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**Handbook on Automated UT**

**Draft of the German Committee of UT, DGZfP**

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# *Handbook Automated Ultrasonic Testing Systems*

# *IIW Handbook*

## Preface

Ultrasonic testing systems with automated and location-related data acquisition through mechanical control, have progressively gained importance in ultrasonic non-destructive testing.

This document discusses those stationary and mobile test devices that are applied in factories (testing of slabs, plates, pipes) and those used in construction sites (welds). Furthermore, systems being used for periodical tests (power station areas, pipelines etc.) are touched on. Many automated testing systems are available on the market, and they are frequently complex and not easy to survey by the potential user.

Therefore, the Technical Committee „Ultrasound“ of the German Society for Non-Destructive Testing (DGZfP) e.V. decided to establish a subcommittee „Automated Ultrasonic Testing Systems“ which evaluated this subject and prepared this handbook as an aid for specification, selection and use of these devices.

The handbook is the result of this co-operation. Special thanks are given to:

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# 1 Purpose and scope

With respect to the requirements of the customer (customer-related tests and quality standards) as well as to existing national and international test and quality standards, this handbook is designed to support the user, through typical examples and enable the user to specify

- Probes, probe systems and sensors
- Manipulation systems including controls
- Ultrasound electronics
- Data storage and presentation systems
- Evaluation and assessment techniques

It also provides support to the user to evaluate and select existing systems accordingly, it makes recommendations for application-oriented performance tests.

This handbook aims to suppliers and users of automatic scanning systems also by including practical examples. This includes:

- Tests during production of primary and end products and facilities in factories (stationary testing devices) as well as
- Tests with mobile mechanized test devices

Moreover, this handbook could be used as a training document.



# 2 Terms and definitions

Terms and definitions are given in standards EN 1330-2 and 1330–4 (see 10). Those which are not included in these standards are described in this handbook.

# 3 Basic set-up of the test equipment

## 3.1 Test equipment

Test equipment for the detection of flaws (cracks, pores, geometry etc.) and for the determination of material characteristics (e.g. sound velocity, sound attenuation and sound scattering) are discussed.

Essential characteristics of automated systems are:

- Mechanical motion of probes and/or test objects
- Automated data acquisition
- Position-related measurement data and test results

Definition:

A system is comprised of all components usually applied for the execution of automated scanning. These are:

- Probe handling system
- Probes and probe cables
- Coupling techniques
- Ultrasound electronics
- Acquisition and processing of data
- Evaluation and graphic representation of data
- System controls

The requirements for the layout of a system for a particular test application are determined by the goal of the test (single test statement up to quantitative results) and by its area of application (size and geometry of test object, test dimension, environmental conditions).

The test equipment can be stationary or mobile.



Characteristics of stationary systems are:

- Stationary installation
- Normally laid out for inspection during production of a particular product group
- High level of automation
- Automated evaluation
- High test velocity

Examples of stationary systems are:

- Systems for continuous inspection during production of steel products like billets, plates, pipes, rails
- Systems for mass products like steering knuckles, coils, balls, bolts, pressure cylinders etc.
- Systems for the inspection during production of components of general mechanical engineering like shafts, wheel disks etc.

- Systems for the inspection during production of aircraft parts, e.g. vertical stabilizer shells made of composite materials, and CFRP and GFRP components
- Systems for random sample tests (batch test), like process accompanying checks, e.g. test of steel samples for hydrogen-induced cracking (HIC)

Characteristics of mobile systems are:

- not stationary
- typically configurable for varying examination tasks through adaptation or replacement of single components

Examples for mobile systems are:

- Systems for basic and periodical tests of components like fittings, tubing, vessels, screws, turbine parts in power stations and chemical plants
- Systems for basic and periodical tests of means of transport (aircrafts, railway tank wagons etc.)
- Systems for basic and periodical tests of piping, like oil or gas pipelines
- Systems for maintenance tests of rails (rail car)



Test system configurations can be divided into several categories depending on the number of channels. Examples are given in 3.2:

- Single channel systems
- Multi-channel systems with multiplex operation of the single channels
- Multi-channel systems with parallel operation of the single channels
- Systems with parallel operation of multi-channel systems with multiplex operation of the single channels (see also 4 and 6)

The extent of the handling system is dependent upon the examination task, beginning with simple tools for the probe guidance and going up to complex testing robots with simultaneous multi-axes control (see.3.3). Typically, the extent of the data acquisition and evaluation system is contingent upon the number of test channels, the test velocity and the requirements to the test results.

### 3.2 Basic structure

The essential components of an automated testing system are represented in Fig 3.2.1. In Chapter 5, a detailed description of the operation characteristics of the individual components is given.

A significant feature of automated testing is location-related ultrasonic data acquisition. In order to obtain a definite assignment of the acquisition position and the respective ultrasound data, positioning units can be applied based upon angular encoders, optical recognition systems or those with ultrasonic locating. Time marks are used in facilities that operate in one motion direction only. Then, actual sound beam position can be determined through synchronous acquisition of the motion speed.

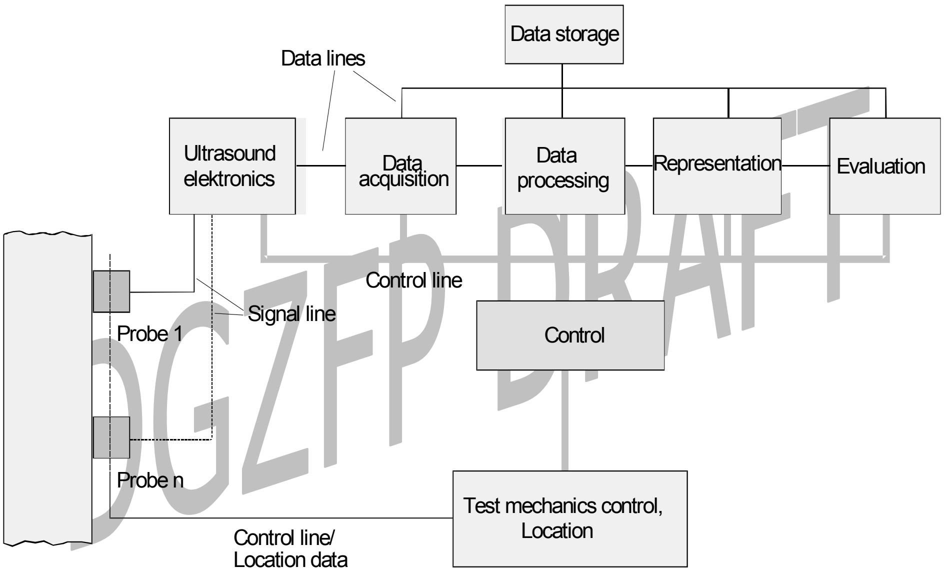



**Fig 3.2.1:** Basic structure of an automated ultrasonic system

With the help of testing mechanics, probes are moved relative to the test object. The simplest approach to a mechanical testing system is a manual move of the probe over the object and determination of the position by using simple tools. In this case, guiding the probe manually replaces the mechanical controls otherwise necessary. Multiple-axes systems normally require large-scale computer-aided controls.

**Fig 3.2.2:** Simple manipulation set-up with one probe

In the simplest approach, an ultrasound probe system contains one single probe (see Fig 3.2.2). However, depending upon the requirements of the given task, a system might even be comprised of several hundreds of probes, e.g. in the pipeline test with ultrasound pigs for crack detection (Fig 3.2.3).



**Fig 3.2.3:**

Sensor carrier of a 24“ ultrasound crack detection pig for oil and gas pipelines with 384 probes

The ultrasound electronics is the heart of the test system. In Fig3.2.4, a diagram including the usual is shown.

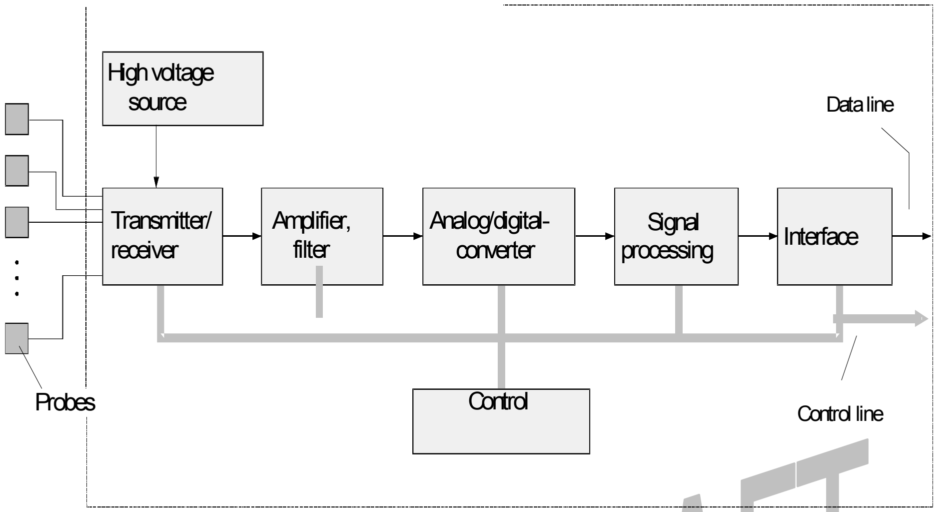



**Fig 3.2.4:** Diagram of an ultrasound electronics system

Depending upon the application, the spectrum of applicable ultrasound electronics extends from commercially available analogue and digital instruments for the set-up of single channel systems, up to modular units for the set-up of multi-channel systems for multiplex or parallel operation of single channels. Moreover, personal computer plug-in cards are offered that combine all analogue and digital components of an ultrasound device on one board. These cards can be used as basic units for the set-up of automatic testing systems with one or more test channels.

Depending upon the examination task to be fulfilled by an automated testing system, the ultrasound electronics provides different types of measured data, which can be registered by the data acquisition unit and be stored on appropriate storage media.

Many modern digital test systems being applied in mobile test service for safety relevant components (e.g. in power stations or chemical plants) enable registration and storage of radio frequency (RF) receiver signals. The registration of RF data enables maximum information volume as compared to all other data registration techniques.

In case large test volumes and/or high test speed, data reduction techniques are often applied. Examples include  testing large components in the area of industrial facilities, pipeline tests with ultrasonic pigs, and  inspection during production of various industrial products (e.g. steel products, plastics, composite materials). These data reduction techniques are described in detail in 5.5.

Data that are transferred from the ultrasonic unit to the data acquisition unit are referred to as measurement data. Measurement data are processed in the data processing unit so that they can be visualised in appropriate form by the display unit, and thus are available to the inspector for evaluation. For inspection during production (e.g. through automated routine test) or during continuous tests of steel products, normally an automated evaluation is performed. The evaluation is done according to guidelines or standards being described for the respective product, or according to an agreement with the customer.

There are areas in which individual and eventually large-scale evaluations have to be performed by experienced test personnel, e.g. weld inspection at vessels and pipes, inspection of forged parts in construction of heavy machinery as well as safety-relevant components in the aerospace industry. In this case, the data processing unit has to compute image data out of the basic data, thus providing a projection or section image to the inspector. This allows the inspector to perform data manipulation, such as amplitude corrections according to an DGS or DAC curve. Further possible tasks are filtering of measurement data, the application of image processing techniques or the use of special algorithms for signal analysis. The data processing unit may consist of a computer equipped with the appropriate software, but can as well be realised through hardware components designed for special production steps.

Data can be stored at different steps within the measurement signal processing as shown in Fig3.2.1. For automated sample test, the storage of the evaluation result as a „good/poor“ statement is normally sufficient. In contrast, during inspection of safety relevant components, measurement data are stored together with their image representation or processed results as well as with the evaluation results.

The control and synchronisation of the individual components of the test system is realised through process control. This ensures that:

- the exact process of a test cycle is followed, in which all probes are operated in the correct sequence with the appropriate parameters
- the correct assignment of test location and the respective ultrasonic measurement values
- the synchronisation of the data transfer between ultrasound unit and data acquisition unit

In many production test systems with automated evaluation, the process control also manages the discarding of defective parts or the marking of defective areas, e.g. with paint jet pistol.

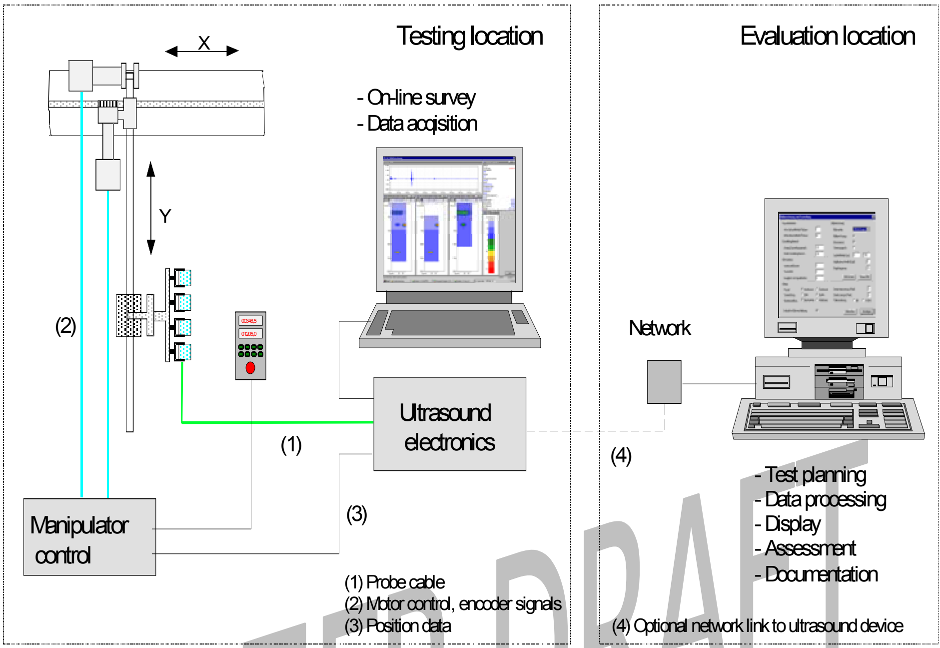



**Fig 3.2.5:** Set-up of a multi-channel test system for mobile test services



In Fig3.2.5, the set-up of a multi-channel test system is shown as an example of the basic structure of an automated testing system. Equipped with an XY-manipulator, it can be applied for tests of vessels and pipes.

### 3.3 Levels of automation

Levels of automation can be as follows:

- manually driven mechanised positioning of the probes
- manual feeding/removal of the test objects
- automated positioning of the probes, machine operated
- feeding/removal of the test objects, operated automatically, mechanically
- automated positioning of probes and test objects outside the production flow
- automated positioning of probes and test objects within the production flow
- semi- or fully automated evaluation of the test results followed by marking or sorting of the test objects

## 4 Test-related technical objectives and conditions

### 4.1 Examination task

The examination task defines the minimum size of flaws to be detected. The features of the test system have to be adjusted accordingly.

The requirement-related threshold for the flaw detection has to comply with the state of the test object and the expected loads. Existing relevant normative documents have to be taken into consideration.

The technical limitation of flaw detection caused by the test system is determined by the following parameters:

- The signal-to-noise ratio the electronic resolution within the transfer chain of the ultrasonic signal (from the electronic transmitter up to the signal processing unit)
- the band width of the probe (-s)
- the acoustic (lateral or axial) resolution

the dynamic lateral resolution is the determining factor in all automatic scanning techniques. Therefore, the dynamic lateral resolution has to be determined in both directions (parallel and perpendicular to the scanning direction) and documented with appropriate methods according to the examination task.

### 4.2 Basic conditions

Preparation for the execution of an automated inspection consists of a test plan that considers given basic conditions. It is comprised of material-related and test-related conditions, specifications according to existing technical rules and limitations given by the customer. These parameters have to be accounted for, when selecting the test technique, the test procedure and the evaluation of the test results.

Technical conditions are, among others: the accessibility of the object to be tested, the surface condition, the coupling medium supply and the environmental conditions influencing the probe and the manipulator.

In the test planning phase, consideration must be given to: the number of incidence directions, the examination sensitivity, the acceptance level and the evaluation of indications.

Customer-specific limitations can be: at offshore sites the examination has to be carried out under water; in-service inspection in the control area of a nuclear power plant has to be carried out following the requirements of the radiation protection regulations; during examination within closed vessels, devices must be used exclusively which are powered by battery or operate under low voltage.

### 4.2.1 Density, velocity and scope of examination

Large amount of data at high test speed is typical for of automated testing. Therefore, automated evaluation of the test results is also a central issue.

During automated scanning, a sufficient coverage of the material volume to be examined is of major importance. Thus it has to be ascertained that:

- the distance between adjacent measurement points (dx) and examination tracks (dy) is selected sufficiently small during XY-scanning to account for the scope of the examination and the probe used (i.e., dx, dy is less than the beam diameter (-6dB))
- the pulse repetition frequency and the test speed are consistent
- when using multiplex systems, the test density for each channel, unlike test channels operating in parallel, is reduced according to the number of multiplex channels

For the relation between feed motion, test speed, pulse repetition frequency and data acquisition the following applies:

If the probe is moved along a direction x and measurement values are acquired equidistantly from a gate (amplitude or time-of-flight), the following condition must be fulfilled:

$$v < \frac{(dx \cdot f)}{n} \qquad (1)$$

where: v = relative speed between probe and test object (mm/s)

dx = measuring grid in the direction of motion (mm)

f = pulse repetition frequency of the ultrasonic instrument (Hz)

n = required number of pulses per measurement value

Example:

In a test, a measurement must be taken every 0.5 mm and the maximum repetition frequency of the device is 5000 Hz. However, because of false indications in the A-scan presentation, only a maximum of 2000 Hz can be used. The peak value detector in the ultrasound instrument used requires 8 pulses (n=8) to obtain the echo height. Therefore, the permissible test speed is given by:

$$v < \frac{0{,}5 \cdot 2000}{8} = 125 mm/s$$

Thus, at a test speed of greater than 125 mm/s there is the risk of missing defects.

If not only amplitude or time-of-flight values have to be measured, but complete A-scans have to be acquired at each  location, Eq.(1) has to be modified:

$$v \leq \frac{dx}{ts} \qquad (2)$$

where: v = relative speed between probe and test object (mm/s)

dx = measuring grid in scanning direction (mm)

ts = acquisition and storage period of a complete  A-scan

Normally, the transfer period of the A-scan to a storage medium (e.g. hard disk) is longer than the duration (length) of an A-scan itself. Therefore, it is important to insert into the equation the time (ts) of the slowest step within the procedure described above.

### 4.2.2 Particular environmental conditions

Special requirements that depend on the test environment, which cannot, or can only be met with difficulty in manual examination, can be reasons for the application of automated ultrasonic testing.

Examples of these are:

- Ionising radiation
- Extreme high or low temperature of the test object or the environment
- Very high or low pressure in the environment (air or water pressure)
- Aggressive atmospheres
- Explosion endangered areas

### 4.2.3 Particular material characteristics

Ultrasonic tests can be hampered by particular material properties in different ways. Frequently, this problem can be solved using automated test procedures only

Unlike in the ideal case of isotropic and homogeneous materials, the following material properties cause particular requirements during examination:

- Coarse-grained material (castings, austenitic steel, concrete)
- Inhomogeneous material structure (mixed structure, differently formed structures at different areas of the same object)
- Anisotropic materials (texture in rolled and reshaped products, columnar crystals in austenitic welded material, fibre reinforced composites)
- Structure boundaries (dissimilar welds, composite materials,  hardened surfaces)

In practice, a combination of these properties can also be present. They can dramatically influence the propagation of ultrasound, and thus can lead to the following problems:

- False indications
- Incorrect localization
- Wave mode conversion
- Alterations of test sensitivity
- Generation of local test gaps

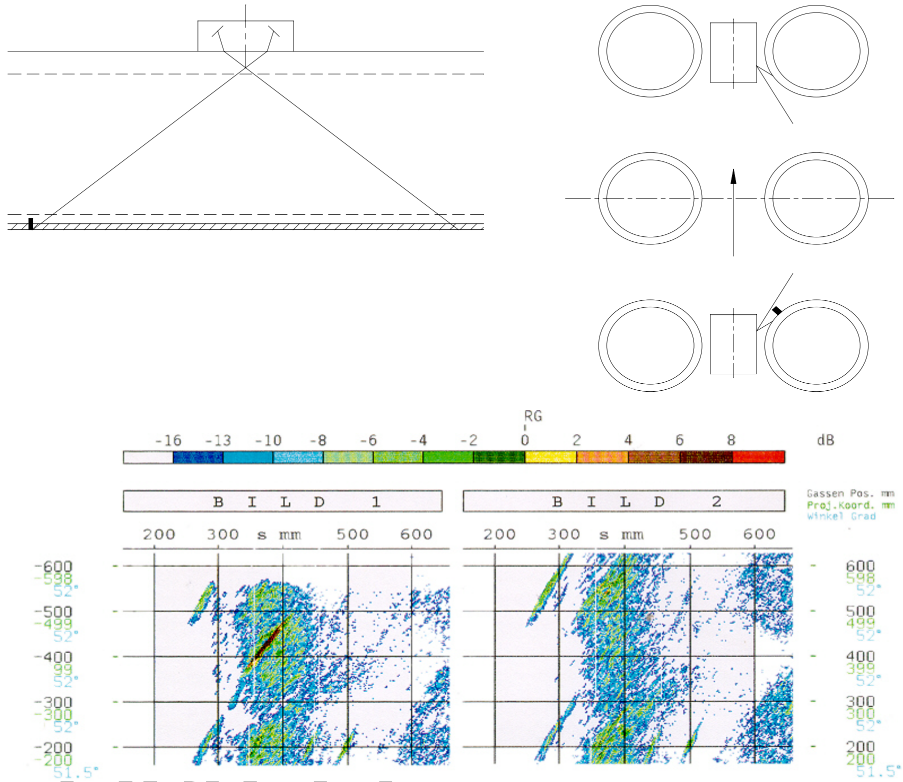
These influences, and their respective effects, can be diminished through appropriate measures.

The examination of austenitic welds serves as an example. Here, B- and C-scan representations enable an evaluation of the results obtained. Hereby, signal patterns of the tests can be compared with those obtained from preceding examination results or from measurements on reference specimens./9/

### 4.2.4 Complex component geometries

If the geometry of an test object is complex, then in most cases a complex shaped coupling surface is also encountered. This can render difficult, or even impossible manual ultrasonic inspection. Moreover, in the case of limited accessibility of the object, manual examination is sometimes not possible and manipulator-controlled probe motion and automated data acquisition is required.

Due to complex part geometry, geometry related indications in the A-scan representation can appear, which in the case of manual testing can be difficult to discern from defect signals. If A-scans are taken, location-related B- or C-scans as well as reconstruction images like SAFT, holograms and tomograms can be constructed. These images, by their time-of-flight and amplitude structures, enable differentiation between geometry related signals and defect signals. This can be supported by pattern recognition procedures (refer to Fig 4.2.4 for an example).




symmetrical geometry signals with defect echo

symmetrical geometry signals without defect echo

**Fig 4.2.4:** Pattern comparison of symmetrical geometry related signals during spherical bottom test of nuclear pressure vessel

In the examination of upper shells and spherical bottoms of nuclear reactor pressure vessels, phased array probes are used which are moved on defined tracks between the control and measuring rod nozzles on the spherically curved surface. At each incident sound beam position the relevant areas of the inner surface are tested, with different rotation and incidence angle for detection of cracks. The B-scan representations from tracks running parallel to each other are compared. Due to their time-of-flight structures, indications of cracks can be differentiated from geometry-related indications of the nozzle borehole soffit.

