range of 500 kHz to 30 MHz
- Low-noise A/D conversion providing 14-bit resolution and scanning rates of up to 100 MS/s

PCUS® *pro* Multi

PCUS® *pro* Multi is a 16-channel ultrasonic front end for fully automated ultrasonic testing with several probes. Thanks to the USB 2.0 interface and the ability to compress the measured data, very fast measurements become possible in the industrial context, e. g. in sheet metal testing or hollow shaft testing for rail vehicles. With its modular structure, PCUS® *pro* Multi can be adapted to almost any testing task.

Product details

- Compact ultrasonic electronic unit for automated testing with up to 16 probes
- For IE/SE probes within the frequency range of 500 kHz to 30 MHz
- Low-noise A/D conversion providing 14-bit resolution and scanning rates of up to 80 MS/s
- Up to 300 V transmission voltage
- Integrated encoder interface for four axes

PCUS® *pro* Array

PCUS® *pro* Array enables fast automated phased-array ultrasonic testing in industrial contexts, e.g. in railway construction or automotive engineering. The testing system is ideally suited for weld seams, adhesive joints or other test areas that are difficult to access. Thanks to the large bandwidth and the high scanning rate, CFRP and GFRP structures can be tested as well.

Product details

- Several phased-array probes at one electronic unit possible
- Compact ultrasonic electronic unit for automated testing with phased-array probes, up to 64 elements (16:64)
- 64 parallel transmitters for flexible beam forming
- For phased-array probes within the frequency range of 500 kHz to 30 MHz
- Conventional phased array, full matrix capture, total focusing method and SAFT are possible
- Integrated encoder interface for four axes

PCUS® *pro* Array II

PCUS® *pro* Array II is an enhancement of the PCUS® *pro* Array electronic unit for particularly fast phased-array testing with many elements. The fully parallel design and the USB 3.0 SuperSpeed interface enable the highest cycle rates. The bipolar original pulse enables a signal-to-noise ratio that is even better.

Product details

- Compact electronic unit for automated testing with phased-array probes, up to 128 elements (128:128)
- Several phased-array probes at one electronic unit possible
- For phased-array probes within the frequency range of 500 kHz to 30 MHz
- Low-noise A/D conversion providing 14-bit resolution and scanning rates of up to 125 MS/s
- Bipolar original pulse for the best signal-to-noise ratio
- Conventional phased array, full matrix capture, total focusing method and SAFT are possible
- Integrated encoder interface for four axes
- Self-tests and self-diagnosis for highest reliability

PCUS® *pro* HF

PCUS® *pro* HF closes the gap between traditional ultrasonic testing and acoustic microscopy. The inline-capable front end enables automated testing of thin sheets, composites, complex compounds or electronic components. Thanks to its extremely compact design and very low power consumption, the device can be mounted directly near the probe.

Product details

- Compact high-frequency ultrasonic front end for tests in the frequency range from 5 to 150 MHz
- 1 channel IE or SE
- 500 MS/s low-noise analog-to-digital conversion
- Adjustable rectangular transmitter
- USB 3.0 with up to 320 MB/s data transfer rate
- Integrated encoder interface for four axes

PCUS® *pro* LF

PCUS® *pro* LF can be used for air-coupled ultrasonic testing and evaluation of special materials such as wood, CFRP or concrete with low-frequency probes. The front end thus also enables automated testing of glued CFRP or metal components with robots or scanners.

Product details

- Compact low-frequency ultrasonic front end for tests in the frequency range from 50 kHz to 10 MHz
- 1 channel IE or SE
- 80 MS/s low-noise analog-to-digital conversion
- Bi-polar rectangular transmitter with burst function
- USB 3.0 with up to 320 MB/s data transfer rate
- Integrated encoder interface for four axes

PCUS® pro Multi.

Software

Software is an elementary part of testing systems in the industrial environment. Users define the features they need and expect an intuitive user interface. Software has to be innovative and available at short notice, all without giving up on flexibility for future modifications and extensions.

In PCUS® *pro* Lab, Fraunhofer IKTS has developed a software suite that makes it easy to perform and visualize automated and semi-automated ultrasonic tests with single elements or arrays, suited for the PCUS® *pro* device family.

In this context, the standards of the PCUS® *pro* Lab software suite are always defined by the expectations of its users. At the center of attention are topics such as modern manufacturing (Industry 4.0) and the ever-growing demands regarding integration, efficiency and cross-linking between components used within the industrial context of ultrasonic testing.

PCUS® *pro* Lab

PCUS® *pro* Lab is a modular software suite for non-destructive testing. Automated, semi-automated and manual solutions are quickly adapted to the testing task at hand in a flexible way.