## 4.3 Examination data

The completeness of the data must be ensured so that an evaluation according to a given test specification is possible, and a redundancy regarding quantitative statements is provided.

The completeness of the measurement data assumes that the distance between the measurement spots within the test track and the distance between the test tracks allow to clearly recognise the dynamic course of a defect signal.

With the help of the stored data, a conclusion about the complete coverage of the tested areas must be possible. Furthermore, loss of coupling and limitations in the accessibility have to be recognisable. The registered data and the respective scanning areas on the test object must be linked in a unique way.

The stored measurement data must allow a comparison of examination results from different testing techniques. It is therefore important that the measurement data from the current technique be able to be compared to previous measurement data using older automated systems and/or techniques.

It is important to achieve a high degree of reproducibility and objectivity of the findings, through complete documentation of all test parameters and a high, constant precision of the examination levels. The precision and constancy of the sensitivity levels (test sensitivity) must also be documented.

The image representation of the acquired and automatically processed data enables the application of retraceable evaluation techniques. Whilst for defect detection a complete documentation of images representing the measurement data is necessary, for defect analysis the defect position is already known. The selective image representation of single defects supports improved defect recognition during flaw analysis.



### 4.4 Reference specimens

The registration of the measurement signals must enable a relation to reference reflectors or to the reporting level. The measurement of reference reflectors to be repeated in certain cycles during automatic measurements offers the possibility to check the constancy of the test sensitivity.

The flaw detection sensitivity is dependent upon the dynamic behaviour of the test system. It is thus characterised that during an inspection a defect can be detected within the spatially extended sound field from several measurement positions with different echo amplitudes, and the corresponding time-of-flight values. Thus, the distances between the measurement positions and the distances between the test tracks have to be selected so that the dynamically retraceable alteration of a flaw signal allows differentiation between a parasitic and a real reflector echo.

Therefore, a generalised set of reference specimens is required. According to the examination task, different sized test reflectors at the relevant depths must be available so that the dynamic features of the scanning test equipment can be checked.

The acquisition and representation of the measurement data must have tolerances above and beneath the recording level required so that the dynamic behaviour of the defect signal can be observed.

## 5 Components and performance of a test equipment

The requirements for a test equipment are determined by the respective application. Hereby, design and operation mode have to be established with respect to the technical objectives and conditions.

### 5.1 Test mechanics and positioning systems

Systems are required for the automated ultrasonic testing which enable a relative motion between the probe and the test object. The mechanised guidance between the ultrasonic probe and the test object automatically provides the spatial relation of the test data.

Detection and processing of the co-ordinates is usually performed with electro-mechanical or electronic means.

Further tasks of the mechanics besides providing the spatial relation can be:

(a) Control/guidance of the probes (manually or mechanically)

(b) Control/guidance of test object

(c) Synchronous control/guidance of the probes and the test object

(d) Feeding and removal of the test objects

(e) Supply and removal of the coupling medium

(f) Ensuring stable coupling conditions

Test mechanics that moves probes can be found in mobile as well as in stationary testing systems.

Test mechanics moving the test objects and also moving potentially synchronously probes are usually applied in stationary test systems. Frequently, these are integrated in the production process of the test objects.

In the layout of such systems, the following parameters generally have to be considered:

(a) Degree of mechanisation / automation (see 3.3)

(b) Properties of the test object

- Shape
- Material

- Surface condition
- Temperature

(c) Test scope
- Total or partial volume coverage
- Directions of insonification
- Redundant tests

(d) Test speed / scanning path speed
- Pre-set operation cycle
- Approach and reset time
- Pulse repetition frequency
- Sound path length
- Single or multi-channel operation

(e) Requirements for accuracy of positioning in order to
- Detect discontinuities (minimum size)
- Describe discontinuities (location and size)
- Reproduce the test result (accuracy of access)
- Consider obstacles (edges, mountings, etc.)

Frequently, these requirements are fixed in respective standards or rules.

(f) Quality of coupling
- Contact pressure
- Distance between probe and test object
- Mobility
- Supply and removal of the coupling medium

(g) Further requirements
- Environmental conditions
- Availability (wear resistance)
- Life cycle
- Ease for maintenance and repair / conditions
- Long-term availability of software and hardware
- Legal regulations concerning safety of personnel and installations.

## 5.2 Coupling techniques

### 5.2.1 General

A coupling medium is primarily needed to transfer the mechanical vibration of an electro-mechanical transducer resident in the probe to the test object, and then back to the transducer. Further uses, such as corrosion protection, can also be considered.

There are other ultrasonic test techniques that can operate without a coupling medium, such as ultrasound generated electro-mechanically (EMAT) and laser ultrasound. In these techniques, the elastic vibrations are produced in the test object itself (see 5.3).

Media with all states of aggregation are used for coupling. Typical coupling media are:

- Gaseous    air
- Liquid    water, oil etc.
- Solid    metal foils, rubber, low-melting crystals

However, not all of these are useful in automated scanning systems. Most commonly, water, oil and emulsions can be found and air, or combined liquid/solid coupling in the Ultrasound wheel probe, where appropriate.



### 5.2.2 Testing environment requirements

When selecting the appropriate coupling media, a number of conditions regarding the testing environment must be considered, e.g.:

- Compatibility with the test object (e.g. avoidance of corrosion)
- Contamination of the test object by the coupling medium and decontamination/cleaning after completed examination, if necessary
- Surface of the test object (e.g. waviness, roughness of the surface)
- Contour (complex geometry)
- Accessibility of the test object
- Temperature of the test object resp. the test environment
- Test speed
- Contamination of the coupling medium by the test object (e.g. radioactivity, dangerous chemicals)
- Environmental compatibility and disposal of the coupling medium

### 5.2.3 Ultrasound-related requirements

Selecting the coupling, parameters of the ultrasonic inspection itself also have to be considered, e.g.:

- Wave mode used
- Transferability of the ultrasound by the coupling medium (in order to avoid contamination, bubbles)
- Frequency and band width
- Sound beam diameter
- Ultrasound path length in the delay path and the test object
- Insonification technique (transmission or pulse echo)

### 5.2.4 Coupling through liquids

In automated scanning systems, coupling with liquids is most commonly used (water, oil, emulsions). Variations that are possible are given in Tab. 5.2.4.1.

Whilst the immersion technique is particularly useful for the examination of single items, the other coupling techniques might as well be used for tests in a continuous material flow.



### 5.2.5 Coupling through gases

Coupling through a gaseous medium like air, offers particular flexibility concerning testable geometries and maximum test velocities. The entire coupling-related handling is simplified significantly as well, and problems that arise in the application of liquids as a coupling medium are eliminated.

However, because of large impedance mismatches during coupling and decoupling of the sound energy and the large energy losses caused hereby, it must be inspected at a low frequency (up to 1 MHz) and narrow-band (toneburst transmitter), typically in transmission mode. Due to the low sound velocity in air one is limited to low pulse repetition frequencies.

### 5.2.6 Coupling through solids

If required by the testing environment, coupling also can be performed with solids.

For example, silicone foil enables dry coupling with a soft solid.

The ultrasound wheel probe has an oil-filled tyre with a probe emitting ultrasound in radial direction. Thus a combination of liquid and dry coupling is realised. However, a slight moistening of the tested surface is favourable too.

In practice, however, solid coupling is very problematic since interfering air/gas interface layers can arise between the test object and the probe during the relative motion.

**Table: 5.2.4.1:** Variants of the coupling with liquids

| **Technique** | **Description** | **Guidance of the probe by** |
|---|---|---|
| Immersion technique | Test object completely under liquid | External mechanics |
| Partial immersion technique | chamber or basin with liquid as immersion tank for a part of the test object | External mechanics, test object |
| Jet technique | Sound is conducted over a long, free liquid jet | External mechanics |
| Nozzle technique | Liquid column is guided in nozzles; small distance of the nozzle holes to the test object | External mechanics, test object |
| Bubbler technique | Liquid column from beneath with overflow | External mechanics |
| Shoe contacting technique | Probe fixed in a slide shoe keeping constant the gap, filled with liquid, between probe shoe and test object | Test object |
| Flow gap coupling | Thin liquid film between probe and test object; probe floats on liquid foil | Test object |
| Contact technique | Direct contact of the probe shoe with wear plate with coupling pressure onto the test object while surface moistened | Test object |



## 5.3 Probes

### 5.3.1 General

Electro-acoustic devices for transmission and reception of ultrasound are typically called probes. This are sensors using the piezoelectric effect for conversion of electric energy into mechanical energy. This effect is reversible, thus it can be utilised for transmission of ultrasound as well as for reception.

Other principles of ultrasound generation and reception are also applied in non-destructive testing. Two examples are the application of electro-magnetic acoustic transducers (EMAT) and of pulsed laser sources. In both of these techniques, the ultrasound is generated in the near surface area of the test object.

In most of the inspections, the pulse-echo technique is applied. Short ultrasonic pulses are emitted, reflected or scattered by discontinuities in the material, and finally received. An indication of the relevance of the signal is given by its amplitude. The pulse time-of-flight enables the location of the discontinuity.

With respect to the operation conditions and coupling techniques (see 5.2.4), the integrity of the probes (including connections and cables) must be determined. Furthermore, any damage of the tested object must be avoided. Hence, it might be required that probes are water- and corrosion-proof, pressure- and temperature-resistant, free from chlorides, etc.

Wear of the contact surface of probes must be mitigated during automatic scanning using the contact technique. For example, special slide runners, frames or pins might serve in this case.

The description and measurement of characteristic values of probes are not included in this handbook; for this it will be referred to the standard EN 12668-2. This European standard also describes which data have to be given in the data sheets of probes.



### 5.3.2 Piezoelectric probes

Piezoelectric probes are available in different configurations. Depending upon the actual application, e.g., the design of the probe has to be selected accordingly, as well as, the test frequency, the transducer size, the wave mode, etc. The geometry of the test object, the material properties, the area to be inspected and the required resolution also play important roles.

Besides the transducer, the other basic elements of a probe are the transducer backing, a delay body, protective or adaptive layers, an electrical adapting circuit as well as a housing with cable or plug. Frequently, installations for feeding and removal of coupling media are integrated into the probes for automated testing.

#### 5.3.2.1 Transducer materials for piezoelectric probes

The transducer consists of a piezoelectric material residing in the probe as a thin plate. The nominal frequency f of the transducer is determined by the thickness of this transducer plate

$$f = \frac{v}{2\,d} \qquad (3)$$

where v stands for the sound velocity (mostly of the longitudinal wave) in the piezoelectric material.

The acoustic impedance of the transducer is a significant material characteristic for the sound transfer. This value influences the amount of energy transferred to the test object.

Mostly, piezoelectric ceramic materials are used as transducers because these have a large acoustic impedance and an accordingly high efficiency. Moreover, ceramics are more durable than other transducer materials, which is an important factor for the total lifetime of the probes used for an automated inspection.

Furthermore, piezoelectric foils made of polyvinylidene fluoride (PVDF) are used as transducer material. The low sound impedance of this material enables an efficient sound transfer, in the immersion technique. In addition, high frequencies (about 10 MHz up to 100 MHz) are achievable using PVDF foils. However, a disadvantage is their poor temperature resistance (only up to about 80 °C).

Piezoelectric composite materials show a low acoustic impedance as well. These are ceramic sticks or particles embedded in an epoxy resin body whose properties as transducers are given by the structure, and in particular the mixing ratio of the ceramic and resin portions. Like the aforementioned transducer foils, the composites show excellent sound transfer efficiency and a poor resistance against mechanical load and temperature attack (maximum usable temperatures of roughly 100 °C).



#### 5.3.2.2 Layout of piezoelectric probes

The basic design of a piezoelectric ultrasonic probe is shown schematically in Fig 5.3.2.2.1. The transducer is coated with electrically conducting layers on both sides. The electric signals during transmission and reception are fed to, rep. acquired from these electrodes.

Usually a transducer backing is located behind the transducer influencing the vibration behaviour and the band width of the probe. The transducer backing absorbs sound waves being emitted backwards. Interfering reflections are suppressed through specific shaping of the transducer backing.

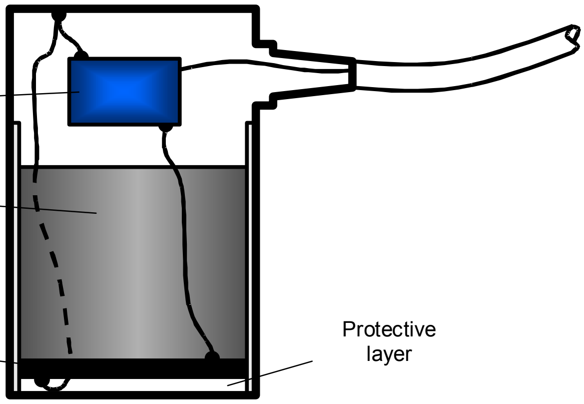



**Fig 5.3.2.2.1:** Schematic of the design of a piezoelectric ultrasonic probe



Protective and adaptive layers provide both mechanical protection of the probes and acoustic impedance matching for optimum sound transfer into the test object.

The probe may contain an electric matching circuit in order to achieve good electric impedance matching to the ultrasound transmitter. Occasionally, this unit is incorporated in the preamplifier close to the probe.

### 5.3.2.3 Probe types

The most straightforward design is the **normal beam probe** for emission and reception of longitudinal waves perpendicular to the coupling surface.

**Angle beam probes** contain a plastic wedge in order to enable the excitation of a wave at a given angle caused by refraction. Angle beam probes are utilised for the detection of reflectors oriented perpendicular or at an angle to the coupling surface. Weld inspection is a typical field of application for angle beam probes.

**TR-probes** contain two separate transducers in one housing, one for transmission and one for reception only. To avoid cross-talk both transducers separated electrically and acoustically. These probes are used preferably for examinations of near surface areas, because due to the spatial separation the receiver will not be interfered by the transmitter pulse. However, it is important to note that a TR-probe can be used in a defined depth area only, which is defined by the angle of inclination between the two transducers (roof angle) as well as by the transducer size and shape. TR-probes can be designed as normal beam or angle beam probes.

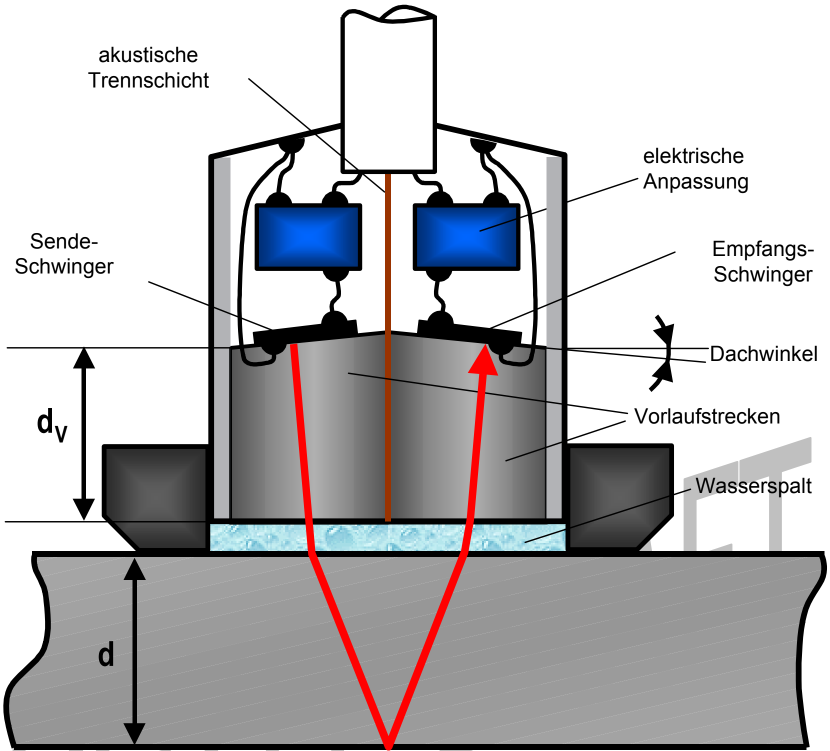



**Fig 5.3.2.3.1:** Principal design of a TR-probe, shown in typical arrangement for testing of plates with coupling by a small water gap

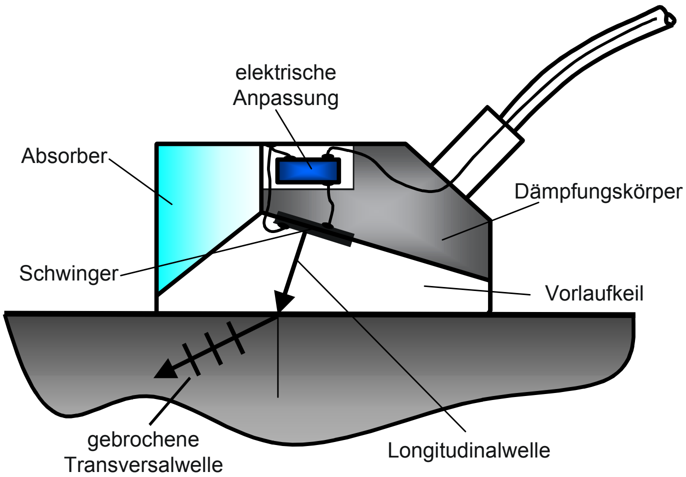



**Fig 5.3.2.3.2:** Principal design of an angle beam probe

### 5.3.2.4 Array probes

Contrary to a conventional ultrasonic probe, the array probe (phased array) contains a piezoelectric transducer divided into single elements or a large number of small electro-dynamic transducer, in order to control the sound beam electronically. In both types, the ultrasound generation and the signal processing during reception of the ultrasound wave can be performed separately by each single element. Hence, a freely selectable time-delay for shape and direction modification of the wave-front can be applied.

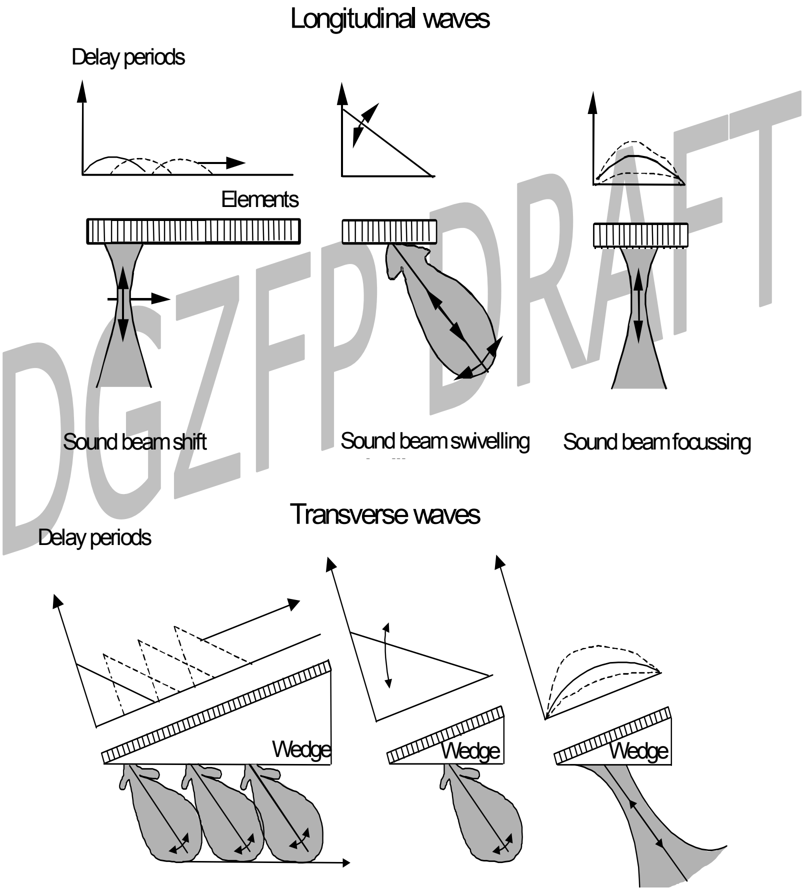



**Fig 5.3.2.4:** Sound beam control of array probes

The designs of the array probes, operating either with single or with dual transducer techniques, differ regarding the geometrical arrangement of the probe elements. In linear arrays the transducer areas are divided in one direction only. Conversely, in a mosaic array the transducer area is divided in two directions perpendicular to each another. In a ring array, the single elements are arranged in a circle. The most important parameters for the structure of the sound field are the number and size of the single elements, the slot width and the slot depth between elements.

Due to the time-delayed electronic triggering of the transducer elements the resulting sound field can be swivelled, focussed or shifted dependent of the inspection requirements without mechanical movement.

In shifting of the sound beam, a selectable number of transducer elements can be combined to a transducer group, which then can operate as a conventional probe. Thus, during flat or XY-scanning, a mechanical manipulator operation can be replaced by electronic shift of transducer groups (real-time scanning).

A set-up of two tandem probes can be replaced by a real-time scanning transducer, whereas for the detection of reflector at different depths, appropriate angles of the ultrasound and distances between the two transducer groups have to be set.

The arrangement and size-distribution of the elements is adjusted according to the used wave mode determined by the coupled wedge. Possible operation modes are: longitudinal waves at normal or angular refraction, angled incident transverse waves, creeping or surface waves at angular refraction.

Array probes containing 16 to 128 elements are conventional. Depending upon the test frequency, the width of the elements range between 1 mm and 3 mm.

The multiple array is a special probe design which allows controlled sound beam swivelling in the entire volume of the object being tested.

Arrays equipped with elements divided into units oriented parallel and perpendicular to the coupling surface combine vertical and horizontal swivelling.

The swivelling ranges for transverse and longitudinal waves for vertical and horizontal swivelling are given in Tab. 5.3.2.4 below.

**Table: 5.3.2.4:** Swivelling ranges for linear array probes

| **Angular range for::** | **Transverse waves** | **Longitudinal waves** |
|---|---|---|
| **Vertical swivelling** | 10° through 80° | 0° through 90° |
| **Horizontal swivelling** | -45° through 45° | -45° through 45° |

Whilst during the vertical swivelling the angle of refraction is modified the squint angle can be varied on minute modification of the angle of refraction during the horizontal swivelling. In this case, the minimum angle step equals 0.5°. The range of the angle of refraction and the squint angle depend upon the wedge angle.

Thus, when using array probes further requirements have to be applied for the calibration for example.

The near field length can be shortened up to 50% by focussing through modification of the delay periods.

In TR-probes, angle variations and focussing for transducer and receiver array can be performed separately.

The array probe has to be connected always to an appropriate ultrasonic electronic. For each single element of the array probe this must provide a transmit and receive channel to be triggered individually. Through multiplex operation, it can be switched between transmit and receive operation. The probe operation control and the measurement data processing is realised by a specially adapted computer program.

#### 5.3.2.5 Special designs

Special inspection tasks frequently require specially designed probes. For plate and pipe inspection probe rulers with multiple transducers are used to reach broad test tracks at constant sensitivity level.

For the test of rods and pipes probes bearing curved foil transducers with a linear focus have been developed. Using these probes a complete covering of the test object without a helical relative movement between probe and test object is achievable.

The wheel probe is applied predominantly for the test of plate and pipe material. The transducer is linked solidly with the axis of the tire filled with liquid. The operation mode (perpendicular or angular) is determined by the inclination of the transducer. The probe can adapt to the surface of the test object through the flexibility of the tire. The major applications of this technique are to avoid the use of coupling aids (see also 5.2.6).

### 5.3.3 Electromagnetic acoustic transducer (EMAT)

The principle of electro-magnetic sound generation is based upon the interaction of a current density induced by eddy current with a permanent magnetic field. The ultrasonic wave is thus produced in the test object itself. Therefore, these probes are only applicable for conducting materials.

An EMAT probe consists of one or more coils residing in a magnet field produced either by a permanent magnet or electromagnet. By the geometry of the coils and the structure of the magnet field the generated wave type is defined, as for example:

- Horizontally polarised transverse waves
- Vertically polarised transverse waves
- Non-polarised transverse waves
- Surface waves
- Plate waves

EMAT probes operate without a coupling medium, which can be of particular advantage during automated inspection of plate, pipe and wire materials. Thin, non-metallic coatings of the examination object usually do not interfere. A further advantage is that hot test objects can be inspected well with EMAT probes.

However, in using the EMAT probes the smaller dynamic range and the lower resolution as compared with piezoelectric probes is problematic. Furthermore, for a constant high test sensitivity it is necessary to keep the distance to the test object constant and small. Variations in the electromagnetic surface properties of the test object influence the sensitivity of EMAT testing. The frequency range is limited to a maximum 3 MHz. /1/

### 5.3.4 Laser ultrasound



In laser ultrasound, the thermo-elastic effect for generation of ultrasound within the test object is exploited. This is realised by rapid heating or vaporising of the surface of the test object. Depending upon the excitation mechanism, different wave types and directional characteristics are produced. The pulse repetition frequency achievable is very low as compared to piezoelectric transducers. /1/

The test object can be inspected through optical redirection of the laser beam and scanning of the surface. For the generation of the ultrasonic wave in the test object, the angle of incidence is of minor importance. This is of particular advantage during scanning of items with complex geometry.

A laser interferometer is used for the reception of ultrasound. The technical effort required in this technique is much higher compared to conventional testing techniques. Interference of the beam path (e.g. by vapours, smoke, striae) can handicap the test.

Further advantages of laser ultrasound are:

- The distance to the surface of the test object is of minor relevance.
- There is no need for a coupling agent.
- Short ultrasonic pulses at high frequencies can be produced e.g. providing high resolution for the measurement of wall thickness.
- Sound generation in objects at high temperature is possible.

### 5.3.5 Special requirements for ultrasonic probes

For automated ultrasonic testing, there are special requirements to the probes with respect to the test environment, the test objects, the test scope, the ease of maintenance and to the replaceability.

#### 5.3.5.1 Environmental conditions

In this context, the most important parameters are environmental and coupling medium, temperature, pressure, interference fields and radioactive radiation. Thus, the requirements are:

- Tightness and chemical resistance against the environmental/coupling medium.
- Materials of the probe and the transducer, as well as all joints must resist the expected temperatures and pressures.
- Cables and housings must be shielded to avoid unallowable interference by electromagnetic fields (e.g. emitted by motors or welding machines) which can inadmissibly deteriorate the signal-to-noise ratio during the test. Additionally proper grounding of device components can reduce interference.
- The decontamination of probes must be easily possible, e.g. after contact with health endangering substances.

#### 5.3.5.2 Test object

The shape of the test object eventually governs the layout of the probe and the probe mounting (e.g. gimballed). Test locations with difficult accessibility might be reached through specially designed probe housings only.

To reduce wear during automated scanning, direct contact between probe and object is avoided in most cases. Areas of possible contact must be designed to prevent damage and deposits.

#### 5.3.5.3 Test scope

In order to fulfil the examination task, with minimum effort the required probes, test mechanics and controls must be matched accordingly.

E.g., special probes for plate testing cover a broad scanning track. To minimise the gaps between the individual probes, more than one transducer can be incorporated in one housing. In pipe testing, similar designs are used to provide a broad scanning track by a number of transducer elements in one housing.

Increasingly, probes containing transducer arrays are applied. Hereby, significant improvement concerning both test speed and mechanical effort, can be achieved by electronic scanning, swivelling and focussing instead of using fixed probe assemblies (see also 5.3.2.4).

#### 5.3.5.4 Ease of Maintenance and replacement

Probes are wear parts of an automated scanning system, whose fast replacement at moderate cost must be possible. Probe replacement could also be needed when the object dimensions change or on servicing (e.g. cleaning of the test mechanics). This must be considered in the mechanical layout of a test system.

Probe and probe mounting must be matched so that the position of the probe is reproducible within the permitted tolerance after replacement. During several applications, production-related tolerance values of the probes must be accounted for through adjustable probe carriers.

## 5.4 Ultrasound electronics and digitisation

### 5.4.1 Transmission and reception system

The essential components of the transmission and reception system of an ultrasonic device are: high voltage supply, transmitter, receiver, amplifier, attenuator and filters (see also Fig 3.2.4).

The following remarks refer exclusively to typical commercially available devices for piezoelectric probes. Devices for specialised probes, such as piezoelectric arrays and electromagnetic-acoustic probes requiring special transmission and reception circuits, will not be discussed here.



#### 5.4.1.1 Transmitter

The transmitter serves as a source of electric pulses (typically several 100 Volts) exciting the piezoelectric transducer to perform mechanical oscillations.

Normally used pulse shapes are spike pulses, rectangular pulses and bursts.

- A spike pulse serves for broad-band excitation of damped probes, i.e. equal transmitter pulses can excite probes with different test frequencies. Rise time, fall time, amplitude and polarity (typically negative) of the pulse are essential parameters.
- A rectangular pulse enables specific excitation of probes at their nominal frequency through adjustable pulse width and amplitude.
- A burst serves for narrow-band excitation of weakly damped probes; burst length, frequency and amplitude are adjustable.

According to the number of test channels, multiple transmitter circuits are usually present in multi-channel test systems.

#### 5.4.1.2 Receiver

The received electric signals coming from the probe, in the range from μV to V, are processed by the receiver. It contains a circuit for selectable matching to the impedance value of the probe plus test cable, and also a low-noise preamplifier.

In multi-channel test systems operating in parallel mode, multiple receivers must be present according to the number of test channels. For multiplex operation, this number is reduced accordingly.

#### 5.4.1.3 Main amplifier and attenuator

Together with a controllable attenuator, the main amplifier serves for the adaptation of the large dynamic range of the received ultrasonic signals to the dynamic range of the subsequent signal processor. Usually, linear amplifiers are used for this. Additionally, time-of-flight-dependent amplification and attenuation can be performed using distance-amplitude compensation.

If a large dynamic range (greater than 80 dB) is needed, logarithmic amplifiers are used which require more complex circuits. Alternatively, fast analogue-to-digital converters (ADC) with high resolution can be used (see also Tab. 5.4.2).

In the case of multiplex operation of the different test channels in multi-channel systems, one single amplifier/attenuator can be utilised for several test channels each. However, according to the examination task, each test function must be adjustable individually in this case.



#### 5.4.1.4 Filter

Filters are used for suppression of certain frequency components of the receiver signal (e.g., parasitic signals). Thus, an improvement of the signal-to-noise ratio is achieved. Filters are selected according to the examination task regarding:

- centre frequency,
- band width and
- other filter characteristics.

After appropriate digitisation, this analogue filtering can be replaced partially by digital filters. These are independent of temperature and ageing. Furthermore, they are exactly reproducible. These filters can also be fitted for purpose and extended as desired if implemented by software.

Filters as well can be used commonly for several test channels operating in multiplex mode in a multi-channel system. With respect to the examination task, the channels must be adjustable individually for each test function.

### 5.4.2 Digitisation

#### 5.4.2.1 Analogue-to-digital conversion

After being processed by the receiver unit the ultrasonic signal is digitised. This is carried out in an analogue-to-digital converter unit, also referred to as an ADC. The digitisation of the receiver signals is a prerequisite for further signal processing and transfer to the data acquisition unit through an appropriate data interface (see 5.5.1).

At the output of the ADC, the digitised ultrasonic signal is available as a sequence of temporally equidistant amplitude values (see Fig5.4.2.1), which can only be discrete.

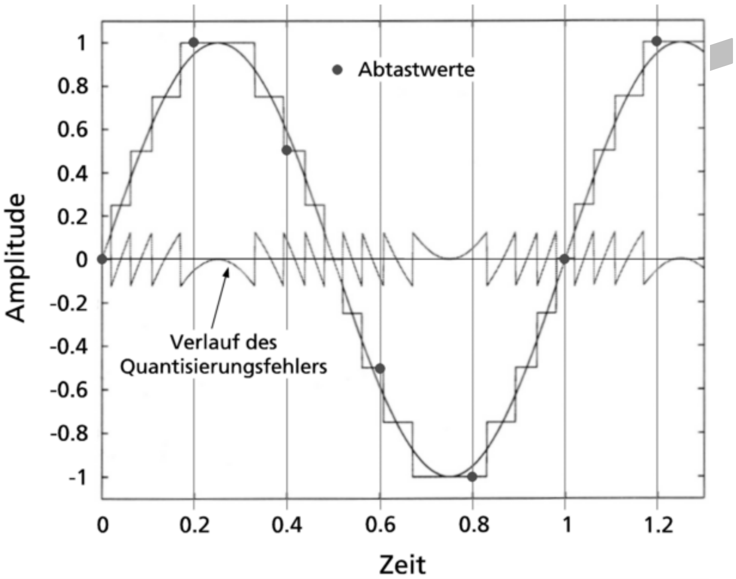



**Fig 5.4.2.1:** Digitisation of a sine wave signal and resulting quantisation error

The amplitude resolution depends on the digitisation resolution of the ADC used. The higher the resolution of the converter, the lower the quantisation error will be. The correlation between the digitisation resolution, the dynamic range achievable and the resolution of the amplitude values is given in Tab. 5.4.2.

For example, the digitisation of the amplitude values for a linear signal input and a required dynamic range of 48 dB must be performed with a resolution of at least 8 bit (see Tab.5.4.2).

Regarding the examination requirements it is sometimes useful to generate logarithmic values prior to digitisation (logarithmic amplifier). At equal digitisation resolution, this offers the advantage of a better dynamic range allowing big differences in the amplitude values to be handled. In this case, however, the amplitude resolution in the upper dynamic range is poorer than for linear amplification.

**Table 5.4.2:**
Correlation between digitisation resolution, dynamic range and resolution

| Digitisation resolution [bit] | Dynamic range [dB] | Resolution | Resolution [%] |
|---|---|---|---|
| 8 | 48 | 1 in 256 | 0.3913 |
| 10 | 60 | 1 in 1,024 | 0.0977 |
| 12 | 72 | 1 in 4,096 | 0.0244 |
| 16 | 96 | 1 in 65,536 | 0.0015 |



If a high frequency signal is fed to the input of the ADC, after digitisation also the sign is provided for each amplitude value. This is essential if the phase information is required for further signal processing, or for the application of special evaluation procedures, e.g. when using array probes or the SAFT technique. Thus, one has to consider that during digitisation of a RF signal, one bit is used for recognition of the sign. Therefore, at a digitisation resolution of 8 bit, only 7 bits are available for the resolution of the amplitude values.

The sampling rate is another essential parameter of ADCs. Since modern ultrasonic instruments have to process signal frequencies in the range between several hundreds of kHz up to about 20 MHz, ADCs are required which operate much faster than those used for audio applications. The faster the ultrasonic signal is sampled, the better the digitised amplitudes represent the original signal. This is an essential requirement for the standard amplitude evaluation of ultrasonic signals. For instance, if a signal is sampled with an ADC frequency ten times greater than the probe centre frequency, the maximum error of a digital value will be less than 0.5 dB. In the case of a frequency only five times greater, the maximum error will amount to almost 2 dB in the worst case. (see also Fig 5.4.2.1).

If maximum possible information content of the ultrasonic signal is required, then the signal values have to be transferred to the data acquisition unit (e.g., data acquisition computer) without any further data reduction. For many applications, however, a data reduction is necessary, which has to be matched to the examination task. The data reduction techniques most commonly used for ultrasonic data are described in 5.5.4.

### 5.4.2.2 Signal averaging

If the received ultrasonic signals contain considerable electronic noise, a significant improvement of the signal-to-noise ratio (SNR) can be achieved by signal averaging. The more signals can be used for averaging, the greater the SNR improvement will be. The improvement factor equals the square root of the number of averaged signals. So, averaging four signals results in an improvement factor of 2, i.e., a SNR improvement of 6 dB. Accordingly, averaging of 16 signals results in a SNR improvement of 12 dB.

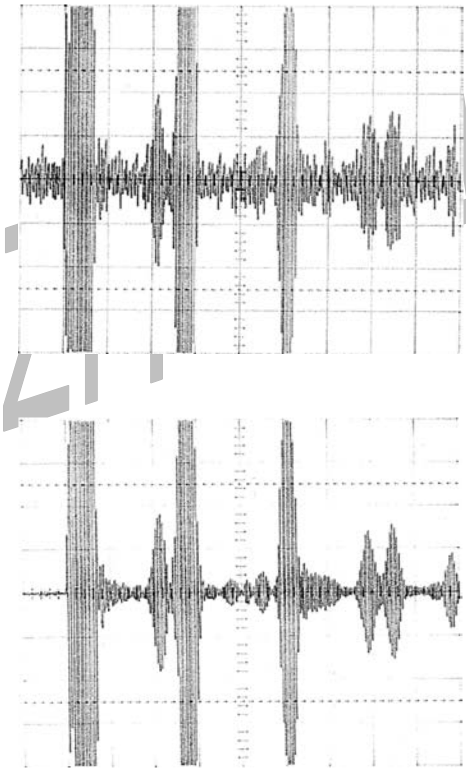


**Fig 5.4.2.2:** Improvement of the signal-to-noise ratio through signal averaging

During automated scanning, the test speed has to be adjusted according to the number of signals averaged, so that the signals to be averaged originate from approximately the same location (time averaging). Signal averaging can be applied advantageously, e.g. using the EMAT technique, where the received signal voltage levels are low and large amplification factors have to be applied. Consequently, the resulting noise level will be high. Moreover, electromagnetic interference from industrial sources can deteriorate the SNR further. An example is given in Fig 5.4.2.2. It should be noticed that signal averaging is only effective if the noise signals appear stochastically.

Generally local averaging can also be performed to reduce structure-produced noise. However, signals of structural origin usually are not stochastic, so in these cases an improvement can seldom be achieved.

#### 5.4.2.3 Time-of-flight measurement

If the peak position of the echo signals has to be determined with high accuracy (e.g. for a precise wall thickness measurement), the sampling frequency must be matched to the required accuracy of the time-of-flight measurement. Depending upon the scan path range to be measured, the electronics of the time-of-flight counter has to operate at a sufficient digital resolution.

An example: If an accuracy of 10 μm (resolution ±5 μm) is required for a wall thickness measurement of 30 mm, 6000 digitisation steps at 10 μm fall into this range, according to the expression:

2 x 30000 μm / 10 μm = 6000

With a 16 bit time-of-flight counter (resolution 1 in 65536) the aforesaid requirement is by far fulfilled.

To achieve the resolution required at a given sound path range, it could be useful to gate the time range within which the measuring values are acquired.



## 5.5 Data acquisition, on-line data processing and storage

### 5.5.1 Hardware

The prerequisite for automated data acquisition, processing and storage is a processor-aided system containing interface units which enable the dialog/data interchange with the ultrasound electronics, the manipulating system and the data storage unit, and equipped with appropriate software to control the processes. Interfaces are for example:

- Data interfaces (usually parallel) for acquisition of digital values (ultrasonic data and position information)
- Analogue-to-digital converters for ultrasonic devices with analogue data output
- Interfaces for ultrasonic unit control (usually serial) if computer-aided
- Interfaces for long distance data transfer
- Interfaces for the synchronisation of the entire system

For signal processing programmable electronic units are used that enable the very fast execution of logical and arithmetic operations. Predominantly FPGA units (Field Programmable Gate Arrays) are used and in some cases ASICs (Application Specific Integrated Circuits), too. Digital signal processors (DSP) are applied for the execution of highly complex algorithms.

### 5.5.2 Software

For reproducible automated testing, the software should be able to register and document all settings characterising the test procedure, and to store these together with the measurement data acquired. The settings can be in general:

- Settings of the handling system ( index, track length, number of tracks, speed, scan path characteristics)
- Transmitter amplifier settings (gain, impedance matching, pulse duration, intensity etc.)
- Receiver settings (attenuation or gain, input filtering, signal rectification etc.)
- Gate settings (start, stop, trigger, thresholds if applicable)
- Measurement mode (pulse echo or through transmission)
- Mode of time-of-flight measurement (flank or peak)
- Sound velocity and digitisation cycle
- Distance-amplitude compensation values
- Angle of incidence and delay path
- Probe parameters
- General data (test object data, inspector, date, time etc.)

Except for the general and probe data, all parameters on modern computer-aided ultrasonic test instruments can be set, read, or both by computer. The measurement parameters can be stored in one file together with the measurement data, or in separate files using a common data file name, in the latter case preferably in editable and printable form. With respect to the requirements (e.g. to prevent falsification), the former or the latter option will be preferred.

Digital or analogue measurement data are acquired by software via the data interface, e.g.:

- Amplitude values
- Pulse time-of-flight values
- A-scan presentations (video, RF-data, pixelised data)

During digitisation of time-of-flight and amplitude values, the dynamic range and the resolution must be selected according to the test requirements (see 5.4.2).

### 5.5.3 Relation to object co-ordinates

Tab. 5.5.3 summarises the options available for establishing the relation between object co-ordinates and the acquired data (amplitude and time-of-flight values):

**Table 5.5.3:** Link between position data and measurement data

| **Link of co-ordinates with measurement data** | **Position** | **Ultrasound electronics measurement data** | **Manipulator** |
|---|---|---|---|
| Asynchronous, time-related | Calculation through time and path co-ordinates | Internal triggering with known cycle rate, running freely | Parameters known (starting time, start position, path, scan speed) |
| Asynchronous, insertion of the local co-ordinates into the measurement data set | E.g. angular encoder, pulse counter | Internal triggering with known cycle rate, running freely | Known start position, known path |
| Synchronous, position-related generation of measurement data | E.g. angular encoder, pulse counter | Position resp. path-dependent triggering | Known start position, known path |

If the manipulator itself operates computer-controlled, it is recommended to synchronise the manipulator control and data acquisition by software.

It has to be assured by appropriate synchronisation that a false co-ordination of position and time does not occur in any case.

### 5.5.4 Data acquisition and data reduction

According to the examination task, there are two methods to start the measurement, independent of the mode of data acquisition (storage of the entire A-scan or of reduced data). In tests using the contact technique, the time-of-flight measurement is started by the transmission trigger pulse. In the case of the immersion technique, the time-of-flight measurement is usually initiated by the interface echo. The echo start operation used in this case is described below.

**Echo start operation**

In tests using the immersion technique, the sound is coupled to the test object via a water delay path. To obtain the depth of reflectors detected relative to the surface of the object, the time-of-flight measurement is initiated with the interface echo with the help of a specially designed electronic circuit. The A-scan evaluation thus starts with the reception of the interface echo. Alternatively, the A-scan presentation can be evaluated starting with the transmitter pulse. Hence, the shift of the interface echo during scanning of uneven objects can be observed. Through determination of the position of the interface echo, the shape of the object can be obtained and brought into the inspection results.

By setting the start of the time-of-flight measurement at the sound entrance into the examination object, the correct depth determination of reflectors is ascertained, independent of the shape of the component (see Fig 5.5.4.1). If a time-of-flight dependent amplification correction is necessary (distance amplitude correction) it starts at the surface of the object for each probe position.

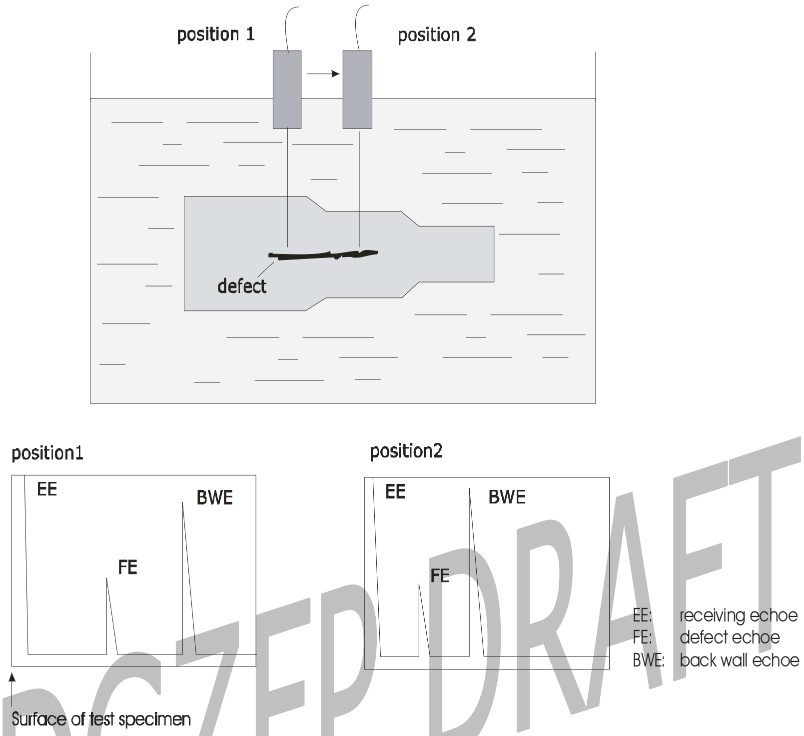



**Fig 5.5.4.1:** Effect of the echo start gate



One type of data reduction of the original A-scan is the extraction of single amplitude or time-of-flight values. Depending upon the examination task, the total information content of the A-scan might be needed for evaluation. The maximum information volume obtainable from the A-scan is dependent upon the amplitude resolution and the sampling rate (see 5.4.2).

The huge data accumulation (e.g., data transfer rate > 100 Mbytes per second at a sampling frequency of 100 MHz and an amplitude resolution of 8 bit can result in a data volume of >10 GByte per single test) causes high requirements for the features of the data acquisition system. However, due to the fast development in the field of data processing and data storage systems, hardware meeting these requirements is commercially available today.

It is advantageous that many processing steps can be carried out, repeated or extended at any time when complete acquisition of the A-scan is done. Gate parameters can be set, averaging, time-of-flight measurement respective corrections and frequency analyses can be performed using a previously stored data set. Furthermore, interferences having shown up during testing can be eliminated quite reliably through comparison of an A-scan with neighbouring ones. Error search and analysis can be carried out without additional data acquisition. Generally, the acquisition of A-scans also offers the option for later application of reconstruction and tomographic methods like SAFT or ALOK.

A reduction of the measurement data to a volume required by the examination task could be needed already during acquisition. This „filtering“ can be performed in various manners:

- Gate technique
- ALOK reduction
- Pixelisation of A-scans

These techniques will be described in the following sections and illustrated in Fig 5.5.4.2.

Moreover, data evaluation criteria could be applied for further reduction already during data acquisition. For instance, A-scans or data sets are stored only if they are recognised by the measuring system as deviating from given criteria. Indication length, indication area or indication pattern can be such criteria.

It is essential for the permissibility of any data reduction that all individual information needed for the examination task is registered. Data reduction or compression can be applied on-line during data acquisition or off-line after data acquisition is completed.



**(a) Gate technique**

On ultrasonic devices operating with the gate technique one or more measurement gates can be set in the A-scan (see Fig 5.5.4.2).