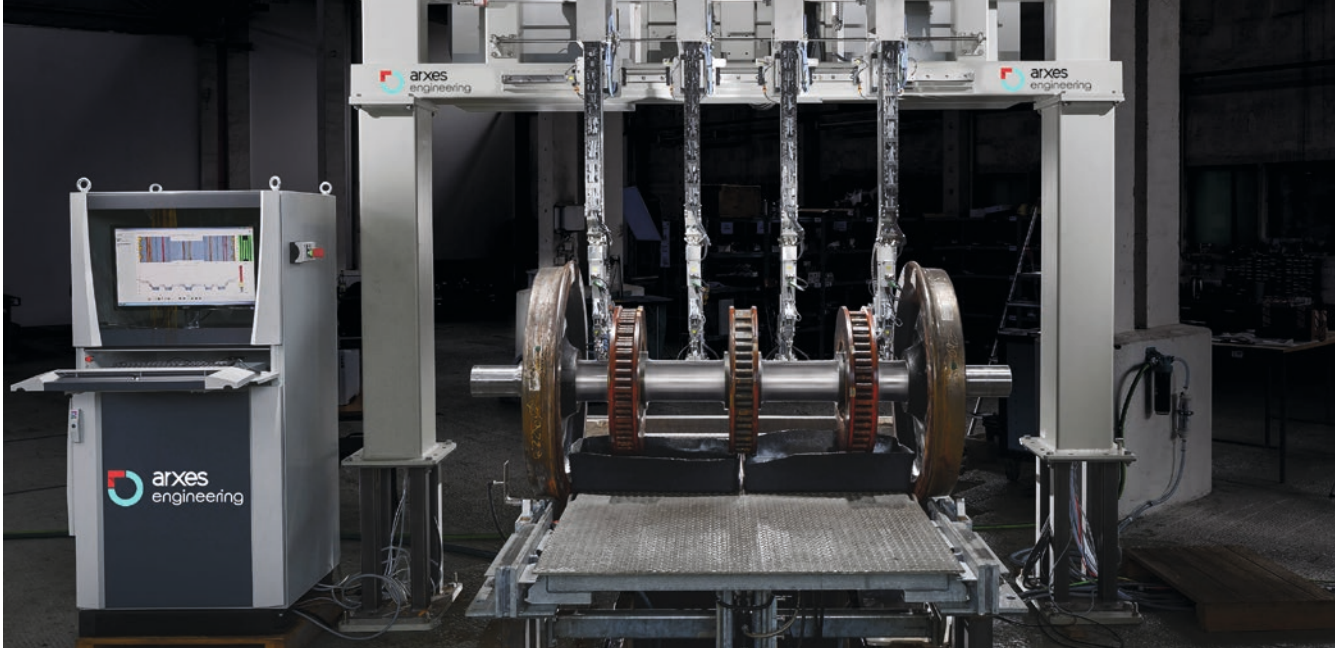
Usability and user acceptance are the focus of software development when implementing complex test scenarios in accordance with the standards. This goal is supported by defined interfaces and modules to integrate existing automation concepts of the client. PCUS® *pro* Lab thus guarantees the best possible integration with existing industrial production lines and technologies.

The software supports the creation of parameterizations for actuator and sensor control, visualization and analysis. The data is organized and managed within the revision system, which is flexible and adaptable.

The methods of agile software development guarantee a traceable development process in close collaboration with the client. Wishes and requirements are implemented fast and safely, in order to guarantee a high degree of quality and safety. The user interfaces and process controls can be adapted individually to best fit the process.

Features

- 64-bit application
- Runs on all typical Windows systems
- Touch enabled
- Intuitive use thanks to a modern, accessible and easily adaptable user interface
- Industry 4.0 – fully cross-linked integration into existing manufacturing concepts
- Easy transition from the lab to the industry environment through uniform software for all application areas
- Combination of any devices and methods in one test for the highest possible efficiency
- Representation of typical volume images (B, C, D, S, L, TD etc.) offers deep configuration
- Professional implementation of client-specific requirements through a modular concept in the area of parameterization, test sequence and analysis (e. g. user interface fully adapted to the testing process)
- Representation of complex testing requirements at any geometry
- Real-time representation of the volume images during data retrieval
- Support of commissioning through flexible calibrating modes
- Storage of measured data as raw data with optional loss-free compression or as reduced image data
- Integrated logging and archiving of tests
- Fast integration of external modules for the control of the most varied actuators and sensors
- Retrieval and management of very large test data quantities
- Retroactive adaptation of parameters for all values independent of recording (visualization, apertures etc.)
- Individual error logs and reporting as required by the client
- Numerous options for easy rights management via Windows User Access Control
- Uniform software development kit (SDK) for the whole PCUS® *pro* device family for the integration of PCUS® *pro* Hardware with the client's own software



Array testing system for wheel-set solid shafts with ultrasonic electronics and software from Fraunhofer IKTS (Source: arxes engineering GmbH).

Modular design

- Required functions can be combined freely
- Integration of the client's own modules into the user interface
- Features can be associated easily with user profiles
- Comprehensive master data base for sensors, materials, test methods, layouts etc.
- Management system for the comfortable management of test results and data

Parameterization/adjustment

- Modular, library-oriented parameterization for quick, easy extension, modification and further use
- Up to four freely configurable coordinate axes
- Simulation of all coordinate axes allowing to adjust the actuators with the test sequence
- Adjustment of all probe and material parameters
- Unlimited number of focal laws
- Comprehensive standard libraries
- xml export for client-specific layout
- User-friendly plausibility check of data input for parameterization and automatic tool tips to support the user

Testing

- Quick integration into automated production processes
- Any given combination and number of devices is possible
- USB 3.0 with up to 300 MB/s transfer speed
- Tests triggered by coordinates, time or externally
- Live representation of the volume images during testing

Analysis

- Any projection plane of the test specimen can be selected
- Display of several test groups simultaneously
- Parallel display of different tests and files
- Automatic or manual detection and application of transfer correction
- Metric or imperial units of measurement
- Zoom function in all planes
- Intelligent algorithms, such as hiding fault messages, searching maximum values, determining surface areas or dynamic cutting of test data along the object geometry
- Individually adaptable layouts and representation of measured values
- Setting offline apertures retroactively
- Versatile reporting and logging
- Export of error reports to xml files to suit the client's own log layout
- Numerous measuring tools in all volume images
- Comprehensive and easy-to-adapt color charts
- Freely adaptable offline visualization (B, C, D, S, L, TD etc.)
- Export of raw data into common text-based formats
- Unlimited amount of test data within the scope of the available storage capacity
- Comfortable use of basis parameterization across systems and users

Simulation and modeling

When it comes to optimizing ultrasonic testing systems and developing new approaches to measuring in today's world, simulation technologies are essential. They allow to check the method for physical plausibility and determine the best possible measuring and probe parameters even before the first measurement setup has been built. This saves time and money in development and results in testing systems with significantly improved performance parameters.

At Fraunhofer IKTS, simulation-supported modeling is carried out with commercially available numerical procedures as well as with procedures developed by ourselves specifically for the ultrasonic field.

Our own developments are based on the Elastodynamic Finite Integration Technology (EFIT) and allow for a complete simulation of testing systems with regard to wave physics, taking into account diffraction, interference, mode conversions and multiple scattering.

Isotropic and anisotropic as well as homogeneous and heterogeneous materials can all be modeled. Coupled models combined of solids and fluid media can also be realized.

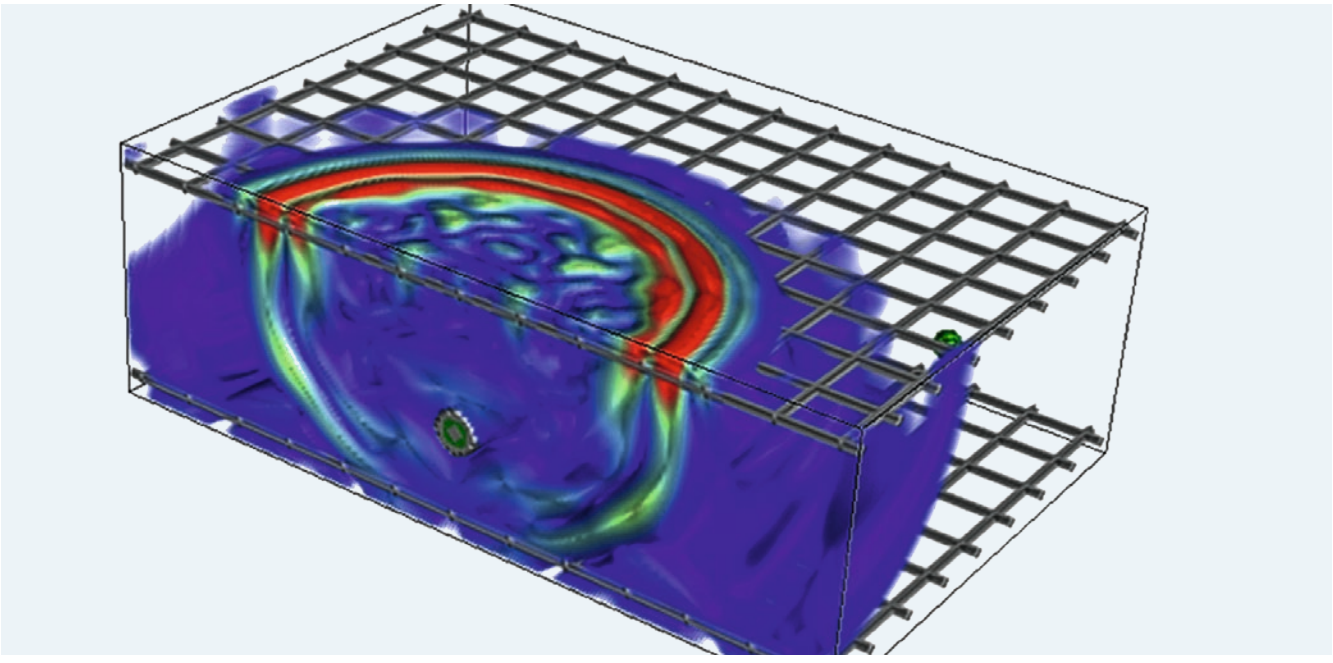
The simulation results are made available in the form of time signals, B and C images, sector images, wave front snapshots or video animation.

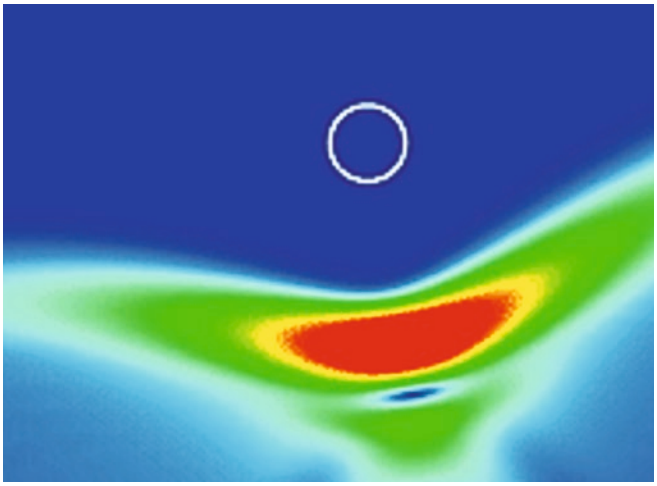
Fields of application

Simulation-supported methods are suitable for various fields of application. Fraunhofer IKTS has been using simulation-supported tools successfully for many years in numerous ultrasonic and acoustic projects from industrial and research fields:

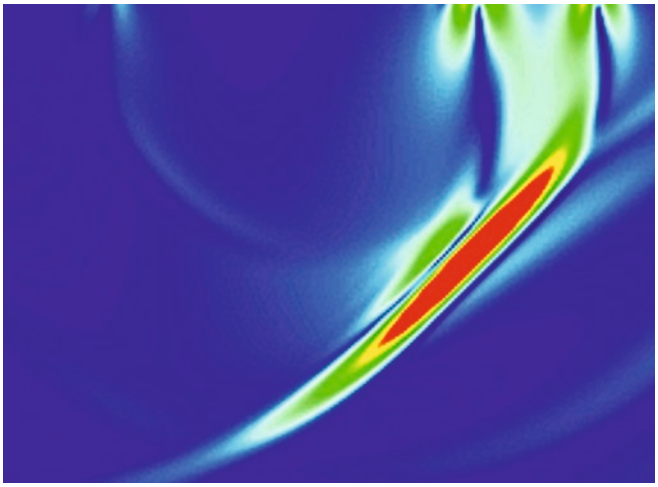
- Simulation-supported optimization of probe wave fields including phased array
- Optimization of test setups and sensor configuration
- Determining model-supported POD (probability of detection) curves for ultrasonic testing
- Examination of fixed shafts for condition (Structural Health Monitoring)

Elastic waves in a reinforced concrete part following mechanic impact.