A gate relates to a selectable sound path range in the A-scan presentation together with an amplitude threshold. Registration of exceeding or falling below a pre-selected threshold is the simplest kind of data processing and yields the highest degree of data reduction (yes/no statement). Otherwise, the maximum amplitude and mostly the respective time-of-flight or the respective sound path in each gate are acquired and stored. The gates can be set separate, adjacent or overlapping.

The particular advantage of the gate technique is the small amount of data out of each test shot. If the depth position of a reflector does not have to be determined, then recording of the maximum amplitude within each gate is sufficient. Due to the small data flow, the interface to the data acquisition system is not loaded excessively, hence the gate technique is particularly suitable for those examinations in which high test speed and data processing speed are required.

A drawback of the gate technique is that only the echo signal with the highest amplitude is detected within the gate. Any further echoes appearing elsewhere in the gate are not registered, so useful information can be lost during tests that require detailed description of reflectors detected. E.g., a crack tip signal could be „hidden“ within the corner reflector echo in the case of a surface breaking crack. Furthermore, geometry-related echoes could run into the measuring gate during scanning of components with complex or irregular geometry, so that material defects possibly existing could remain undetected. In some cases, a sophisticated signal processing technique can help, such as automatic gate tracking.

In the following techniques are described which circumvent the aforementioned restrictions of the gate technique.

**(b) ALOK technique**

The ALOK technique, through a special signal processing, enables the detection of all echo maxima within the radio frequency receiver signal without the aforementioned limitations of the gate technique. Thus, even those reflectors can be resolved, which are closely adjacent as shown in Fig 5.5.4.2. Each maximum being recognised in the A-scan is described by its amplitude and respective time-of-flight. Together with the respective probe position, these coupled values are stored as basic data.

The ALOK signal processing technique leads to an efficient data reduction as compared to recording of the complete digitised RF signals. This is needed for the achievement of high test and evaluation speed. Particularly, this is true for examinations using multiple test channels. The detection of all relevant echo signals within the A-scan is ascertained, in spite of the data reduction

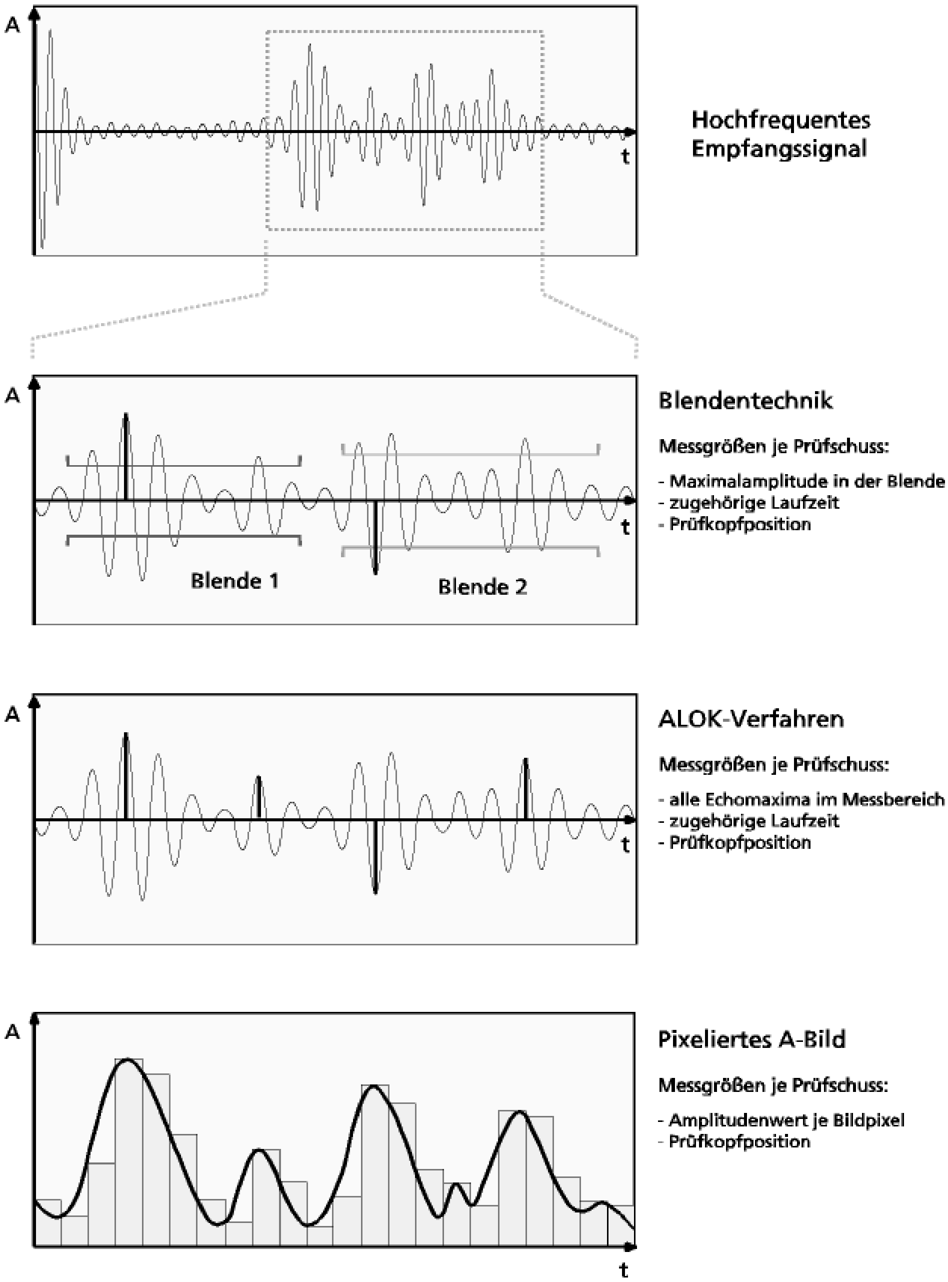



**Fig 5.5.4.2:** Data reduction techniques

using the ALOK signal recognition technique. Therefore it can be applied advantageously for large-scale tests at high speed (e.g., test of large components, pipeline inspection, heavy plate inspection).

Through application of the ALOK signal recognition and subsequent use of a pattern recognition technique for clearance of the measured signals from stochastic noise the described procedure is quite insensitive against electrical and acoustical interference. This also can improve the results in the case of geometry related indications.

The application limits are reached when storage and processing of the radio frequency input signal is needed, e.g., if defect analysis with the SAFT technique is required (see 5.6).

**(c) Pixelisation of A-scans**

If during an examination a high resolution capacity for separation of closely adjacent ultrasonic signals is required, a useful alternative to the ALOK technique can be the pixelisation of A-scans described in the following.

In this technique, the complete A-scan is recorded for each test position. After digitisation, the receiver signal is divided into a selectable number of A-scan pixels. An A-scan pixel thus contains several sampled values from the digitised signal. If a digitised amplitude value within the pixel range is greater than the first and greater than the last amplitude value, this value is recorded. If this does not occur, the first amplitude value within the pixel range is stored as the measured value. The result of a pixelisation is shown in Fig 5.5.4.2.

Compared to the acquisition of RF data, through pixelisation as described a data reduction is achieved. The reduction factor is determined by the number of values in an A-scan pixel. The resolution of the stored pixelised A-scan is dependent upon the test frequency and the degree of data reduction; it is selectable according to the test requirements through adjustable pixel width. After the test is completed, the stored pixelised A-scan can be displayed e.g. for analysis purposes.

### 5.5.5 Data storage

For carrying out those assessments that cannot be performed on-line, or for archiving the test data for later documentation of activity and proof of quality or for re-evaluation, different electronic storage media are available:

- Magnetic tapes
- Magnetic disks
- Diskettes
- Magneto-optical disks
- CD-ROM's
- DVD's

It is recommended to keep at least two copies of the data, if long-term archiving over tens of years is required. Readability check cycles have to be run regularly.

Regarding the highly dynamic and innovative market for electronic storage hardware, data will have to be recopied on modern data carriers well in time before media, operating systems and data storage software currently in use are no longer available.

For data storage, an appropriate data format should be selected. As touched on above, existing requirements concerning reproducibility and accuracy of the data have to be considered, along with the required storage capacity. Furthermore, it is essential which subsequent data processing steps should be carried out by which software and whether data exchange between differing systems should be possible. Respective universal data formats shall be defined.

Images can be stored as BMP-, JPG- or TIFF-files, for example, which than can be inserted into documents by many word processing programs. Used program versions must be compatible. If original data can only be stored in special binary formats, data format and structure have to be specified and documented in detail.

“TRAPPIST“ /6/ and “ZEUS” /7/ are examples for ultrasound data formats already defined and generally applicable.

A detailed specification of the requirements defining the features of the archiving system is recommended.



### 5.6 Data representation, evaluation and assessment

For optimum representation, evaluation and assessment of examination data, those conditions outlined in 5.5.2 through 5.5.6 concerning data acquisition, processing and storage must be considered.

Type and scope of data representation, evaluation and assessment are dependent upon the examination task. Data processing can be performed on-line or off-line.

On-line techniques will be applied if assessed test results are required in short time, e.g., during mobile in-service inspections prior to moving the test system to another site. In this case, evaluation and assessment are mainly performed by computers. This requires that all measured values are available for evaluation and assessment simultaneously to the data acquisition, e.g. on the same server. Data transfer can be accomplished via a network (on-line) or a data carrier (quasi-on-line). In special cases, test results are available in real-time and then can be used for process control. Another example is a good/poor sorting during tests of mass products, mostly using fully automated test systems (e.g. for tests of plates, rods, pipes, wheels, billets etc.).

Off-line processing is always required, if time-consuming assessment steps are needed. Examples of this are: analysis of indications at poor signal-to-noise ratio or data synthesis using tomographic techniques. It is also called off-line processing, if for technical reasons, data acquisition has to be carried out at different time and different place, e.g. pipeline inspections using pigs.

In practice, mixed procedures are frequently applied, e.g., a real-time alert on threshold override (acoustical, alarm lamp, colour marking by paint jet) followed by off-line re-assessment of indications.

Besides standard software for evaluation of echo-height and time-of-flight, specific analysis programs can be  required.

It is recommended to write a detailed specification for the evaluation of measurement results of mechanised ultrasonic tests, e.g. as described in the VGB guideline  R515 for power stations /see10/.

### 5.6.1 Representation of data

For evaluation and assessment, depending upon the respective requirements, the measurement values have to be represented as acoustical/optical signals, analogue/digital display presentations or as hardcopies on paper. Here it has to be ascertained that agreed assessment criteria are clearly recognisable.

General requirements are the representation of sufficient coupling, of complete coverage of the area to be tested  and of missing of measurement data.

The advantages of automated testing can be fully exploited, when using graphic images of the stored results. The great amount of measuring data can be evaluated and assessed completely and quality-assured only if the results are represented graphically.

According to EN 1330-4 (Non-destructive testing – Terminology - Part 4: Terms used in ultrasonic testing) the data representation formats most frequently used are:

**A-scan representation:** Signal representation of amplitude (ordinate) over time (abscissa).

Note:
The amplitude is represented either rectified or as RF signal (see Fig5.6.1a).

**B-scan representation:** Acoustical image whose image plane is perpendicular to the test surface. Position-related A-scan presentations are recorded along a path. The acoustical axis is located in the image plane at each probe position (see Fig5.6.1b).

Note:
The amplitudes are displayed in either colour- or

grey scale formats. In contrast to the TD-scan representation (Time-Displacement), the refraction angle is considered when using angle beam probes.

**C-scan representation:** Acoustical image whose image plane is parallel to the test surface .Amplitude values (or gated values) are represented in the image plane. C-scan representations are obtained through scanning of the test area using the pulse-echo or transmission technique (see Fig5.6.1c).

Note:
The amplitudes are displayed in either colour- or grey scale formats.

**D-scan representation:** Modified C-scan representation; time-of-flight values are recorded and represented instead of amplitudes (see Fig5.6.1d).

Note:
Frequently, time-of-flight values are converted into sound path values. The values are displayed in either colour- or grey scale formats.

**P-scan representation**: Projection image of several B- or C-scan representations.

Note:
Normally in this case, the inspected volume is represented as top view, side view and end view on one page (see Fig5.6.1e).

With respect to the examination task, non-standardised representations of results can also be useful, e.g. the TD-scan representation.

**TD-scan representation**: Acoustical image, whose image plane is perpendicular to the test surface. Position-related A-scan representations are recorded along a path. The acoustical axis is located in the image plane at each probe position (see Fig5.6.1f).

Note:
The amplitudes are displayed in either colour- or grey scale formats. The refraction angle is not considered.

Further graphic representations are produced by reconstruction from measurement data. They require specific software and, if necessary, a special data acquisition technique (see 5.5), which enable improved indication assessment up to a precise indication sizing, e.g.:

SAFT (Synthetic Aperture Focussing Technique)

TOFD (Time-Of-Flight Diffraction Technique)

Echo tomography

**SAFT representation** Using a probe with large angle of divergence, RF A-scan representations are acquired in dense intervals along the scanning path, then digitised and stored in the computer. For reconstruction, the echo amplitudes are distributed across the sound beam aperture dependent on their time-of-flight-values. Then the amplitudes are added with respect to their positions of sound entry and their phases. Thereby, reflector signals are enhanced while noise signals are minimised (improvement of the signal-to-noise ratio). With increasing density of A-scans, the reflector signal can be better distinguished from the background. (See Fig5.6.1g)

**TOFD representation** The TOFD representation is a B-scan representation composed from RF A-scans acquired by separate angle beam probes arranged in V-transmission geometry. The transmission signal of the lateral wave at the test surface, diffraction signals of discontinuities within the bulk material and the back-wall echo are displayed. The amplitudes and phases are coded in colour- or grey scales. The time-of-flight values in the indication pattern of the TOFD representation are evaluated. Thereby, depth and position of discontinuities can be determined. (See Fig5.6.1h)

**Echo tomography representation** The echo tomogram is a SAFT representation in which A-scans are acquired with a straight beam probe along a rotationally-symmetrical path. To improve the signal-to-noise ratio as well as the detectability for oblique reflectors array probes can be used, whose sound beams at each probe position are swivelled between defined angles . RF as well as rectified signals can be used. (See Fig5.6.1i)

Note:

Tomograms are typically taken on cylindrical objects. Tomograms from non-cylindrical objects can be generated using modified probe guidance and signal processing.

Statistics based on measurement data can be used for integral evaluation and assessment of measurement results. By comparison with a reference statistics, they enable an integral assessment of the test procedure, of hardware operation and of acoustical features in the entire tested area.

As an example, the frequency distribution of the echo amplitude values of an entire weld area is displayed in Fig5.6.1j. The peak of this frequency distribution at about 25% FSH (-38 dB) represents the background noise of the test scan. The values in the range of 35% through 75% FSH originate from the echoes of a test reflector. The noise peak can be represented by a Gaussian curve. Since no significant peak is detectable at zero FSH, correct coupling can be assumed.

If in the frequency distribution no amplitude values exceeding the reporting threshold are detected, further evaluation can be omitted. Coupling losses, or reduced coupling can be recognised by the shape of the frequency distribution. In this case a shift of the peak position towards lower signal heights will appear, or the curve will show a peak at zero FSH respectively.

On all representations the information necessary for coordination and interpretation of the measured data must be included. Depending upon the type of representation and the requirements of evaluation and assessment, the following parameters may be needed:

- Test object
    - Material characteristics (e.g., sound velocity)
    - Component co-ordinates (e.g., weld position)
- Identification code of the test respectively the representation
- Date
- Probes
- Inspection technique
    - Inspection from inside or outside
    - Multi-mode techniques: information about each wave mode required
- Instrument setting, e.g.:
    - Amplification
    - Recording level
- Evaluation level

- Representation type
- Representation area
- Representation threshold
- Image processing parameters
- Colour scale with fixed assignment to recording and evaluation level
- Sound path in mm or time-of-flight in µs

### 5.6.2 Evaluation of data

The evaluation of the measured data is performed in compliance with the test specifications and the required assessment criteria, by selection of an appropriate data representation (see 5.6.1). This includes the check of the represented data for completeness, for ability to be assessed and for compliance with the given test parameters.

It is possible to minimise the scope and effort of evaluation through the following techniques:

- Setting of amplitude thresholds and time-of-flight gates
- Reduction of classification levels (colour steps)
- Elimination of interfering and geometry-related indications
- Statistical evaluation (e.g., of the amplitude distribution) for selection of test areas requiring evaluation
- Automatic sensitivity compensation (e.g., DAC-compensation curves)
- Image enhancement through weighted averaging and filtering
- Automatic recognition of indications requiring evaluation

It has to be ascertained that by this evaluation no information is lost that is required for subsequent assessment.

### 5.6.3 Assessment

Generally, technical specifications are the basis for assessment. The assessment criteria are defined there according to the product and its field of application.

These assessment criteria can relate to:

- Height of the echo amplitudes
- Equivalent flaw size, i.e., the size of a reflector of defined shape (e.g., circular disk, notch) producing equal echo amplitude

- extension of the indication in the scanning direction and/or perpendicular to the scan tracks
- Depth position of indications (embedded or at the surface, respectively)
- Orientation of the indication extension (longitudinal/transverse)
- Clusters of indications
- Formation of indication patterns
- Flaw type (volumetric or planar)
- Actual flaw size

According to the requirements, the assessment can be performed manually, semi- or fully automatic. The assessment steps have to be definite and reproducible.

An echo-height assessment, usually combined with a determination of the indication size, is performed as standard practice. Added amplification included in the evaluation must be considered.

To determine the indication size, usually the half-amplitude technique is applied. The half-amplitude extension is determined using echo dynamic curves at a 6 dB drop of echo height, with respect to the maximum or at a registration level previously established. The half-amplitude extension is a measure for the respective reflector size only if the diameter of the sound beam within the range of the discontinuity is smaller than the half-amplitude size of the indication.

The quarter-amplitude technique (echo height drop of 12 dB) is applied when the difference between half- and quarter-amplitude sizes is in the order of the beam diameter.

The representations (e.g., C-scan representations) of different measurement results are compared by pattern comparison:

- Measurement results of different tests of the same test area (periodical tests)
- Measurement results of a reference object (master image) with those of the test object
- Measurement results with modelling calculations

Pattern comparisons are required, e.g., if the echo height criteria are not definite, if the signal-to-noise ratio is insufficient or if the evaluation is hampered by geometry related indications.

If actual flaw sizes are required as assessment criteria, further analyses of the flaw signals will be necessary. Besides SAFT, TOFD and echo-tomography, other analytical techniques are available, e.g. the assessment of crack tip signals /10/.

In the case of poor signal-to-noise ratio, geometry related indications, complex object geometry or complex reflector geometry, the results of other test methods as well as the knowledge of a qualified level III expert could also be required.

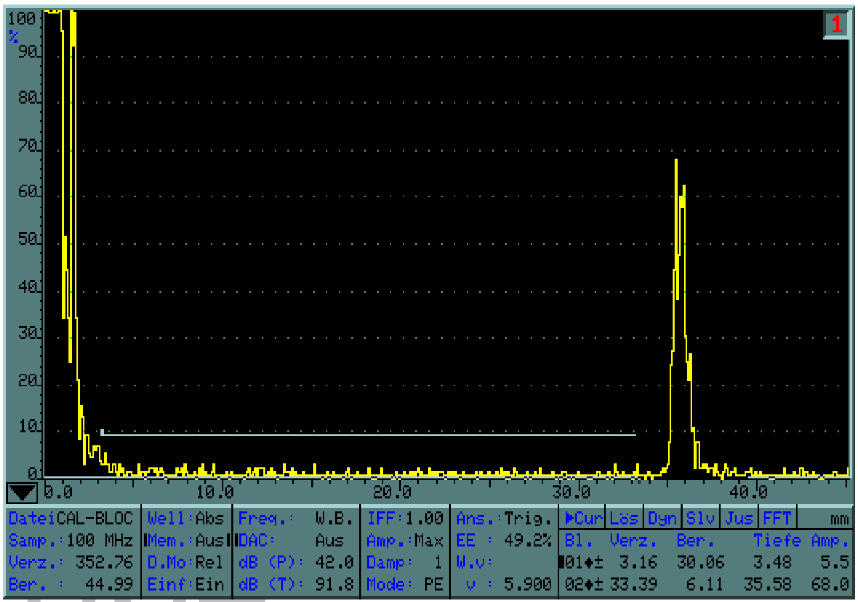



**Fig 5.6.1a:** **Typical** A-scan representation

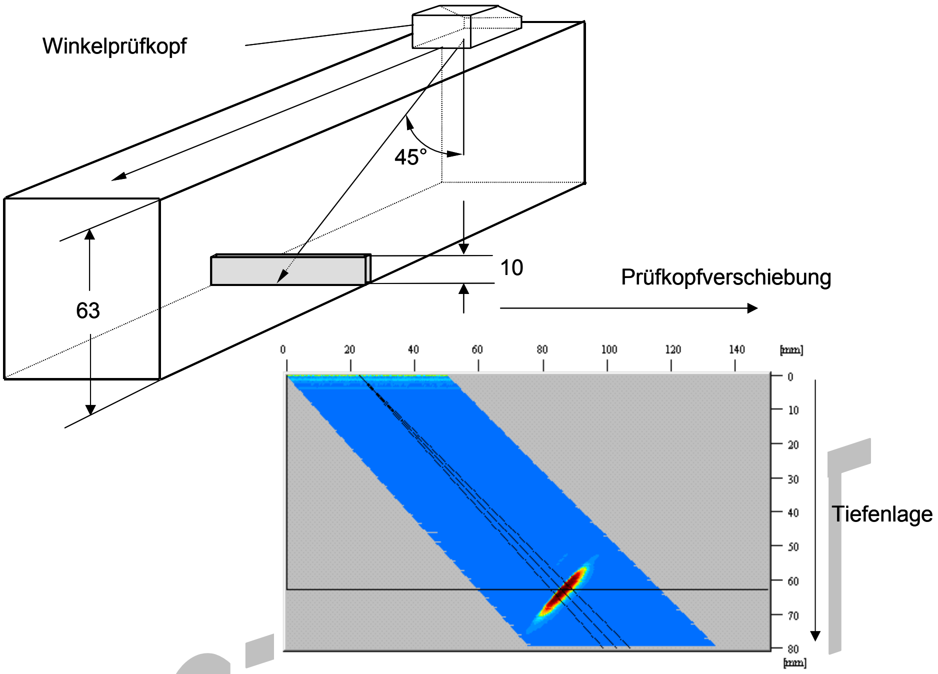
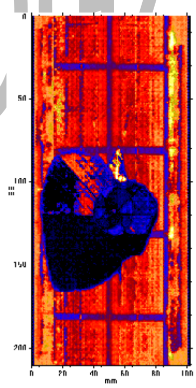
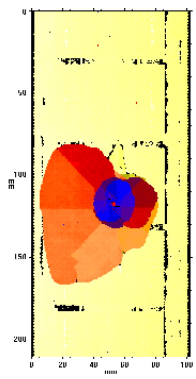



**Fig 5.6.1b:** B-scan representation with notch indication by an angle beam probe





**5.6.1c:** C-scan representation (back wall echo amplitude)

**5.6.1.d:** D-scan representation (time-of- flight of back wall echo)

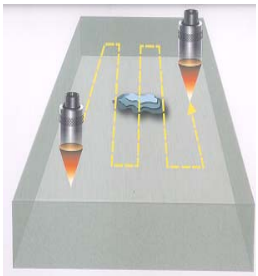
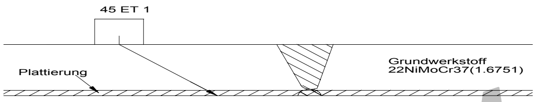