Focused acoustic field of ultrasonic phased-array probe.



Acoustic field of an ultrasonic angle probe.

- Applications based on surface waves as well as laser and air ultrasound
- Acoustic problems (room acoustics, sound emission, noise protection etc.)

Performance characteristics

- Numeric ultrasonic solvers developed in-house
- Simulation with regard to wave physics
- Consideration of diffraction, interference, mode conversions, multiple scattering etc.
- Isotropic and anisotropic, homogeneous and heterogeneous materials
- Solids and fluid media
- 2D and 3D models
- Time signals, wave front snapshots, video animation

Fraunhofer IKTS has an extensive and flexible module library for the most varied applications in research and development.

When processing new projects, we always choose the best-suited existing simulation model and adapt, optimize and develop it further for the respective task. This means that the development effort for individual modules and related costs remains relatively moderate and early results are available more quickly.

Thanks to our close collaboration with the Fraunhofer IKTS working groups doing experimental work, the simulations are realistic and related to applications.

Service portfolio

- Basic research (specifically for new approaches to testing)
- Feasibility studies
- Test planning and supervision
- Interpretation of results (if the measured results are unclear)
- System optimization (including probes and sensors)
- Visualization and imaging
- Demonstration and training (among others, didactic introduction to ultrasonic physics and ultrasonic non-destructive materials testing using wave front images and animation)
- Simulation services (simulation results and their interpretation based on the tasks posed by the client)
- Development of application-specific simulation tools for clients wanting to perform their own simulations
- Completed by, and coupled with, commercial solver(s) (such as CIVA, ANSYS, Comsol etc.)

Mission

As a provider of ideas and driver of innovation, Fraunhofer IKTS has a strategic interest in the constant further development of simulation tools.

In order to implement these projects, partnerships with other research institutions and companies are sought through publicly funded national and international projects.

Augmented reality for rapid development and easy operation of test equipment

At Fraunhofer IKTS, the development of testing devices is closely accompanied by a usability engineering process. This ensures that the testing systems meet client requirements at the end of the development process, are adapted to the client-specific application and can be operated intuitively. Visual models are used for this via virtual reality at an early stage of development. The user-centric design concepts developed for this purpose are examined as to their usability and utility throughout different prototype levels. Augmented reality data glasses (mixed reality) can be used to demonstrate interactions and operating methods before the physical production of the testing devices and, if necessary, to identify and solve problems in advance.

But even after the testing device has been taken into operation, usage concepts for augmented-reality data glasses developed by IKTS offer a recognizable added value with regard to Industry 4.0. The focus is on the cooperation between man and machine. With the help of a digital twin, operating instructions can be shown directly, which enables two-handed working and virtual training scenarios. Work-relevant data and information such as inspection cycles or test instructions for maintenance work can also be displayed. For this purpose, interfaces are implemented that are adapted to the work steps and authorizations of the operators.

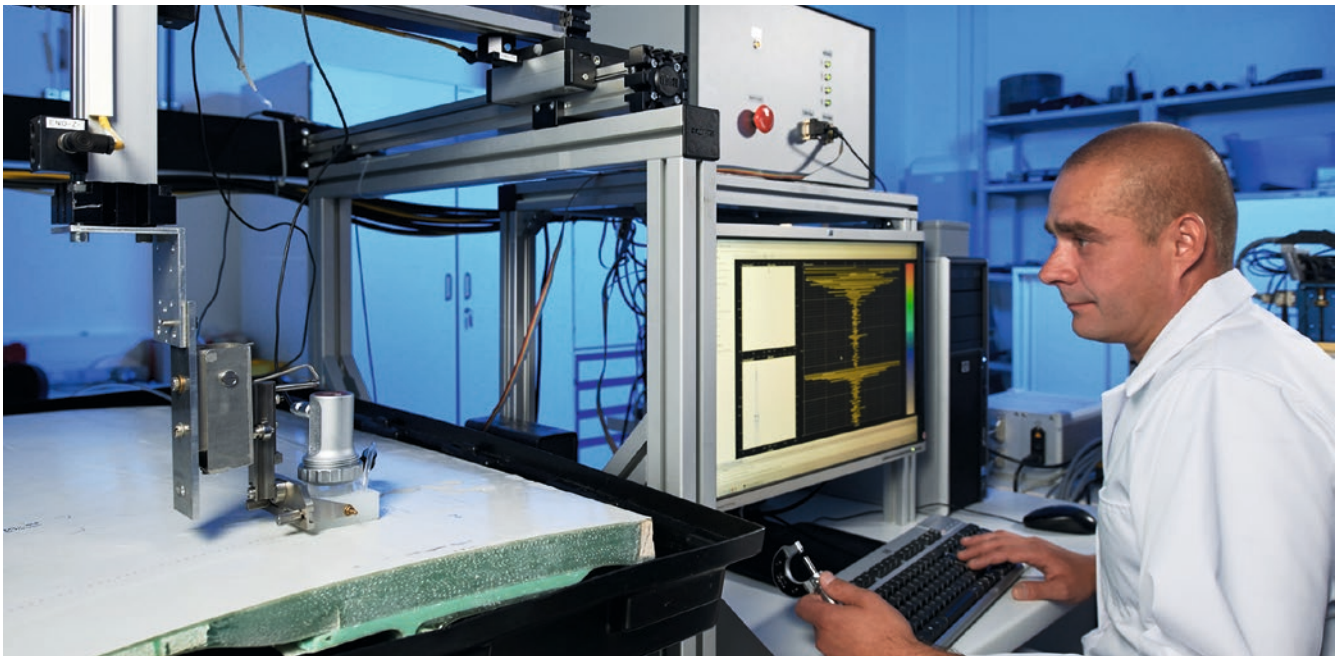
Service portfolio

- Creation of a digital twin for use in augmented-reality data glasses
- Integration and optimization of CAD/virtual models to the requirements of end devices
- Animation and interaction according to user requirements
- Lighting adjustment and rendering of each animation or video sequence
- Creation of user-centric interfaces
- Visualization of test data of various NDT procedures

New usage concepts for augmented reality (AR): a digital twin can be used to show information directly, for example when servicing machines and plants.