**Fig 5.6.1:**
C- and. D-scan representation of ultrasonic testing of a delamination (impact in a CFRP plate)



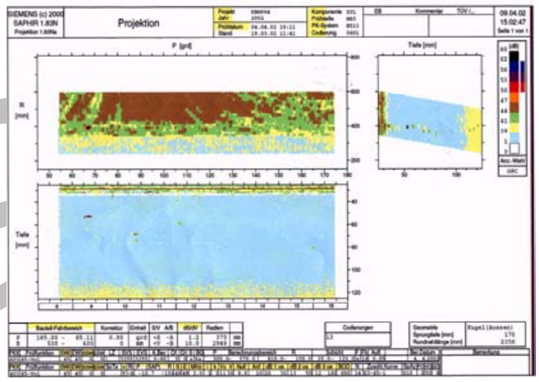




**Fig 5.6.1e:** P-scan representation

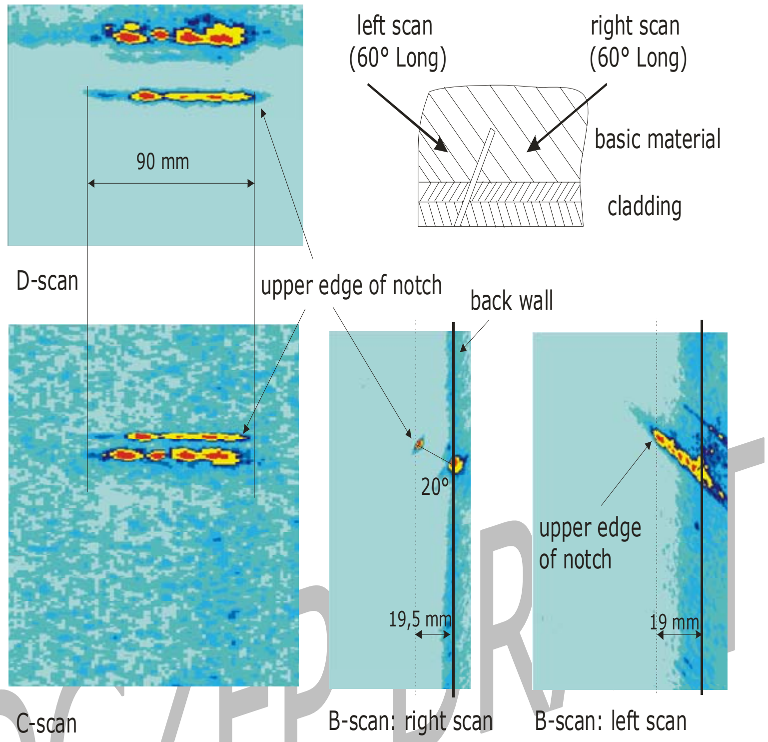





**Fig 5.6.1f:** TD scan representation of a cylindrical hole indication by a normal beam probe

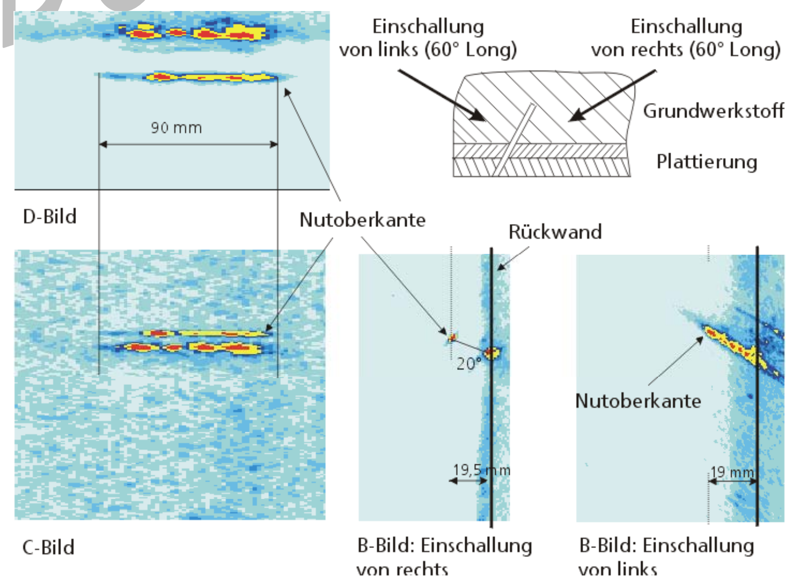



**Fig 5.6.1g:** SAFT-representation of an ID connected reflector in the cladding

area of a heavy walled vessel (wall thickness 150 mm)

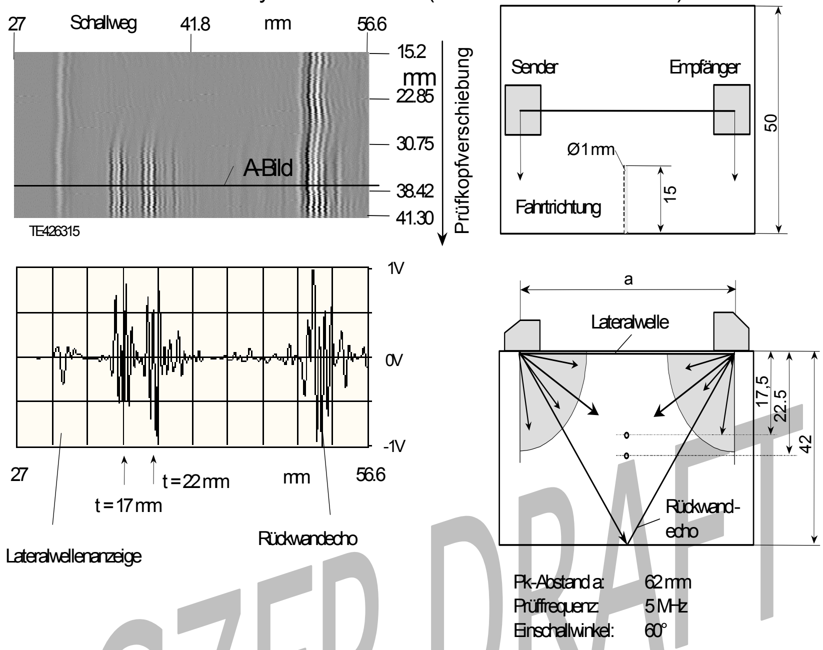





**Fig 5.6.1h:** TOFD representation

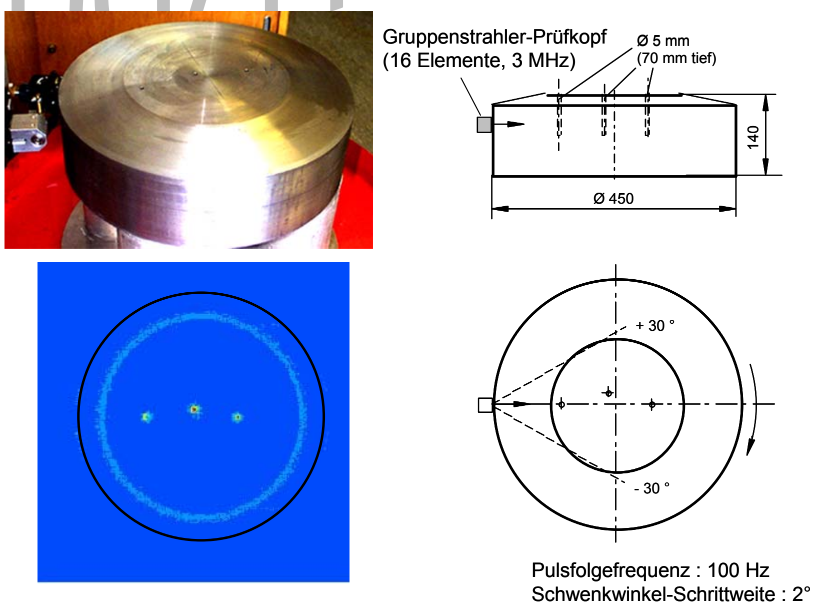



**Fig 5.6.1i:** Tomographic representation of indications from cylindrical holes by an

array probe

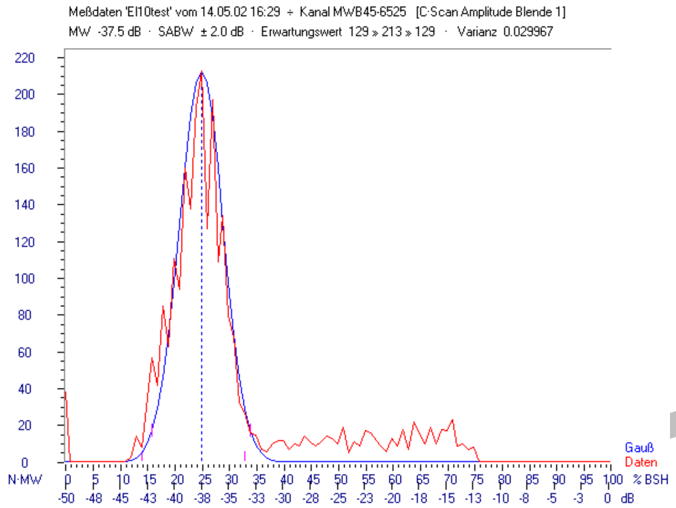



**Fig 5.6.1j:** Frequency distribution with a Gaussian function fit



## 5.7 Process control

Automatic testing equipment requires processing of all tasks necessary for the testing. Depending upon the examination task, the test requirements and the degree of automation, examples of these are:

- Object feeding
- Object recognition
- Assignment of test parameter
- Activation of auxiliary and supplemental systems, safety measures
- Control of test mechanics
- Initialising of the testing
- Test monitoring, coupling control, system checks, interface monitoring
- Acquisition, processing, transfer and storage of data, data safety measures
- On-line assessment and representation
- Control of colour marking, sorting
- Logging, documentation
- Object removal
- Release

Due to the multitude of design variants of testing systems and due to the frequently close link to individual industrial processes (testing systems in production lines or maintenance systems), a generally applicable process control cannot be described. A practical example is described in 8.8 (billet test facility).

### 5.8 System check

An essential condition for the application of automated testing systems is the reproducibility of the test results. Reproducibility/repeatability of the test means that equal test results are obtained within the system tolerance limits when using equal test conditions. To achieve this, certain control measures are required.

A system check is defined as the execution of an integral test run using appropriate aids (e.g., reference or test objects) during which all components of the test system (e.g., probe, ultrasonic instrument, manipulator, storage unit, display, printer etc.) are checked for functionality and interaction. It serves for monitoring of the system status and for quality assurance of the examination. The results of the system check must be included in the documentation.

The system check includes checks of the system and its components before and after the testing, as well as operation monitoring during the testing.



**Component test:**

Prior to start and, if needed, after termination of the test, each component of the test system is checked for its functionality. Component checks can also be required during operation.

Depending upon type and scope of the system check the component test can be executed in three steps:

1) Electrical self-test

   On initialising (normally after power-on and/or reset), each active system component executes a self-test routine. Hereby, the component tests itself for correct electrical functionality.

2) Functionality test

   An ultrasonic device can be checked for the reproducibility of its acoustic performance and its tolerance values, e.g. by execution of a pattern comparison of an reference object using a connected probe.

   A manipulator can be tested for reproducibility of its positioning precision, e.g. by approaching particular reference spots.

3) Checking of operation parameters

During routine test equipment systems checks, testing relevant operation parameters, such as amplifier linearity, have to be done regularly.

**System test**

Following the component test, a test comprising the entire system (system test) can be carried out, e.g., by a reference test using a reference object with well-known reference indication patterns. This object can be a calibration block or the component to be tested itself.

The system test can be executed in fixed intervals or continuously. Thus malfunction of single components or misadjustments are recognised and documented during the next scheduled system test.

**Operation monitoring**



Operation monitoring supplies the user of the testing system with feedback containing information about the basic functioning of the single components and their correct interaction during the testing. Therefore the information about the operational status of the components (e.g., temperature, voltage, position, remaining available storage capacity, statistical data) is evaluated and displayed. On overriding the predefined tolerance limits of an operation parameter an immediate alert has to be released and documented.

The assessment of the malfunction with regard to its relevance concerning the examination task and the decision about immediate correction is up to the user of the test facility.

# 6 Performance of tests

## 6.1 System setting and adjustment

Prior to testing, the system configuration has to be set. Usually this is given by the test specification. Essential parameters are:

- Testing range (e.g., gate setting, scanning range)
- Testing frequency (dependent upon flaw type and size, material characteristics)
- Testing sensitivity (dependent upon test specification)
- Testing process (scanning range, repetition frequency, sequence, testing speed, testing grid)
- Detection criteria (threshold setting dependent upon test specification)

In automated testing systems, usually all settings are entered, executed and documented by computer.

The aim of the adjustment is, according to the examination task, to establish a defined correlation between signal time-of-flight and reflector position and/or signal amplitude and reflector size.

For this purpose reference specimens or calibration blocks with well-known sound paths and defined reference reflectors are used. Depending on the examination task, notches, flat bottom holes, cylindrical holes or others are used as reference reflectors. It is essential that the reference material exhibits acoustic characteristics largely identical to those of the examination object. Depending on application, (e.g. the testing of mass products with identical geometry) the use of an original test object as a reference standard is recommended (see also EN 583-2 „Non-destructive testing – ultrasonic examination - part 2: Sensitivity and range setting).

Besides adjustment of the ultrasonic components, the test mechanics have to be positioned correctly on the test object (e.g., reference point and orientation of the co-ordinate system).



## 6.2 Testing

Besides system settings and adjustment, prior to the testing an operation check of all system components has to be made, so as to recognise possible interferences or malfunctions (see 5.8).

Furthermore, it has to be assured prior to test execution that the basic conditions are met required for quality assured testing, e.g.:

- Preparation of the testing surface
- Feeding and removal of the coupling agent
- Safety measures

During testing the operation of all test channels of automated scanning systems should be permanently monitored (e.g., loss of coupling; see 5.8).

## 6.3 Interferences during testing

Typical interferences occurring during testing are due to influences like:

- Electromagnetic interferences (e.g., welding or crane operation)
- Other sources of ultrasound (e.g., mechanical treatment of the test object)
- Influence of temperature upon propagation of ultrasound and the probe behaviour
- Irregular coupling (e.g., air bubbles or surface effects)
- Excessive material wear due to disadvantageous environmental conditions

These can lead to a test stop or to incorrect test results.

These influences have to be assessed and, by appropriate measures, avoided or at least corrected. Such measures could start with grounding of the system and extend to filtering of interference signals through pattern recognition procedures.

### 6.4 Evaluation and assessment

As a first step in evaluation and assessment it has to be ascertained that:

- The representations required for assessment are complete
- The information compiled in the data representation concerning the test parameters meets the specifications
- The testing range, depending upon the specific examination technique, was completely covered
- No, or tolerable, coupling losses occurred
- An assessment of the measurement data is possible with respect to actual signal-to-noise ratios and existing geometry/spurious indications.

Assessment restrictions also have to be accounted for regarding to the specifications. If necessary the data acquisition has to be repeated.

Furthermore it has to be ascertained that the entire procedure leading to the result is reproducibly documented.

Spurious and geometry related indications should be clearly identified and, in doubtful cases, treated as defect signals. It is recommended to refer to the presence of spurious/geometry related indications or to restrictions of the assessment in the documentation of results.

The plausibility of proper data acquisition and evaluation/assessment can be checked by known geometry related indications (pattern comparison) or by statistical representations of the measurement values.

Regarding the specifications, assessment results have to be documented as yes/no statements (“fulfilled“/“not fulfilled“), as qualitative statements (e.g., “no indication of alteration“) or as quantitative statements (e.g., “planar separation 20 mm x 10 mm“).

If the assessment criteria as quoted in the specifications are not fulfilled, any further measures must be agreed upon with the customer.

### 6.5 Documentation

The documentation is an essential part of each testing and it should contain all information relevant for the testing. These are for example:

- Date/time of the testing

- Inspector identification (including signature)
- Description of the examination task
- Description of the system including device identification number
- System settings
- System failures
- Probe documentation including:
    - Identification-no.
    - Probe type
    - Design
    - Housing dimensions
    - Frequency spectrum
    - Echo dynamic
    - S/N-ratio
    - Transducer dimensions
    - Number of transducers
    - Delay path
    - Angle of incidence
    - DGS diagram
    - Sound field

In the case of multi-mode operation, information about all modes applied have to be documented.

- Inspection results including:
    - List of indications/defects
    - Notes on geometry/spurious indications
    - Notes on restrictions of assessment
    - Description of defects
- Evaluation/assessment documents as required.
- Raw data as required.

# 7 Performance proof

## 7.1 General considerations

The user or purchaser of non-destructive testing expects from the application of an automated testing system the assurance respectively the check of quality. The essential points of this expectation were defined in the examination task from which the requirements to the test system have been derived (see 4).

Based on these requirements procedures for performance tests of the system must be mutually described. (Acceptance of the test system). The major objective is the clear evidence that the particular testing system meets the defined demands. The procedure and the results obtained from the performance proof shall be documented.

### 7.2 Contents of the performance proof

The essentials of a performance proof are:

- Nomination of the parties involved, the description of their qualifications, their duties and responsibilities
- Definition of the scope
- Definition of criteria for assessment of the testing system
- Consideration of valid standards and guidelines
- Description of the procedure concerning the execution and assessment
- Definition of statistical methods for assessment of the testing system
- Definition of the reference specimens and the reference reflectors, respectively
- Definition of the type and scope of the documentation



### 7.3 Execution of a performance proof

The performance proof can be carried out modularly or with the entire testing system.

Practical experiments are of essential importance. These experiments can be carried out using original test objects as well as reference specimens. The latter ones must be representative of the test objects with respect to geometry and physical properties. Number and variation in size and position of the incorporated reflectors must be sufficient for a statement on the detection efficiency of the system. Artificial flaws like drill holes or notches, as well as natural flaws can serve as reference reflectors.

In any case, the actual reflector dimensions have to be measured either in advance with appropriate techniques or, for instance, by subsequent destructive examination.

The performance proof can be carried out with knowledge of the reflectors incorporated into the reference specimen as well as with unknown reflectors (blind tests).

During execution of the performance proof, the required probability of detection must be determined by a sufficient number of experiments.

### 7.4 Documentation of a performance proof

The result of the performance proof shall be documented in a report. This final report must contain at least the following information:

- Objective and scope
- Testing technique, testing system and techniques applied
- Execution (procedure, workflow etc.)
- Identification of the test object and the area tested
- List of all standards, specifications and instructions applied
- Deviations from the standards, specifications and instructions applied
- Influencing parameters including discussion and assessment (weighting)
- Limits of the performance proof concerning methodology, testing method, testing system, test technique, test block/reference specimen, etc..
- Qualification, competence and area of responsibility of all personnel involved
- Results of system calibration
- Examination results
- Discussion and assessment of the examination results including detected deviations from the expected results (aims of the examination), tolerances, spurious echoes, geometry related indications, false indications etc.
- New test instructions as a result of the performance proof
- General data like location, date, etc.

To write this report, the guidelines VGB R-515 and R-516 as well as the CEN-report CEN/TR 14748 give valuable advice. In addition, the standards of the series EN 10246-... for automated testing of steel pipes can be used as examples.

The final report must be accessible at any time. It must be archived for the entire period of application of the procedure.

# 8. Examples

## 8.1 Examination of laser welds on a truck indexing gear-wheel

Dr. Rudolf Bilgram, EADS, München

### 8.1.1 Basic set-up of the testing system

The system consists of a semi-automatic immersion facility, including a rotating robot manipulator with the probe attached. The test object and support table remain stationary. The system operates using the pulse-echo technique with a USIP 20 instrument.

Specimens are fed and removed manually. The different types of gear-wheel are identified automatically by sensors located at the bottom of the immersion tank. The subsequent test procedure and the evaluation are also conducted automatically.

### 8.1.2 Test-related technical objectives and conditions

The aim of the test is to detect welding defects such as pores, lack of fusion and cracks in the laser welds. The circular weld connects the gear-wheel and synchronizing ring (see Fig 8.1.2.1) of different truck gear units, where different gear-wheel types have to be tested.

The test procedure has to be integrated in the production process without causing any delay. This system enables 10% of the lot produced to be tested non-destructively, where the weld receives a complete scan within 15 s. The period of a complete test cycle is 50 s. The result of each scan is recorded in the system, and is available as a C-scan representation.

### 8.1.3 Components and features of the testing system

In the immersion tank, the probe (15 MHz, type H15 MN30) is positioned at the gear-wheel by the robot manipulator and this performs all the movements during scanning (rotation and indexing in radial direction); the direction of sound incidence is axial. Positioning information is therefore obtained by robot axis control.

An ultrasonic instrument USIP 20 is used operating with gate technique and threshold value discrimination. No further signal processing is performed.

The motion of the probe is linked via an incremental angle encoder unit with a CNC control and the USIP 20 by computer, in order to obtain the positional co-ordinates for image visualization.

Automatic component recognition initiates a re-adjustment of the ultrasound and motion parameters from the configuration file.

The test scan is interrupted automatically on detection of a defect (exceeding threshold level). Then the operator acknowledges the process and the testing is continued. The defective gear-wheel is discarded.

### 8.1.4 Test execution

The gates and evaluation thresholds are set using a component segment containing test reflectors that serves as a reference object. The gate setting is obtained by comparison of the A-scan representation with the geometry of the reference object. The setting of the recording level is verified by test reflectors, and by evaluation of micrographs of real defects. The system is adjusted on-site using these data.

Reproducibility is ensured through computer-aided parameterisation of the USIP 20 with defined stored values as well as by regularly scheduled comparison with reference data of a complete component.

The adjustment parameters of the probe motion are: starting point of the scan, distance of the probe to the edge of the component and radial track index. The weld is scanned by eight circular tracks.

The test is performed in the following steps:

- Positioning of the wheel onto the centre cone and then immersing it into the tank
- Program launch by start button (manually)
- Centring by up-and-down movement of the centre cone, identification of the wheel type
- Scanning of the wheel by eight radial positions and evaluation/assessment of the ultrasonic data in real-time mode by computer
- Removal of the wheel

An operational check during series production is performed by testing components with well-known defects (pores, cracks, root flaws etc.). Thus, a fast system check is possible without interrupting production.

A computer printout of the test result can be triggered if a defect is detected.

The main source of interferences leading to incorrect test results is contamination of the immersion fluid. This means that regular scheduled cleaning has to be performed.