Accredited NDT lab

The reproducible performance of non-destructive tests requires know-how and experience. The rules are determined by a number of international standards. Germany's national accreditation body (DAkks) has granted Fraunhofer IKTS accreditation in the field of ultrasonic testing.



Ultrasonic defect testing of a GFRP sample.

The accredited NDT lab at Fraunhofer IKTS performs classic non-destructive testing of metal, non-metal, ceramic and composite materials. All relevant standardized procedures are used for this. Furthermore, IKTS provides support solving unusual and highly specialist problems in measuring and testing.

The range of services offered by the NDT lab includes the testing of individual components or large quantities of units, as well as the construction of individual semi-automated test facilities for special tasks. The test lab examines components of the most varied materials, geometries and component sizes for defects, however complex or safety-relevant they may be, using a large number of methods.

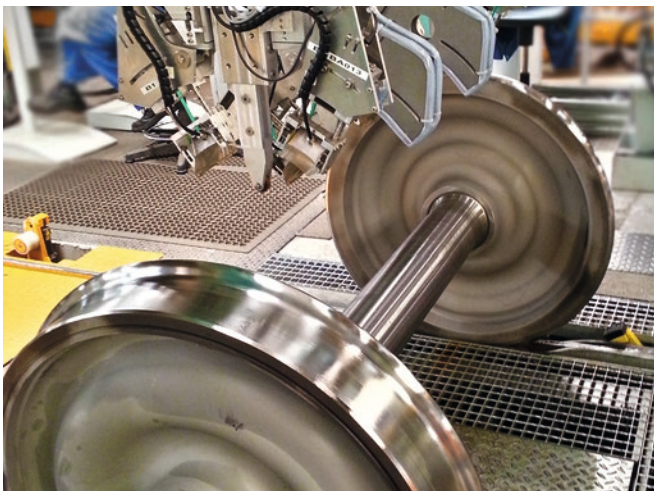
Testing expertise

- **Material** (steel, titan alloys, non-ferrous metals, polymers, ceramic composites, polymer composites, natural fibers)
- **Material joints** (welding, sandwich/layers, semi-finished parts, rivet, bolt, adhesive and soldered joints)
- **Geometry** (voluminous bodies, complex geometries, flat plates etc.)
- **Component size** (few millimeters up to several meters according to the task)
- **Defects** (cracks, pores, delaminations, geometric defects, inclusions etc.)

Test systems

Fraunhofer IKTS develops client-specific ultrasonic test systems for the lab as well as for industrial applications, carrying out their installation and commissioning, including staff training, as required by clients.

Lab system of the VARIUS ultrasonic scanner for detecting hollow spaces and cracks in weld seams and glued joints and other faults in composite materials.



Phased-array test system for wheel-set solid shafts (Source: arxes engineering GmbH).

Test systems for lab applications

Fraunhofer IKTS develops highly specialized ultrasonic test systems used in fields not fully served by the current product portfolios of testing device manufacturers.

The development of a testing system always starts with the assessment of the client's individual requirements with regard to maximum scan area, required precision, electronics and analysis software. Based on this assessment, ultrasonic testing systems for lab applications that comply with the requirements can be developed within collaborative or bilateral projects, e.g. for sample quality testing of materials or products.

One focus of IKTS is the supply and implementation of measuring systems for sound fields and other probe parameters such as center frequency and bandwidth, for the manufacturers of ultrasonic probes. IKTS also implements upgrades of systems for newly developed measurement methods that were already tested for fixed probes positions and are now to be extended by a scanning option.

Service portfolio

- Building of customized multi-axis scanners according to client requirements
- Integration of ultrasonic electronics from the PCUS® *pro* device family of Fraunhofer IKTS or from second-source providers
- Control of single probes and/or phased-array probes
- Signal analysis options and dynamic depth focusing
- Adaptation of alternative sensors is possible (e.g. laser vibrometer, small manipulator systems, such as HUGO III)

Test systems for industrial applications

Industrial testing systems are used for interval-based inspection and maintenance as well as for integrated quality assurance within a production line. The requirements for this with regard to robust hardware and intuitive software vary depending on the actual use case. Besides providing installations from the institute's own development efforts, IKTS also builds client-specific test systems for manufacturing processes from commercially available industrial robots.

Ultrasonic test systems for rail vehicles and railway infrastructure

The testing systems devised by Fraunhofer IKTS have often been used in the field of rail vehicles, where safety is key. The focus is on systems for testing components which experience high levels of stress, such as axles and wheels. These systems were developed in cooperation with partners from the industry and are successfully marketed around the world.

IKTS has provided these systems with the institute's own power electronics of the PCUS® *pro* series, as well as the intuitive PCUS® *pro* Lab software, which enable error-safe testing.

Hollow shaft testing systems for high-speed trains

With the aim of creating an optimized testing process, for instance for detecting transverse cracks in wheel set shafts, Fraunhofer IKTS and partners from the industry have developed a hollow shaft testing system for high-speed trains, such as the ICE, TGV, Shinkansen or Bombardier Zefiro. With its high data rates and the parallel FPGA design, the powerful PCUS® *pro* electronics ensure fast and customizable parameterization, and thus the safe testing of the axles.