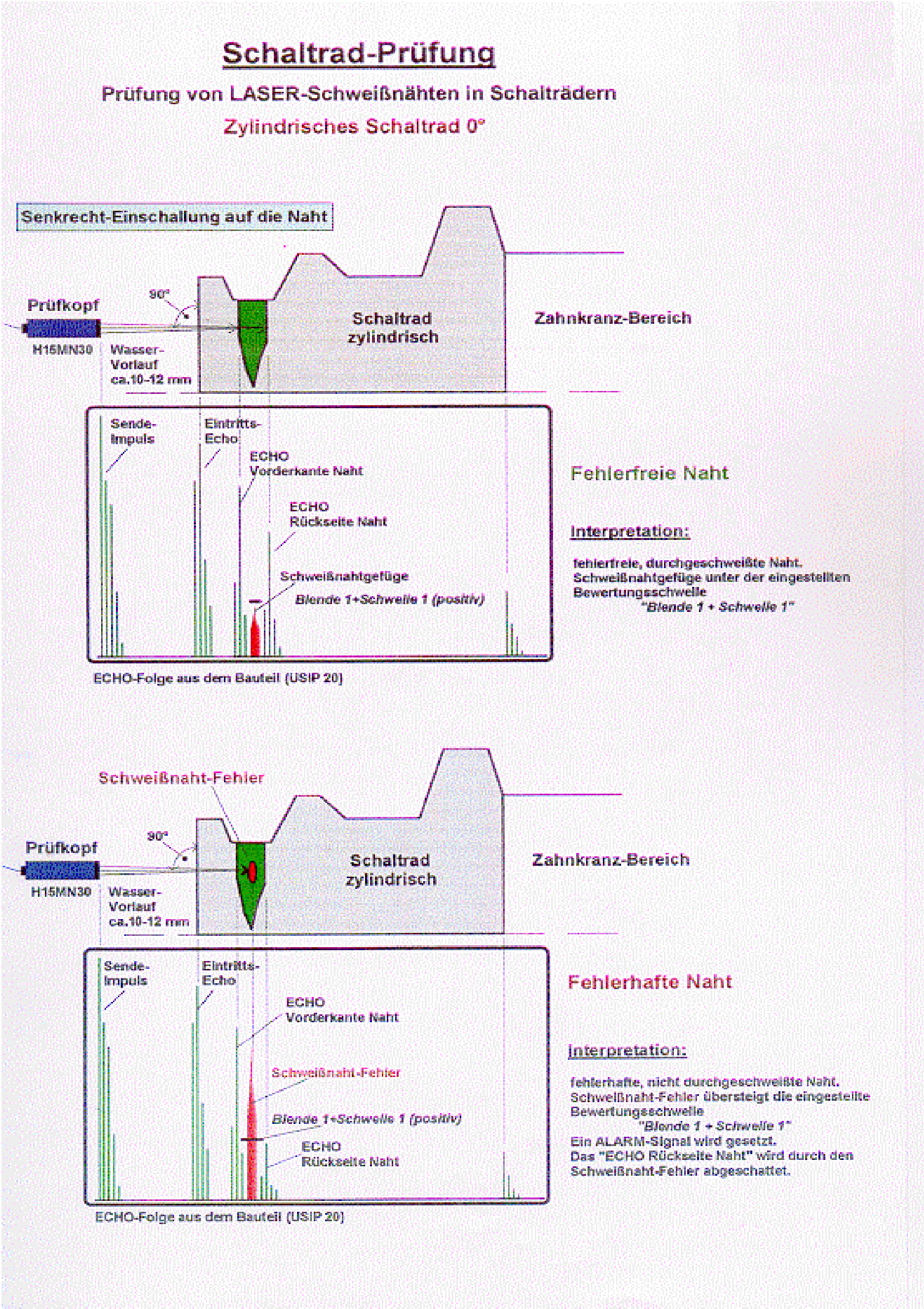



Fig 8.1.2.1: **Testing of a welded indexing gear-wheel**

## 8.2 Automated ultrasonic testing of welds in aluminium pipes

Dipl.-Ing. Roland Reimann, Framatome, Erlangen

### 8.2.1 Basic set-up of the test system

The system LINIUS MK consists of an industrial PC with up to four selectable ultrasound channels, a control unit and appropriate manipulators. The control unit is freely programmable in three axes. Digital ultrasound data are acquired and pre-assessed by software. Different aids like C-scan as well as TD-scan presentations are available through special evaluation software. The documentation can be performed interactively.

In connection with the optimised, compact and modular scanner design, the system is able to meet a multitude of examination requirements. Different manipulator constructions are available:

- a scanner for tests of pipe welds (size from DN 80 through DN 800)
- an area scanner for flat or curved vessel walls
- a nozzle scanner with rotating probe support
- a manipulator for pipe elbow tests (e.g., for tests of longitudinal welds or the base material during erosion/corrosion measurements)
- special manipulators for application in nuclear facilities

This system, connected with a newly developed closed loop water coupling system for the ultrasonic probes, is designed for mobile use.

### 8.2.2 Test-related technical objectives and conditions

As a typical example of industrial use, the application of the test system LINIUS MK for automated testing of orbital welds performed on spirally welded aluminium pipes is described.

For the production of gas insulated conductors (GIL) for high voltage transfer up to 800 kV, pipes with an outer diameter ($D_a$) of 500 mm – 650 mm and wall thickness s from 6 mm to 9 mm made of aluminium alloy AlMg3 are used (example: $D_a$ = 517 mm, s = 8.5 mm nominal size). These pipes serve as a casing for the insulating gas (mixture of $N_2$ and $SF_6$) that surrounds the cables under current. The GIL are designed for a total operation lifetime of 50 years.

The girth welds of these pipes have to be tested completely using LINIUS MK immediately after welding on-site without production delay.

The tested area covers the complete weld, as well as the surface areas adjacent to the root (inner surface) and the heat affected zone (HAZ) on both sides of the weld.

The objective is to detect discontinuities like lack of fusion and elongated pores that could lead to failure of the component. The test is done in accordance with EN 30042, quality class C.

During the qualification process of the ultrasonic testing system LINIUS MK, the required test sensitivity was determined by using natural and artificial flaws. The instrument setting is carried out using appropriate reference specimens containing notches at the inner and outer surface.

### 8.2.3 Components and features of the test system

The components of the test system are shown in Fig 8.2.3.1.

The probes selected for this test (test frequency 3.5 MHz) are attached to special carriers, which are adapted to the contour of the aluminium pipe (see Fig 8.2.3.2).

The probe localisation is performed within an x- y- z- co-ordinate system starting from a reference point permanently marked at the surface of the test specimen. This point serves as zero-adjustment (to correlate the test position to the co-ordinates of the manipulator control) at the beginning of each test.

During the entire test the ultrasonic data are recorded in relation to position and orientation.



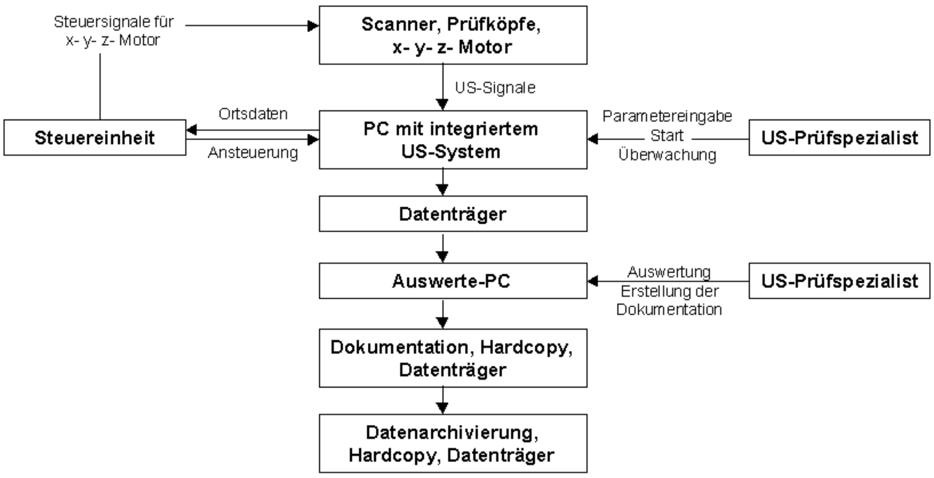



**Fig 8.2.3.1:** Components of the test system

### 8.2.4 Test execution

The entire system set-up is carried with few steps. The scanner is attached via quick clamp device to the guiding unit set up previously.

All cables and supply hoses are connected via quick release connectors.

Only for installing the guiding unit, the scanner and for zero-adjustment of the scanner control the inspector is needed on-site. For zero-adjustment on site the manipulator can be moved to the reference position via remote control.

The surveillance of the testing is performed remotely by an ultrasonic testing expert observing the A-scan presentation, whereby the distance is limited only by the cable lengths (i.e. up to 150m), see Fig 8.2.3.3.

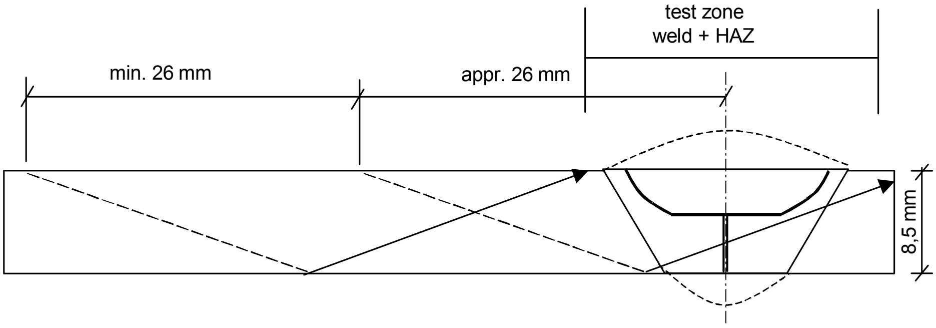



**Fig 8.2.3.2:**
Test manipulator

**Fig 8.2.3.3:**
Data acquisition system LINIUS MK with control unit

The test of the entire weld length for longitudinal defects is carried out with sufficient overlap in circumferential meander mode (parallel to the weld) by insonification from both sides of the weld. Hereby, generally a scanning resolution of 2 mm x 2 mm is used. For analysis, the axial meander mode respectively another test raster is applied.

The weld volume is inspected between half and full skip, i.e., after reflection at the inner side of the pipe (see Fig 8.2.3.4).

**Fig 8.2.3.4:** Weld geometry, sound path, scanning path in y-direction and test zone for a 70° angle beam probe

The scanning path in y-direction is established so that the weld volume is inspected, but the disturbing area of the root is screened out as far as possible. The minimum scan path in y-direction is 26 mm (at a wall thickness of s = 8.5 mm), hence, at a track distance of 2 mm, fourteen tracks are scanned.

With the availability of the A-scan representations, the test is reproducible anytime. Except a pixelisation of the A-scan, no further data reduction or reconstruction takes place, so the evaluation is carried out using the obtained raw data. If required, these data are also available for further analysis.

Projection distance, distance to weld, echo dynamic behaviour, length and position of indication can be used for assessment. By changing the evaluation threshold after the test indications beneath the original reporting threshold can also be analysed.

The differentiation between relevant indications and shape induced indications originating from ovality of the pipe and misalignment of the edges can be performed by analysis of the C-scan representation.

By a threshold value comparison, a colour-coded evaluation of time-of-flight and amplitude values can be made. After termination of the evaluation a test report is set up interactively by the inspector. This contains all test-relevant data in a variable range. The test data and the respective documentation are stored and archived on CD-ROM.

## 8.3 Ultrasonic testing of heavy steel plates

Dipl.-Ing. Joachim Staudt, AG der Dillinger Hüttenwerke, Dillingen

Dipl.-Phys. Otto Alfred Barbian, NDT Systems & Services AG, Stutensee

### 8.3.1 Basic set-up

In our heavy plate rolling mill, the automatic ultrasonic test facility is integrated in the cutting line, between the cooling and visual testing bed and the crop shear (see Fig 8.3.1).

**Fig 8.3.1:** Total view of the testing system within the roller conveyor

The entire testing system is set-up modularly and consists of the following single components:

- Probes
- Test mechanics
- Process control unit
- Test electronics
- Software for
    - Data acquisition
    - Evaluation and result representation
    - Assessment of the test results

- Link to the host computer system

### 8.3.2 Test-related technical objectives and conditions

In order to test the requirements concerning the cleanliness of heavy plates, a modern ultrasonic testing system was installed in the rolling mill, which is capable of detecting and assessing small reflectors, according to the elevated requirements of the customers.

Due to the modular structure, single hardware and software components can be replaced easily in the future by new components without changing the basic concept of the testing system.

The system is designed for testing heavy plates in the thickness range from 6 mm through 60 mm, which are transported as rolled plate (in uncut and undivided state) over the conveyor at a maximum test speed of 1 m/s.

The facility is designed for an inspection covering 100 % of the area, so that in one test run body testing as well as edge testing (longitudinal and transverse edges) can be carried out.



General data of the plates to be tested:

| | |
|---|---|
| - Length: | 6 m – 50 m |
| - Width: | 1 m – 4.8 m (without crop cutting) |
| - Thickness: | 6 mm – 60 mm |
| - Temperature: | max. 100°C |
| - Testing speed: | max. 1 m/s |
| - Sensitivity of detection: | 3 mm ∅ · FBH (distance to both surfaces: up to 1.5mm) |
| - Evaluation technique: | DGS method |

### 8.3.3 Components and features of the test system

#### 8.3.3.1 Probes

The testing system operates using the pulse-echo technique with TR-probes. The probes are built in gimbal-mounted holders (see Fig 8.3.2) and are coupled to the plate to be tested by a water gap (0.2 – 0.4 mm). The water is supplied by the factory's internal water system.

Each wide-beam probe contains one transmitter and three receivers of composite material. The effective width is about 50 mm (i.e., the test track width for each receiver is about 17 mm). The probe operates at a nominal frequency of 5 MHz and is designed specifically for high resolution.

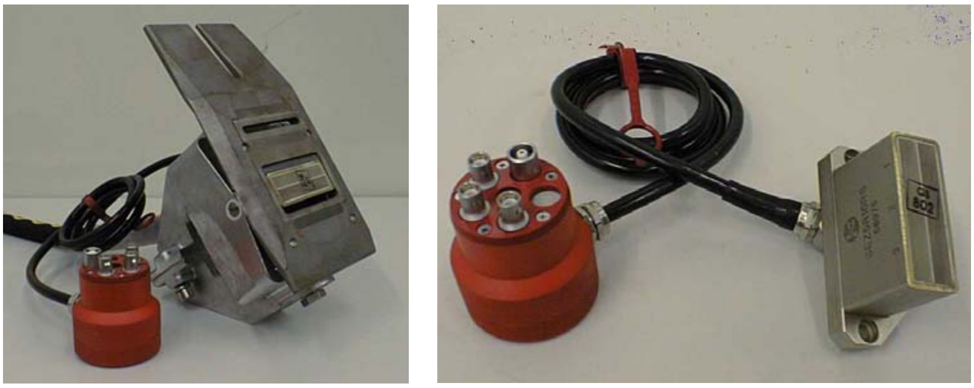


**Fig 8.3.2:** TR-probe in the holder (left),
apart from the holder (right)



### 8.3.3.2 Test mechanics and process control

For combined testing of body and edge zones, the probes are arranged in three test rows beneath the roller conveyor level with a total of 32 probes each. Each of the three rows covers one third of the plate width (see Fig 8.3.3).

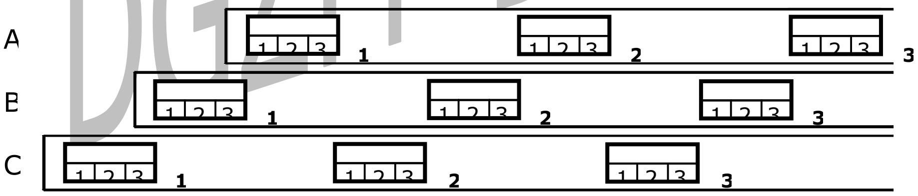



**Fig 8.3.3** Arrangement of the probes in three test rows A, B and C

Initiated by optical sensors, the probes are pneumatically moved to the plate. The process is controlled by the moving plate itself. Via a wheel, running on the plate, path-related pulses are generated for synchronisation.

### 8.3.3.3 Test electronics and evaluation software

Six electronic units, each containing 16 channels, are installed in parallel for each test row. All 288 receiver channels operate in parallel.

At each test cycle the A-scan including the second back wall echo is recorded by the AMUS electronics (Automated Modular Ultrasonic System), logarithmic amplified, digitised and reduced using the ALOK technique.

The ALOK data are processed by DSP modules (Digital Signal Processor). Out of the echo sequence the first and second back wall echo are extracted. By the time-of-flight difference of these echoes the gate where defect signals are expected is established for the respective test shot. The distance-amplitude compensation is also performed in the DSP modules.

Using the DGS technique, areas and lengths of reflectors in defined track sections (registration section) are calculated. The dynamic behaviour of the back wall echo is monitored continuously, assessed and used for alert purpose (e.g., “coupling malfunction“).

The calculated size and the respective depth position of a reflector per registration section are transferred to a central master DEU processor (Data Evaluation Unit). If the reflector area is greater than the pre-set registration level, a message will be stored. The data of each test track will be visualised as C-scan representation on the DEU monitor and/or by printer.

Furthermore, a multitude of process and testing functions are controlled and co-ordinated by the DEU unit (e.g., the self-test initiation for the data processing chain).

The maximum pulse repetition frequency is 1 kHz. Thus, the test shot distance is 1 mm at the maximum test speed of 1 m/s. The actual value is established depending upon the plate thickness.

### 8.3.4 Test procedure

The rolled plate is transferred to the test facility via roller conveyor and positioned along a laser line. The reference number of the plate is then fed into the host computer by the inspector. After a plausibility check the data set referring to the ultrasonic test is loaded (parameter setting of the system).

Thereafter, the inspection is initiated by the system operator. The testing process is controlled automatically by the process computer. It commences with a self-test routine of the system. After the attachment of the probes to the plate, the respective test channels are activated.

At the end of the inspection and after the assessment of the C-scan representation by the inspection personnel, the test result is fed directly into the computer system of the mill.

On non-fulfilment of the quality requirements, for the respective plate a blocking flag and a request remark for a manual retest are set automatically in the host computer.

All occurring operation and failure messages are recorded and displayed in a special event window. Some error messages lead to automatic interruption of the inspection.

### 8.3.5 Evaluation of the test results

The C-scan representation is displayed synchronously to the inspection process. Thus, the test personnel can trace the generation of the image directly. Indications to be registered are displayed as location-related spots in the C-scan presentations (Fig 8.3.5.1).

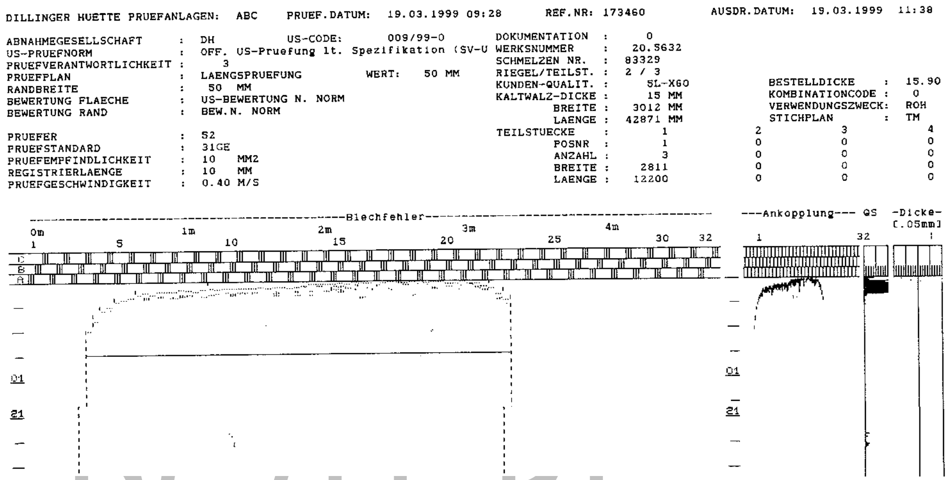



**Fig 8.3.5.1:** Test report (detail) with C-scan representation, coupling control, cross sum and plate thickness

The reflectors displayed in the C-scan representation allow, with respect to their location and distribution in the tested plate, for a different evaluation depending on the specified criteria for body and edge zones.

The evaluation according to delivery standards is carried out by qualified test personnel certified according to ASNT TC 1A and EN 473.

#### 8.3.5.1 Test sensitivity and function control with a reference plate

According to quality assurance requirement, the sensitivity of the testing system is checked in four-hour cycles using a special reference plate (Fig 8.3.5.2). During this test, certain artificial reflectors must be detected depending upon the required testing sensitivity.

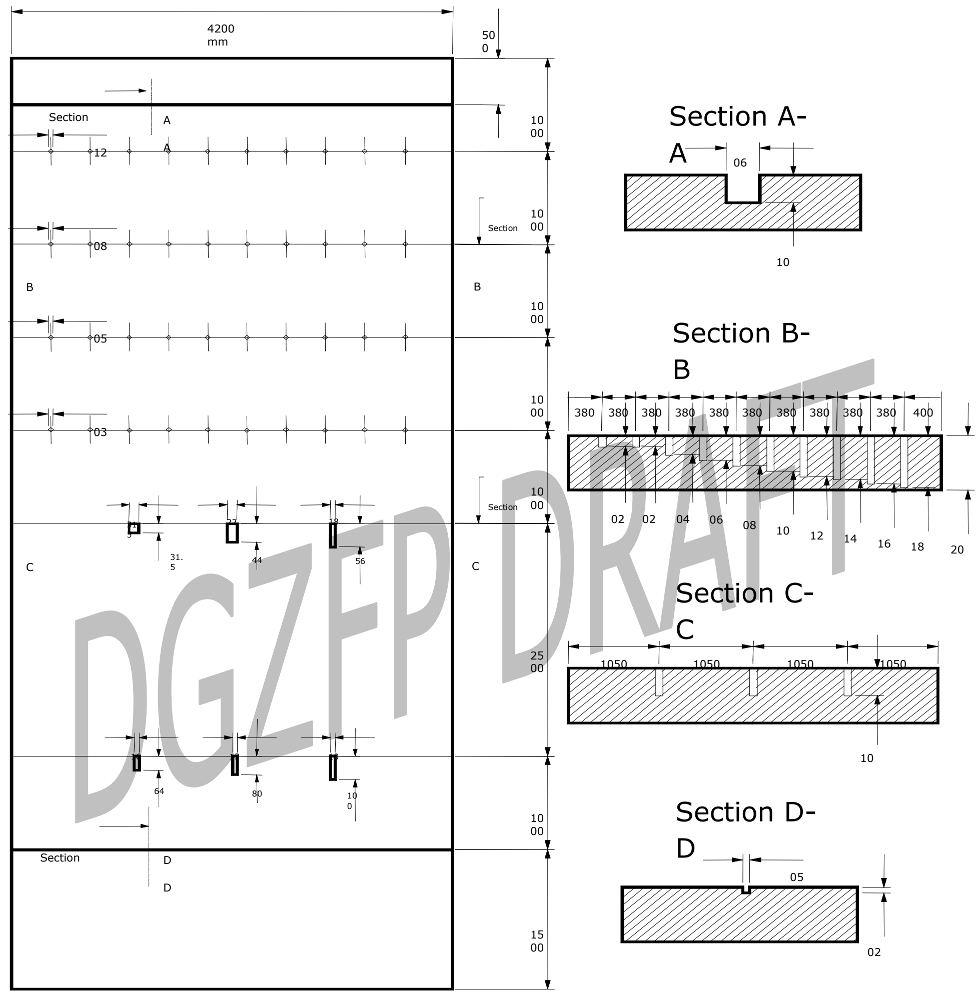



**Fig 8.3.5.2:** Reference plate

## 8.4 Automated ultrasonic testing of a boiling water reactor pressure vessel

Dipl.-Ing. Heiner Eggers, HEW Hamburg

### 8.4.1 Basic set-up of the testing system

The system contains a track-guided robotic manipulator that can scan any area of the test object in a meander-like pattern (circular, peak or rectangular meanders). Attached to the manipulator is a probe module containing seven multi-functional array probes operated by a 96-channel ultrasound instrument. Data are recorded, evaluated and assessed semi-automatically with a data-base supported software package installed on a client/server computer network. The entire testing system is designed to perform mobile inspections.

### 8.4.2 Test–related technical objectives and requirements

The aim of the testing is to verify that no impermissible operation-induced changes of the reactor pressure vessel exist. The detection criteria are laid down in the nuclear technical regulation documents.

All welds are to be tested 100% for longitudinal and transverse oriented defects covering the entire welding volume as well as the adjacent base material in a periodic 4-year interval.

The testing has to be scheduled so that the assessment result is available prior to the restart of the reactor after fuel element replacement. The testing should not interfere with the critical time-path of the fuel element replacement schedule and shall be in agreement with the legal radiation protection requirements.

### 8.4.3 Components and features of the testing system

The probe module is guided by the robot (SRM1, IntelligeNDT Co.) tangentially over the reactor vessel via a three-dimensional trajectory control at a speed of 50 mm/s in such a way that the contact technique with continuous water flow coupling can be used.

The array probes are arranged in the module so that all testing operations (45°/60°/70°, longitudinal and transverse defect orientations, opposite directions of incidence, tandem techniques) can be executed within a single run, see Fig 8.4.3.1. The ultrasound instrument (SAPHIR, IntelligeNDT Co.) executes the different testing techniques sequentially at testing sequence steps of 2 mm. The measurement data are acquired and stored without using gates as RF or ALOK data. The areas inspected and the probe coupling are represented in real-time. For online evaluation and assessment, the results are available to the inspector as P-scan representations, see Fig 8.4.3.2. If required, further analysis programs can be used for analysis of individual defect indications, usually offline.

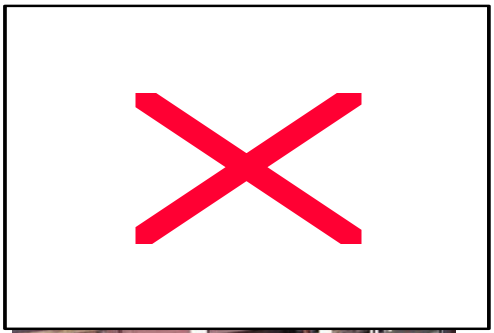


**Fig 8.4.3.1:** Array probe module



## 8.4.4 Test execution

Prior to the first field service, according to the VGB guideline R-516 the testing technique is qualified in the laboratory of the inspector in charge using reference objects that contain real and artificial reflectors.

After set-up and putting into operation at the testing location, the calibration for all ultrasonic probes is performed using calibration blocks containing notches, disk-shaped reflectors or side-drilled holes. The adjustment of the robotic system is performed at marked points at the reactor pressure vessel.

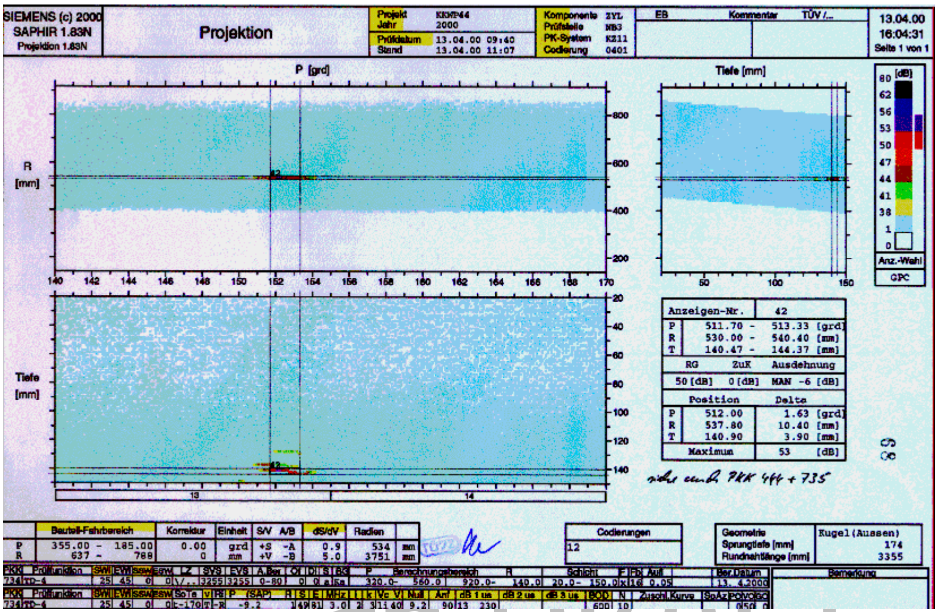




**Fig 8.4.3.2:** Representation of result

The accuracy of positioning and the proper operation of the entire system are proved by integral checks, e.g. by a statistical evaluation of a reference test scan. Pre-programmed scan areas allow for continuous, quality-assured execution of the testing program.

The results are presented as listings of indications and of detected defects. The latter are documented in detail and assessed for potential changes compared to preceding inspections respectively to the base line inspection.

The testing will be completed with a final calibration and by signing of the test report.

By order of the nuclear regulatory authorities a surveying organisation continuously supervises qualification, execution and assessment of the testing on-line.

## 8.5 Automated scanning of a forged shaft using ultrasonic echo tomography

Dr. Gerhard Brekow, BAM Berlin

### 8.5.1 Basic set-up of the testing system

In ultrasonic echo-tomography a phased array probe performs electronically controlled swivelling of the sound beam during scanning in circumferential direction around a forged shaft. A-scans are taken at each measurement point with different swivelling angles. Using these A-scans, echo-tomograms are reconstructed which represent a colour-coded cross sectional image of the shaft (Fig8.5.1.1).

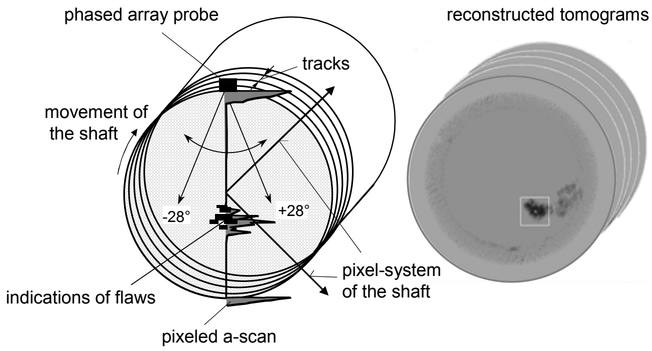



**Fig 8.5.1.1:**

Example for cross sectional images of the shaft

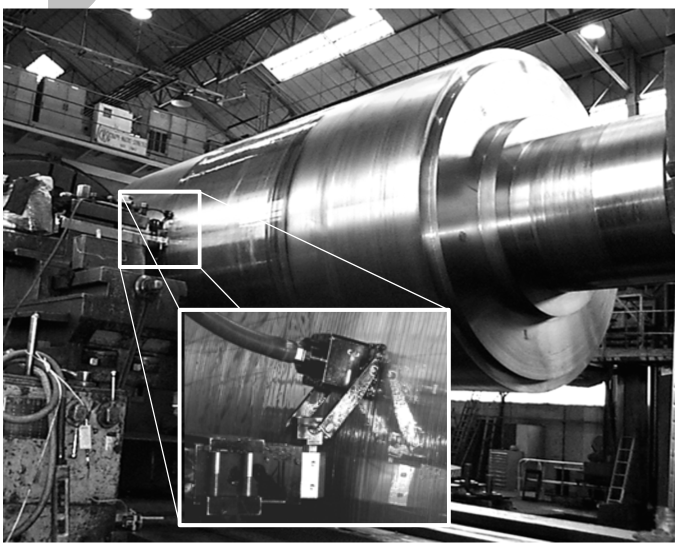


**Fig 8.5.1.2:**

Probe set-up

The test system consists of a phased array probe for normal incidence. The probe is connected to a computer controlled ultrasonic instrument for phased array probes. The control of the array, as well as the acquisition and evaluation of the measurement data, is performed by an integrated computer.

A lathe capable of bearing loads up to 120 tons is used for rotating the forged shaft during inspection. The probe carrier is mounted at the tool clamping device of the lathe. The probe set-up is shown in Fig 8.5.1.2

### 8.5.2 Test related technical objectives and conditions

The detection of reflector locations in the core area of the forged shaft is the goal of this testing. For example, typical dimensions of the shaft are: length 8 m, diameter 1.6 m and raw gross weight 120 tons.

The directives for the inspection laid down in the specification SEP 1923 are used. In this document, the conditions for ultrasonic testing of forged parts for increased operating requirements are established, with specific focus on shafts of turbines and generators. The area to be tested begins at 150 mm beneath the surface and extends to a depth of 900 mm, so that the defects in the core of the shaft can be detected multiple times. A disk-shaped reflector of 1 mm (DSR 1) is established as the evaluation level (DGS method).



### 8.5.3 Components and features of the testing system

The phased array probe applied in this case is a probe for longitudinal wave transmission and reception. The probe consists of 16 transducer elements of a total size of 32 mm x 32 mm with a test frequency of 2.8 MHz. During rotation around the shaft the beam swivels in an angular range of +/- 28°. As a coupling check an additional measurement at 0° is provided. The probe is equipped with a curved sole adapted to the curvature of the object.

The probe is connected to an ultrasonic phased array instrument developed at BAM Berlin (see Fig 8.5.3.1), which contains 64 channels and operates in a frequency range from 0.4 MHz up to 6 MHz, optionally extendable up to 12 MHz.

The ultrasonic phased array instrument consists of transmission, reception and control units and can simultaneously control 4 individual probes with 16 transducer elements each, or one probe with 64 transducer elements. The ultrasonic receiver enables an amplification of 84 dB per channel, selectable in 1-dB-steps. The time-of-flight delay range per channel varies from 0 up to 10 μs in steps of 10 ns.

The digitisation is performed with a resolution of 12 bits per channel.

Two encoders are used to record the rotation of the shaft as well as the indexing of the lathe during measurement. The movement of the shaft is transferred to the rotation axis of the encoder via a contact wheel. The corresponding encoder pulses are transferred to the ultrasonic instrument. Using the known path/pulse coefficient, the acquired A-scans together with the corresponding position data can be transferred to the computer. Here the encoder pulses are converted to angular values, which are then associated to their corresponding A-scans.

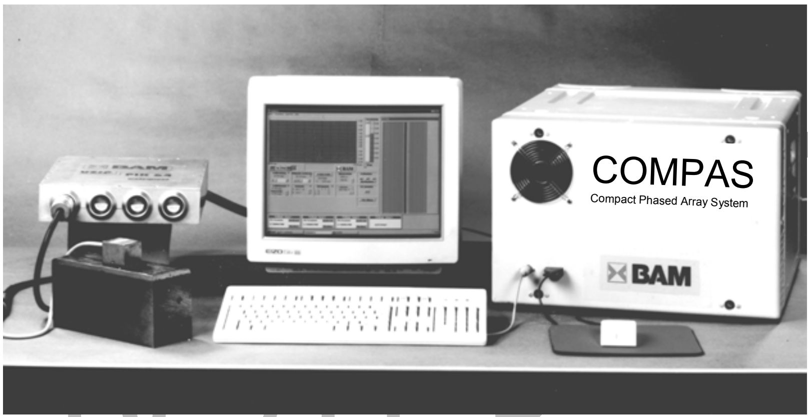



**Fig 8.5.3.1:** Phased array testing system

The limit of the resolution regarding closely spaced inclusions is primarily determined by minor sound velocity variations within the shaft material caused by the production process. These result in time-of-flight differences of the echo signals. Hence, no improvement of the detectability can be achieved by reduction of the pixel size below 1 mm, which is theoretically feasible. Moreover, taking into account the bandwidth of the measurement system, the detection limit of two closely spaced reflectors is about 1 mm - 2 mm disk-shaped reflector, depending on shaft diameter and production quality.

### 8.5.4 Test execution

Prior to starting the measurement, the sensitivity of the inspection system is checked using a reference object comparable to the test object, both in dimension and material. In this case a plane-parallel forged steel specimen ( $C_L$ = 5920 $ms^{-1}$) with a thickness of 700 mm and a flat bottom hole of 1 mm diameter and 25 mm depth is used. Using the phased array probe a detection limit of the system of DSR 0.5 mm for a sound path of 675 mm is obtained.

This corresponds to a detection limit of DSR 1 mm for a sound path of 1300 mm.

The adjustment is carried out according to the DGS-diagram for a reference level of DSR 1 mm. The back wall of the shaft is used as a calibration reflector. The calibration path is 1656 mm and the calibration angle is 0°, respectively.

The following recording levels are established at a gain setting of 29 dB and a distance-amplitude compensation:

- Recording level DSR 1 mm: 40% screen height 49 dB
- Recording level DSR 2 mm: 40% screen height 61 dB
- Recording level DSR 3 mm: 40% screen height 73 dB



Due to the low sound attenuation in the forged shaft, the pulse repetition frequency of the ultrasonic phased array instrument has to be reduced to 20 Hz to avoid interference with delayed echoes.

Oil is used as coupling agent. This is dropped onto the surface of the shaft in front of the probe by a special device.

Scans with different spatial resolution are performed. At high resolution the measurement point distance is 1°, the index is 15 mm, and each recorded A-scan contains 1024 pixels. The total measurement time for 150 scan tracks is 6 hours. At low resolution the point distance is 1.5°, the index is 25 mm, and each A-scan has 256 pixels. Thus, the total measurement time for 93 scan tracks is reduced to 2 hours. The duration of measurement is only determined by the low pulse repetition frequency preventing a faster data acquisition.

In addition to the angular swivelling, an A-scan containing the back wall echo is stored online at each measurement point. This serves as a check for the coupling condition and is performed at reduced sensitivity at an angle of 0°.

The TD-scan representation obtained of A-scans at normal incidence is displayed online on the colour display of the measurement computer. All A-scans acquired are stored in the computer to enable reconstruction of tomograms.

### 8.5.5 Evaluation of the measurement results

During full circumferential scanning the cross section of the shaft and the incidence plane of the phased array probe are identical and perpendicular to the shaft axis. This cross section is represented by a pixelised grid (see Fig 8.5.1.1) whose individual pixels represent the location-related echo amplitudes of the pixelised A-scans. During the 360° scan, the mean or the maximum value of all amplitude values are determined for each pixel. These values are converted into a two-dimensional grey-scale coded or colour-coded tomogram using a computer-aided superpositioning algorithm as shown in Fig 8.5.1.1. In the representation of the mean values, each resulting pixel amplitude is divided by the number of hits (i.e., the number of amplitude contributions). In the representation of the maximum values, only the maximum of the recorded amplitude values is stored in each pixel.

With the aid of the mean value representation the geometric dimensions of a reflector can be determined and furthermore, planar and voluminous defects can be differentiated. On the other hand, the maximum value representation of the echo amplitudes serves to determine the equivalent disk-shaped reflector size. The huge number of different directions of incidence increases the probability of detecting a reflector at an optimum angle.

The evaluation of the measurement data is performed by a software program developed at BAM Berlin. Using this program, each recorded A-scan can be reloaded and retraced with regard to its position and orientation within the tomogram.

The margin of deviation of the amplitude assessment lies in the range of +/- DSR 0.1 mm.

## 8.6 Ultrasonic crack detection in pipelines

Dipl.-Phys. Herbert Willems, NDT Systems & Services AG, Stutensee

### 8.6.1 Basic set-up of the test system

The system (ultrasonic pig, see Fig 8.6.4.1) operates in the pulse-echo mode. Depending on the diameter of the pipeline to be examined up to 800 probes are used. The system components are located in pressure-proof vessels, the power supply is provided by on-board batteries.

Since the system is not accessible after launching into the pipeline, all processes, such as system control, recognition of indications, data reduction, data storage and pre-evaluation of the data, must be executed fully automatically.

### 8.6.2 Testing objectives and conditions

The aim of the testing is the detection of axially oriented crack-like defects that may impact the integrity of the pipeline (e.g. stress corrosion cracking (SCC), fatigue cracks, crack-like weld defects). In axially welded pipes in particular the weld area has to be tested. The minimum defect size to be detected is 30 mm in length and 1 mm in depth.

Generally the examination has to be performed in such a way that the normal pipeline operation remains widely unaffected. This means, for example, that the inspection is carried out at a speed of typically 1 m/s - 2 m/s. The entire testing distance can amount to several hundred kilometres which requires an inspection time of several days. Therefore a high system reliability is a pre-requisite.

After testing, the result of the inspection run is available as recorded raw data. Already during testing the data undergoes a pre-processing, while data evaluation and assessment is mainly performed off-line. The total data volume recorded can amount to approx. 50 GByte.

### 8.6.3 Components and features of the test system

The probes (test frequency 4 MHz) are mounted in a flexible sensor-carrier (see Fig 8.6.4.1) so that a well-defined angle of incidence is maintained (approx. 45° in the pipe wall). In an electronic unit, the received signals are digitised and then reduced using the ALOK procedure. The subsequent signal processing yields further data reduction based on pattern recognition. The remaining data are then stored on hard disks or solid state memory units.

The relation between the test data and the measurement positions is established by means of the recorded distance and rotation information of the system that is stored together with the test data. Further information is recorded such as environmental data (pressure, temperature, etc.) and data needed for monitoring of the system operation, e.g. coupling control.

For the off-line evaluation of the data, PC-based systems are applied.

### 8.6.4 Test execution

Prior to the testing, the test settings dependent on the coupling medium and the defect specification (type of examination, defect expectation range, etc.) are defined and entered into the system.

The actual inspection run starts with the launching of the pig into the pipeline using a special launching facility. The system is then activated dependent on distance and/or pressure. During the examination the triggering of test cycles is performed using position encoders. The inspection run is terminated with the arrival of the pig at the receiving tray of the pipeline. In order to assess the testing result a data check is performed first. Thereafter, the recorded data set is copied from the pig to a transportable data carrier (e.g. DVD).

The evaluation of the data is performed off-line. In the first step, defect candidates are searched for and localised by means of an automatic search routine. These locations are then evaluated and classified by skilled data analysts using special software tools for data visualisation. The results of the data evaluation are stored in a database.



Finally, the results are forwarded to the customer in a final report. This report contains:

- Pipe tally: List of all pipe joints including pipe number, length, wall thickness and position of the longitudinal weld
- Markers list: List of aboveground reference points used (markers)
- Feature list: List of detected features with information about type, location and size
- Detailed documentation (including colour representation) of special features
- Further information as required

**Fig 8.6.4.1:** 24'' ultrasonic pig consisting of power supply unit (front),

electronics unit (middle) and sensor carrier (rear)

Fig 8.6.4.2 shows an internal corrosion as an example of special features provided to the customer as coloured images. Here, the metal loss can be recognized as being internal because the standoff, i.e., the distance between the probe and the internal pipe surface, is changing consistently with the wall thickness. The contour of the corrosion along the position indicated by the line in the wall thickness C-scan is depicted in the B-scans of the wall thickness and the standoff, respectively.

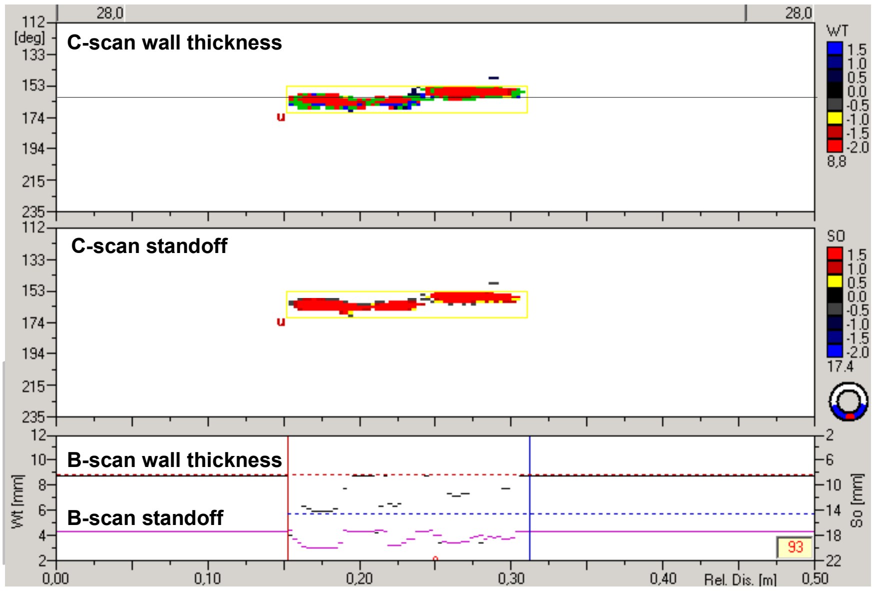



**Abb. 8.6.4.2:** C- and B-scan of an internal metal loss

Figure 8.6.4.3 shows the C-scan representation of a lamination. Laminations are identified by wall thickness information running parallel to the nominal wall thickness that exhibits sudden steps at either end as can be seen in the B-scan. Normally, laminations do not affect the integrity of a pipe joint. However, if a lamination extends to a girth weld (like in this example), it can break up during welding causing crack initiation later on. Such locations have to be especially examined during periodic inspections.

In Figure 8.6.4.4, another defect (a dent) is represented that can be detected with this inspection system. Here, the representations of the standoff signal show characteristic patterns resulting from standoff changes at the edges of the dent while the wall thickness remains unchanged.