Performance parameters

- System with seven independent single element probes
- Based on ultrasonic electronic units PCUS® *pro* Multi and software PCUS® *pro* Lab
- Adapter for connection to different wave types
- Fully automatic operation and analysis mode
- Fast and non-confusable testing from only one side

Solid shaft testing systems for high-speed trains

The solid shaft test system for freight train axles completes the portfolio of ultrasonic testing systems for railway vehicles developed by Fraunhofer IKTS. Based on ultrasonic phased-array, coated solid shafts for wheel sets can be tested for surface defects in areas that are prone to cracks, such as cross-section transitions.

Performance parameters

- Testing of coated solid shafts for wheel sets
- Cycle time: less than four minutes
- Visualization of test results in real time
- Use of up to eight array probes (32 elements) simultaneously
- Fully automatic operation and analysis mode
- Three PCUS® *pro* Array electronic units in parallel operation

Gripper for ultrasonic-based testing of press connectors on catenary lines.

Test system for tension-proof press connectors for catenaries

The ultrasonic test system makes it possible to detect cracks at an early stage. An ultrasonic probe is pressed onto the press connector using test tongs adapted to the joint's hexagonal cross-section. Using a suitable wedge, the ultrasonic waves are guided to the internal cracks to generate echo signals in the reflection and ensure stable coupling. The prototype consists of six ultrasonic probes integrated into the gripper, so that a complete press connector can be tested without turning the gripper.

Performance parameters

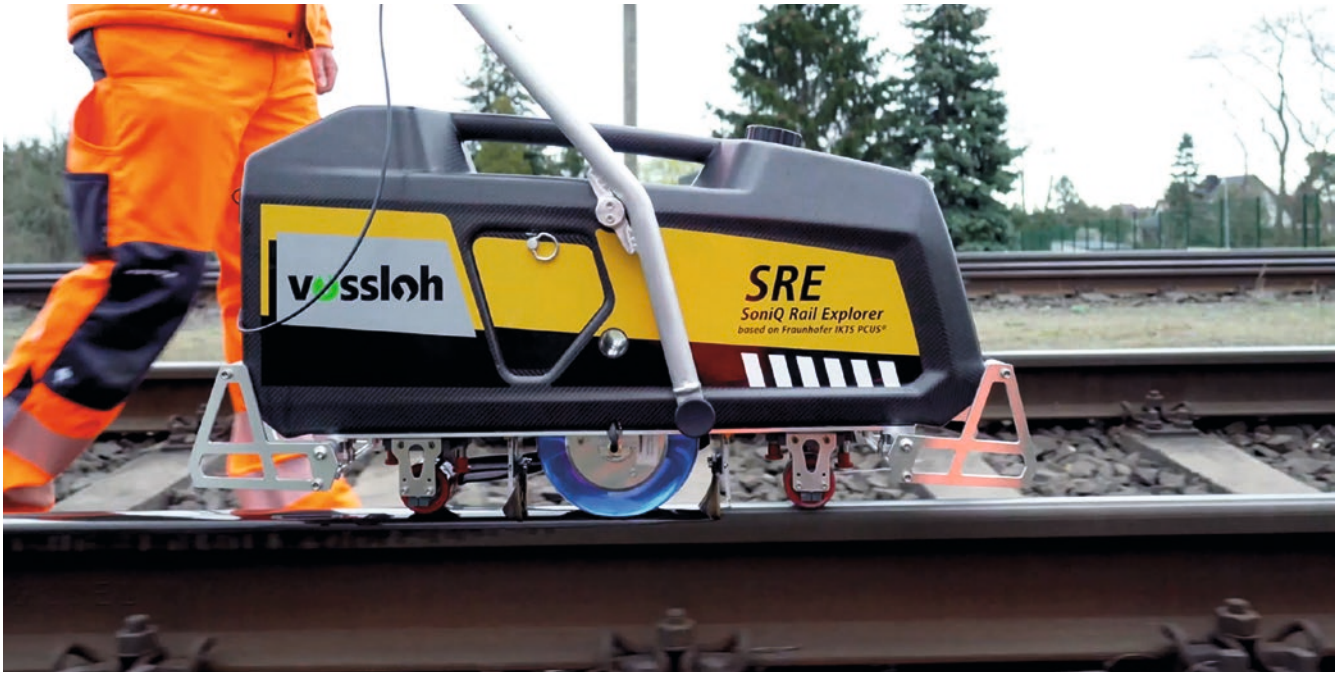
- Mechanical test gripper for locking 6 probes on the press connector for 70 mm² or 50 mm² cross-sections
- Ultrasonic electronic unit PCUS® *pro* Single with MUX extension and outdoor USB connections (IP 65)
- Integrated Hall sensor for monitoring of closing
- Ultrasonic software based on PCUS® *pro* Lab
- Tablet with easy-to-use touch interface

Mobile rail testing system – SoniQ Rail Explorer (SRE)

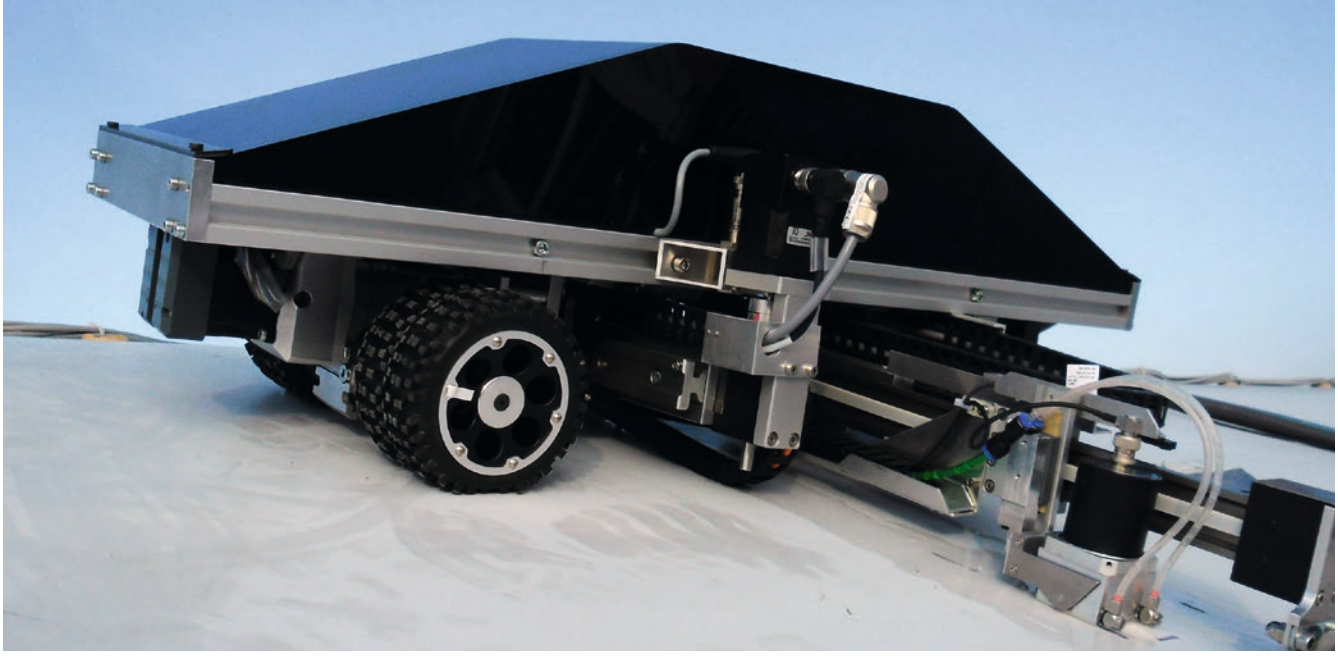
The PCUS®-based mobile rail testing system is used to detect irregularities on the inside of the rail, corrosion at the rail base or defects in the volume. The SRE offers the user more security in data analysis and interpretation and also makes it possible to integrate the test results into the digitized process chains of the railway company or the testing service provider.

Performance parameters

- Use of powerful, modular test electronics and software from the PCUS® *pro* family
- AI-based algorithms for error classification and support of the tester
- Real-time detection of near-surface irregularities and volume defects in rail head, web and base in accordance with DIN EN 16729-1



The mobile rail testing system SRE is ready for use on the track and offers a high level of test comfort thanks to its ergonomic design (Source: Vossloh Rail Services).



Ultrasonic measurements with scan carriage on the GFPR spar boom area of a rotor blade on a wind turbine.

Inline test systems for the electrode production of Li-ion batteries

In order to detect production errors at an early stage, Fraunhofer IKTS develops production-integrated testing systems that are validated and optimized in the "Battery Technology Application Center". The researchers use non-destructive optical, acoustic and electromagnetic processes and adapt them to the individual production steps, depending on the requirements. AI-based concepts for intelligent aggregation, structuring and evaluation are used for assessing the data thus collected. This enables detecting defect patterns, optimizing production processes and establishing a holistic production data management approach. It enables the definition of wholly new quality criteria and standards in battery cell production.

With the inline-capable testing systems, it will be possible in future to test the electrodes during their production for defects, functional changes in the material composition and the resulting properties or the dimensional structure of the cell without being destroyed.

For the evaluation of battery slurry mixing processes, a testing system was developed that combines eddy current and ultrasonic processes. Electrical, dielectric and mechanical material properties can be recorded at the same time with it. This range of parameters offers a high level of information. Thanks to the compact design of the testing system, it can be flexibly integrated into existing plants.

Ultrasonic inspection robot

Service robotics simplify difficult inspection operations. They also increase safety for service staff and reduce costs by saving time. However, the testing manipulators need to be robust and work free of errors.

That is the case for the testing electronics that Fraunhofer IKTS has developed specifically for use in harsh environments, used in so-called crawlers or inspection robots in conjunction with the PCUS® *pro* software. These robots work in pipelines that are difficult to access, mostly installed underground, sometimes at great height.

With the ultrasonic scan carriage, IKTS has developed an inspection robot for the inspection and maintenance of rotor blades on wind turbines, which is also equipped with PCUS® *pro* electronics. This inspection robot has a range of up to one meter and boasts adaptable ultrasonic probes. It can drive along and scan high-risk rotor blades fast and automatically.

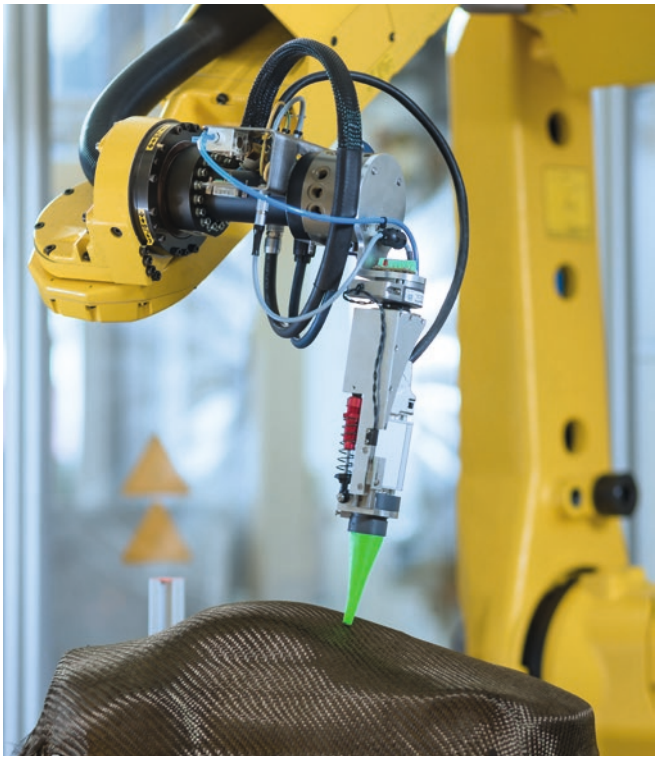
Technical equipment

Robot measuring cell

- Fast implementation of various measurement methods and measurement systems
- Adaptation of various tools for scanning, scratching, cutting, drilling, welding or bonding
- Accuracy of the robot: 80 µm target point difference
- Accuracy of the camera: 20 µm distortion at 800 mm focal point
- Surface pre-scan (optical): stereo camera and software
- Path planning: with software (parametric with gradient, compensation, caster angle, bearing angle etc.)
- Measuring speed: approx. 500 mm/s at 0.25 mm pitch
- Impedance image: 100 x 100 mm at 0.25 mm pitch: 3 min

Ultrasonic microscope

- Scan area: up to 310 x 310 mm
- Position accuracy and resolution: < 10 pm
- Lateral resolution: < 15 pm



Fraunhofer IKTS robotic measuring cell.

- Vertical resolution: < 30 nm (crack thickness)
- Ultrasonic frequency: up to 200 MHz
- Pulse-echo and permeation technology
- Single samples and sample series

Ultrasonic scan carriage

- Automated scanning of surfaces
- Extensive scans over measuring areas of up to 1 m width
- Use of various ultrasonic probes
- Resolution determined by the frequency range of the probes

Four-axis manipulator for special tests

- Three linear axes, one rotary disk, various (rotatable) plunge basins
- Immersion and contact technology
- Attainable object parameters:
  - Weight: < 100 kg
  - Geometry: < 500 x 300 x 300 mm
- Various ultrasonic electronic units with numerous parameters
- Free access to raw data (compliant with various analysis algorithms)
- Can be adapted for many sensors and mechanic configurations
- Methods of sound field characterization: beads in water and electrodynamic probes

Ultrasonic goniometer HUGO III

- Analysis of Rayleigh wave dispersion in layered materials
- Analysis of Lamb waves at thin structures
- Determination of layer thickness
- Experiments with volume waves

Acoustic intensity measurement system (AIMS)

- Acoustic field determination in water bath
- Five-axis hydrophone positioning
- Suitable for characterization and validation of ultrasonic probes

Cooperation models

Innovation and development are the cornerstones of a promising corporate future. In order to create a competitive edge, Fraunhofer offers tailored options for collaboration, so that small and medium-sized companies can work together in the best possible way. This also allows to utilize development skills at short notice and as needed.

One-off contracts

An individual contract is the classic form of cooperation. The company has become aware of a need for research or development. In accordance with the requirements of the company, Fraunhofer IKTS develops a solution that is compliant in terms of deadlines and quality.

Large-scale projects

Some problems are so complex that several partners are needed to develop a solution together. In such cases, the complete environment of the various Fraunhofer institutes is available. External partners may also be consulted.

Strategic partnerships and innovation clusters

Pre-competitive research, which first takes place independent of contract work, often leads to long-lasting partnerships with companies on a regional and international level.

Spin-offs

Fraunhofer employees often use new developments to become founders of company start-ups, of which the Fraunhofer Gesellschaft can become a shareholder. In some cases, even strategic investments and joint ventures are possible. The clients under whose contract the new development was created may also become shareholders of the new spin-off.

Licensing models

Licenses are a way to give third parties permission to use certain industrial property rights under defined terms and conditions. This enables using innovation if further development on one's own would result in high costs, if the capacities are not sufficient to achieve marketability, or if the innovation would not fit into the existing service portfolio. Fraunhofer IKTS offers flexible licensing models for company-wide use, optimizing one's own portfolio or to market services to the end client.

Fraunhofer IKTS in profile

For more than 30 years, Fraunhofer IKTS has been demonstrating the potential of ceramic materials in a steadily growing range of application areas. Our development activities are guided by the demands of nine market-oriented business divisions – supplemented by strategic preliminary research at the highest scientific level. As a research and technology service provider, we develop modern ceramic high-performance materials, industrially relevant manufacturing processes as well as prototypical components and systems in complete production lines up to pilot scale.

In addition, the research portfolio includes competences in materials diagnostics and testing. The testing methods in the fields of acoustics, electromagnetics, optics and microscopy contribute significantly to the quality assurance of products and systems. It is our motivation to develop holistic system solutions and services, but also to solve specific challenges within the processes of our partners from industry and science. Our expertise in the characterization and analysis of materials, components and systems along their life cycle provides us with a unique data pool to carry out new developments more efficiently and quickly.

All this qualifies Fraunhofer IKTS as a contact point for companies and research partners to make ceramic materials and non-destructive testing methods accessible to new industries, product ideas and markets.

Follow us

linkedin.com/company/fraunhoferikts
instagram.com/fraunhoferikts
youtube.com/fraunhoferikts

Contact

Industrial solutions
Ultrasonics

Prof. Dr.-Ing. Henning Heuer
Phone +49 351 88815-630
henning.heuer@ikts.fraunhofer.de

Fraunhofer Institute for Ceramic Technologies and Systems IKTS
Maria-Reiche-Str. 2
01109 Dresden, Germany

Piezoelectric materials, components and transducers

Dr.-Ing. Holger Neubert
Phone +49 351 2553-7615
holger.neubert@ikts.fraunhofer.de

Fraunhofer Institute for Ceramic Technologies and Systems IKTS
Winterbergstr. 28
01277 Dresden, Germany

100-B-23-06-01