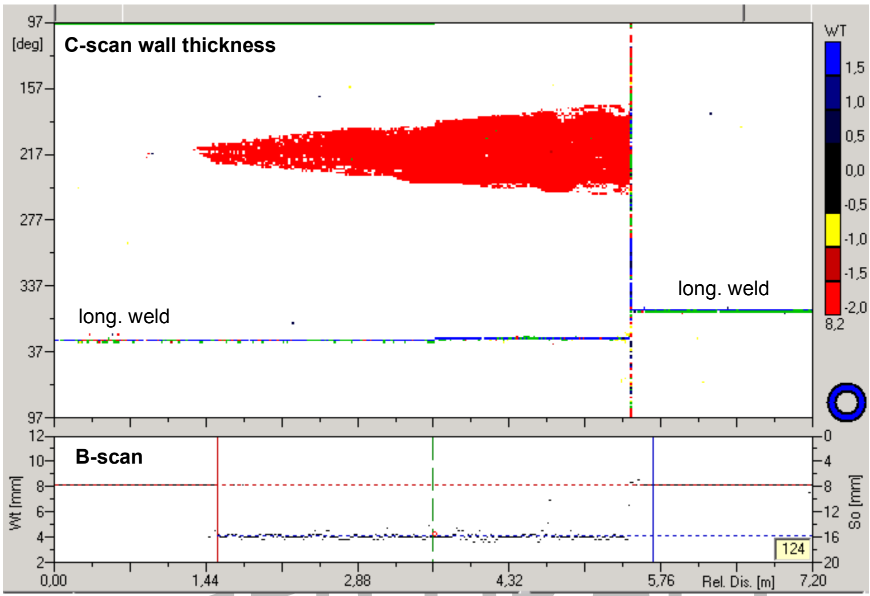



**Abb. 8.6.4.3:** C- and B-scan representation of a lamination



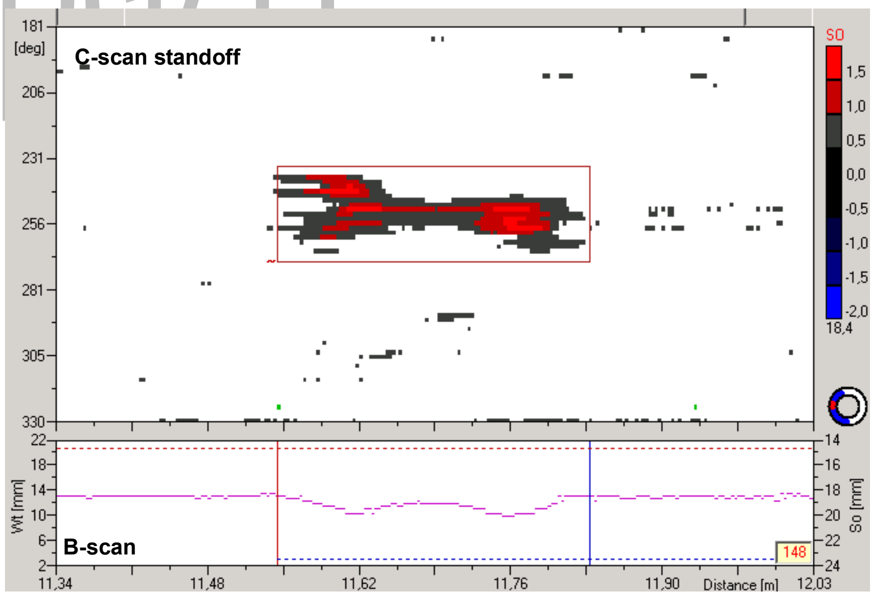



**Abb. 8.6.4.4:** C- and B-scan representation of a dent

## 8.7 Under-floor test facility for wheel sets of high-speed trains

Dipl.-Phys. Wolfgang Kappes, Fraunhofer IZFP – Saarbrücken,
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### 8.7.1 Basic set-up of the test system

An under-floor test facility (UFPE, see Fig 8.7.1.1) was developed in co-operation between DB Systemtechnik, Fraunhofer TEG, BAM Berlin and Windhoff Anlagen & Bahntechnik GmbH. It consists of a mechanical device for lifting and turning of the wheel set to be examined, as well as a handling system by which ultrasonic probe systems can be positioned at the test areas of the wheel (running surface and inner surface of wheel rim). The device is moved beneath the train located on a maintenance track. Depending upon the type of wheel set, up to 42 ultrasound probes are used for synchronous testing of both wheels. The probes are controlled by a 48 channel ultrasonic device (PCUS 40, IZFP Saarbrücken). The data evaluation is performed mainly automatically.




**Fig 8.7.1.1:** Mechanical unit with ultrasonic probe systems on a lifting device

### 8.7.2 Technical test objectives and conditions

The aim of ultrasonic testing of wheels of ICE high-speed trains is the early recognition of material defects. The wheel rims and the disks of tractive and trailing wheel sets have to be examined for volumetric flaws and surface cracks after operation intervals of about 240,000 km.

To reduce the cost of the tests, the wheels are tested in built-in condition. This is of particular advantage for the tractive wheel sets of the trains of type ICE T (tilting) and ICE 3 (all wagons motorized), since dismounting of the wheel sets of these trains takes several hours. The retention period of the trains in the maintenance shops can thus be reduced significantly.

**Fig 8.7.2.1:**

Positioning of a sensor carrier to an ICE T tractive wheel set



### 8.7.3 Components and features of the test system

The mechanical part of the system consists of a lifting device, which can be moved on the maintenance track. The wheel set handling unit, the mechanical probe control unit and positioning units are mounted on this lifting device. The lifting of the wheel set is performed hydraulically as well as the turning of the wheels during testing. Due to the reduced accessibility of the wheels, (see Fig 8.7.2.1) the requirements of the mechanical construction of the probe carriers (made by TEG) and the pneumatically operated positioning units are high.

The test is performed through insonification from the inner rim surface and the running surface of the wheel using straight beam probes and small sized angle beam probes (test frequencies of 2 MHz and 4 MHz, respectively). Specially adapted probes that can be quickly replaced are used, since the different train types have differently shaped wheels.

The ultrasonic electronic unit PCUS 40 records data from the wheel rim by the usual gate technique, whilst from the disks entire A-scans are stored, so using the large information content to be able to differentiate between crack and shape-related indications. The latter are due to the design of the disks and particularly to bore holes in this region. The principle of disk testing is shown in Fig 8.7.3.1.

For a complete test only one revolution of the wheel is required. The test result is available as a graphic representation briefly after termination of the data acquisition sequence (see Fig 8.7.3.2).

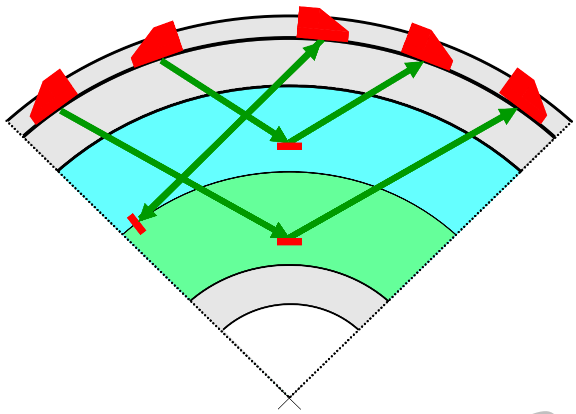

**Fig 8.7.3.1:**

Principle of wheel disk testing



By largely automated evaluation and by clear representation of the results the inspector is supported to a high degree at his substantial task of assessing the test results.

Depending upon the train type and the accessibility of the wheels, the total test duration for one wheel set is about 30 to 45 minutes, including the entire preparation period. The complete ultrasound data acquisition is finalised within about two minutes.

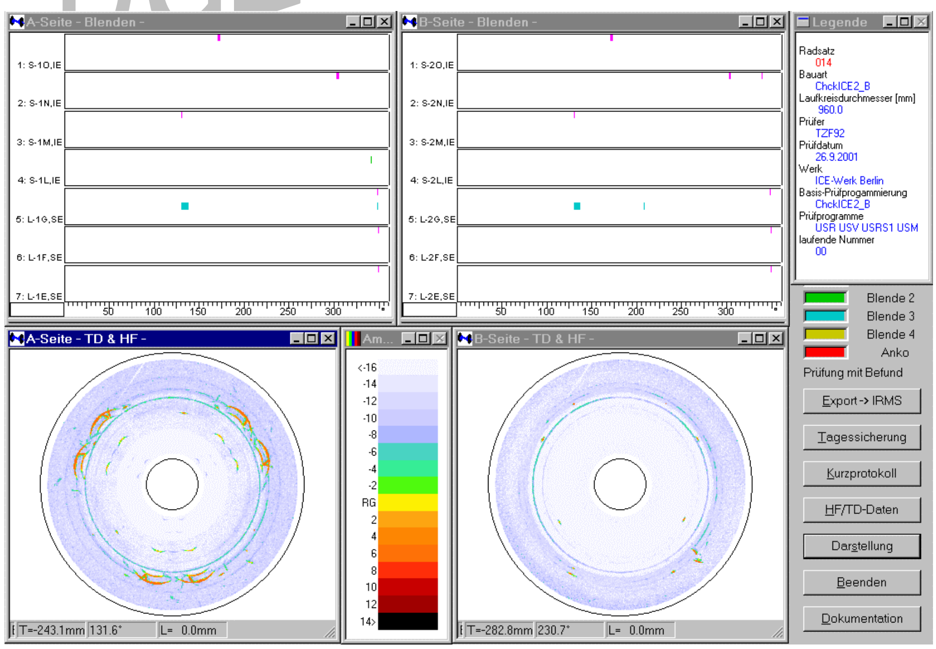

**Fig 8.7.3.2:** Representation of results of wheel rim and wheel disk test of the reference wheel

### 8.7.4 Test execution

The test is performed in the following steps:

- Positioning of the wheel set lift and turning unit beneath the wheel set to be tested
- Lifting of the wheel set (about 10 mm)
- Positioning of the probe systems at the inner surface of the rim and the running surface of both wheels
- Fixing of the zero mark by attaching a magnet to the outer rim surface of the wheel
- Starting the ultrasonic testing program applicable for the actual wheel set type; input of wheel diameter
- Starting the coupling agent supply and the rotation of the wheel
- The ultrasound data acquisition starts when the marker magnet passes a sensor. During the test the inspector can observe the A-scan representations of four test channels simultaneously on the screen
- The data are represented immediately after finalisation of the test; an info box informs the inspector about indications to be registered
- These indications are evaluated and classified, e.g. as shape-related indications or as possible flaw indications which need further evaluation
- Documentation of the test results,
- Dismounting of the mechanical unit and moving it to the next wheel set

Before and after an defined operation period, the sensitivity of the probes as well as the test functions are checked using a reference wheel set.

## 8.8 Ultrasonic testing of steel billets

Dr. (USA) Wolfram A. Karl Deutsch,
Karl Deutsch GmbH + Co. KG, Wuppertal

### 8.8.1 Basic set-up of the test system

The examination of billets described in the following example is performed continuously in the production line of a steel factory. Determining factors are a robust environment and a typical test speed of up to 1 m/s.

Pneumatically controllable probe carriers are fixed to a machine frame. The number of active probes is dependent upon the cross section and the geometry (round or rectangular) of the billet.

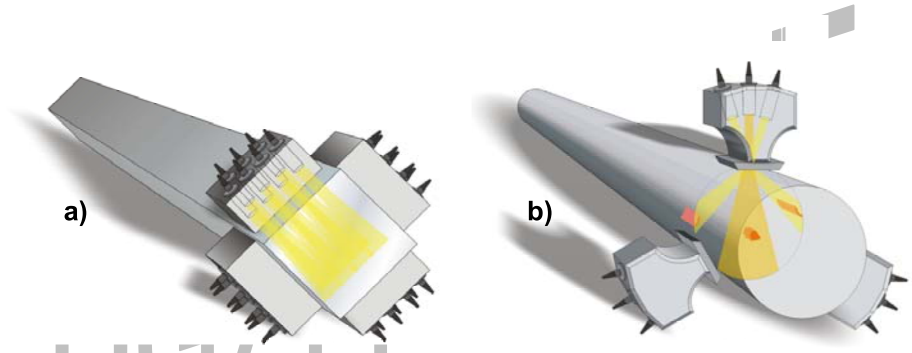


**Fig 8.8.1.1:** Principle of automatic ultrasonic testing of billets
**a)** test of rectangular billets with up to 28 probes,
**b)** test of round billets with 9 probes

The coupling of the ultrasound is achieved by guided water jet. The probe carriers are equipped with water nozzles and are guided along the surface of the billet via hard metal slide shoes.

### 8.8.2 Test-related technical objectives and conditions

In the examination it is essential to cover the entire cross section of the billet, e.g., for billet diameters of 180 mm, up to 28 probes are used.

By flexible mountings of the probe carriers correct positioning is ensured even in the case of larger deviations of the straightness of the billets.

For round (R) and rectangular (Q) billets, typical characteristics are:

| | |
|---|---|
| -Base material | Steel, continuous or ingot casting |
| -Production state | rolled and straightened |
| -Width D | 50 mm – 180 mm |

| | |
|---|---|
| -Length | > 3 m (distance of the guiding rollers with pulse encoders) |
| -Deviation from straightness | maximum of 5 mm/m,<br>deformation of ends 10 mm/100 mm |
| -Surface | as rolled without scale,<br>blasted or brushed |
| -Billet temperature | 5° - 80°C |
| -Ovality (R) | maximum of 2.5 % of D |
| -Edge radii (Q) | about 10 % of D |
| -Angle tolerance (Q) | 90° ± 2° |
| -Profile torsion (Q) | maximum of 2°/m |
| - Crowned shape (Q) | maximum of 4 mm |

In the following table, the examination task is briefly described.

| | |
|---|---|
| Test mode | Linear transport of the billets through the test facility |
| Test speed | Up to 1 m/s |
| Detectable flaw size | 2 mm – 5 mm DSR, depending upon diameter and material properties |
| Front ends untested | About 100 mm during probe positioning at test speed of 1 m/s; depending upon deformation of ends |
| Rear ends untested | 50 mm due to probe carrier width, almost independent of test speed |
| Sensitivity setting (static) | Using reference billets with typical diameter |

### 8.8.3 Components and features of the KNPS ECHOGRAPH test system

#### 8.8.3.1 Ultrasound electronics ECHOGRAPH 1150

Besides multi-channel operation, this digital ultrasonic device allows automatic storage of the test parameters. Hence, when another profile must be tested, the electronic setting can be performed by pushbutton (uploading of the respective test parameters). Regarding the billet diameter, the test channels required are then activated by the electronic controls.

Up to four gates per channel can be evaluated. Typically, one gate is used for registration of the interface and back wall echo. Both echoes are monitored for falling below a defined threshold to control coupling. The so-called echo-start mode is applied to link the gate(s) for the bulk of the billet directly to the interface echo.

For each channel amplitude and time-of-flight of the detected discontinuities are recorded real-time. A programmable amplitude correction curve is used to compensate the sound attenuation at each probe and thus enhancing the constancy of the testing.

Special measures are provided for noise suppression. A so-called verification condition requires a multiple response of the reflector to generate a single indication signal. More complex evaluations (correlation of indications) are also possible, which include up to three thresholds and their override at different test locations. Thereby, reliable detection and classification of objects is ensured.



#### 8.8.3.2 Data management, registration and link to the control computer

Data management serves for organisation of the test parameters and the processing of indications to yield evidence of error-free inspection.

Graphic representation of the acquired data plotted over the length of the billet, tabular compilation and a statistical evaluation are possible.

An information interchange with a master control computer is provided as well. Test data and parameters are stored together with the respective order data (shift, inspector, lot number, component number etc.).

The data management software is designed for an industrial standard personal computer. It operates under Windows NT®. Hence, test data can simply be transferred using standard PC software.

#### 8.8.3.3 Probes and probe carriers

Immersion probes (Type TS 20 WB4, broad-band 4 MHz probes with 20 mm transducer diameter) are used. In the case of coarse grain structures, 2 MHz probes are used instead.

Probes arranged onto four probe carriers, with seven single probes each are used for billets with a square-shaped cross section. The probes are arranged in two rows (3 and 4 probes) so that their sound fields overlap. The probe carrier is equipped with a central water supply for all probes.

When testing rectangular billets, two probe carriers are installed from above and beneath. The V–shaped probe guiding unit rides upon the tested object on hardened wheels. Larger deformations of the billet can be accounted for by readjusting both the height and angle of the entire guiding unit. Both probe carriers are positioned simultaneously with a spindle equipped with a digital encoder, so that they permanently operate in the middle of the billet surface whereby optimum examination of the bulk zone is ensured.

When testing round billets, nine probes are arranged on three carriers. One probe of each carrier is used as a straight beam probe. The other two probes are used for angle beam testing with transverse waves, one sound beam clockwise, the other counter clockwise.

#### 8.8.3.4 Test mechanics

The machine frame contains two probe guiding systems, pre-wetting devices, blow drying unit and a collecting tank equipped with spray shields. Two pantograph units ensure controlled positioning of the probes. The upper guiding system is height-adjustable, and the lower one resides in the collecting tank.

To ensure a proper sound transfer from the probe to the object at high speed, pre-wetting is essential, especially for billets with rough surfaces. Several water nozzles moisten the billet prior to the test. To avoid the transfer of the coupling agent out of the test facility the remaining water is removed by air jet. The air nozzles of the blowing device are arranged circularly around the billet.

#### 8.8.3.5 Processing of the coupling agent (KMA)

The basic elements of the KMA are: water tank, gravity filter, pump, gas separator, temperature and pressure regulator.

The KMA provides a closed water cycle. The coupling agent is pumped out of the water tank to the probe carriers, flows into the collecting tank and then back into the storage tank through a gravity filter. The amount of fresh water required is dependent upon parameters like throughput, surface quality of the billets and ambient temperature. The coupling agent can be supplied with additives like corrosion inhibitors and anti-freezing additives. Temperature control of the water is provided to exclude the interfering influence of the ambient temperature. A gas separator and pressure control unit ensures water jet coupling through bubble-free water at constant pressure.

### 8.8.3.6 Electronic encoders

Pulse encoders and light barriers are provided as electronic encoders to control the scheduled process of the testing.

Guiding rollers running on the lower surface of the billet and corresponding pulse encoders generate position pulses during movement of the billet. These are utilised for exact localisation of indications.

Light-barriers register the entrance and exit of the billet with release of the testing system. Pre-wetting and drying device are activated on entrance of the billet and deactivated after the test. A first light-barrier announces unacceptable deformations of the billet and protects the test mechanics from damage by stopping of the process and lifting of the probe systems. A speed measurement is then performed by a pair of light barriers. This is essential for the exact placing of the probe guiding systems as well as for the correction of the test path measurement, which can be erroneous through slippage of the guiding rollers and the roller conveyor.

### 8.8.3.7 Colour marking

The colour marking system consists of a support carrying two paint jet pistols for precise colour marking of indications or billet ends. The results “good“ or “poor“ are provided, but others like “not certain“ or “partly good“ are possible as well.

### 8.8.3.8 Optical and acoustical signal unit

A red lamp indicates material defects during test execution. A yellow lamp indicates malfunctions of the electronic system or of the water-jet coupling unit. Audible alarm in the case of malfunction is also provided.

### 8.8.3.9 Process control

A Siemens SPS process control unit is applied for:

- Setting the drive units and pneumatic system into operation
- Interface for transport control by the customer
- Realisation of different operation modes of the test system (“set-up“ or “automatic“)
- Reaction upon interferences
- Interface between the electronic encoders (light barriers, pulse encoders) and the ultrasound electronics (test release and colour marking).

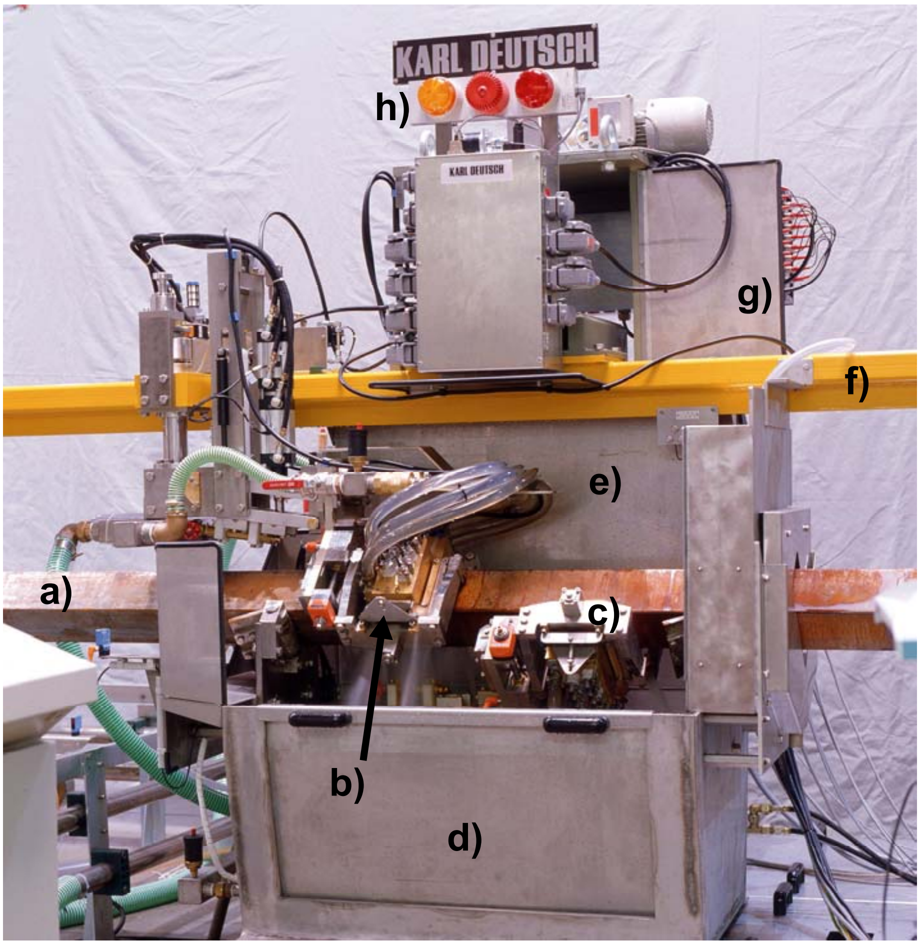


**Fig 8.8.3.9.1:** Set-up of the KNPS ECHOGRAPH test system;

a) reference billet with disk-shaped reference reflectors;

b) test system for positioning from above;

c) test system for positioning from beneath;

d) collecting tank;

e) height-adjustable machine frame;

f) support for light-barriers and paint jet pistols;

g) ultrasound preamplifier;

h) signalling unit

### 8.8.4 Test execution

The pre-setting of the roller conveyor is an essential condition of the testing. Therefore, the setting of the drivers (height of the guiding rollers, transport speed) to the respective diameter is monitored. A backwards-transport of the billet can cause damage to the test mechanics with placed test systems and is therefore electrically locked. Further monitored conditions are: “Ultrasonic electronics ready“ and “pneumatics ready“.

First, the billet passes a light-barrier that monitors the geometry of the billet. Thereafter, the billet passes two light-barriers for speed measurement. A guiding roller for generation of path pulses is attached from beneath.

Then the billet moves through the pre-wetting unit.

The signals from the light-barrier also activate the positioning of the probe-guiding systems. The time schedule of the positioning process is controlled by an electronic process control unit, which calculates the exact speed of the tested object and accounts for the inertia of the probe systems during positioning. Hence, the electronic control unit enables short untested ends. During the placing operation, damage of the test mechanics by larger end deformations or burrs is thus avoided.

When testing square-profiled billets, all straight beam all probes are activated now. When testing round billets additional the angle beam probes to test the near-surface areas are activated.

After the ultrasonic test the billet moves through the blowing device for drying.

Finally, marking of the indication locations is performed. Signals for a subsequent sorting facility are provided.

The indications are documented according to the test specification, printed and then transferred to the master control computer.

## 8.9 Examination of aluminium shells with EMAT probes

Dr. Peter Kreier, Innotest AG, CH-8360 Eschlikon, Switzerland

### 8.9.1 Basic set-up of the test system

The test system includes a fully automated test mechanics which - after manual insertion into the pre-centring adapter - clamps and turns the shell and guides the EMAT probes along the shell according to their pre-selected test areas (Fig 8.9.1.1).

**Fig 8.9.1.1:** EMAT shell test system with test mechanics, service panel and electronics rack

The EMAT probes are operated by a four-channel EMAT ultrasound electronic system (PCUS 40 / EMUS). The assessment of the indications is performed automatically with Windows NT® based control and evaluation software.

### 8.9.2 Technical test-objectives and conditions

The goal of the ultrasonic testing is the reliable full-scale detection of axial cracks on the entire surface of the shell (inside and outside at different wall thickness ranges) without using a coupling agent.

A total test cycle period of less than one minute is required. The data obtained from each tested shell must be stored in a database so that they are available for later evaluation and archiving.

### 8.9.3 Components and features of the test system

Three different EMAT probes (T/R) are used, which operate at a frequency of 670 kHz with horizontally polarised shear waves (SH–waves).

The first probe scans the lower external thread area of the shell from inside. The probe is adapted to the circumferential curvature of the shell in this region. The cylindrical part above this area is scanned from the outside by the second probe, and the upper conical part is tested by the third probe. In order to achieve the required test sensitivity (notch width of 0.3 mm, length of 5 mm and depth of 0.6 mm) the entire upper section of the shell can only be inspected using a special probe with divided transducer elements.

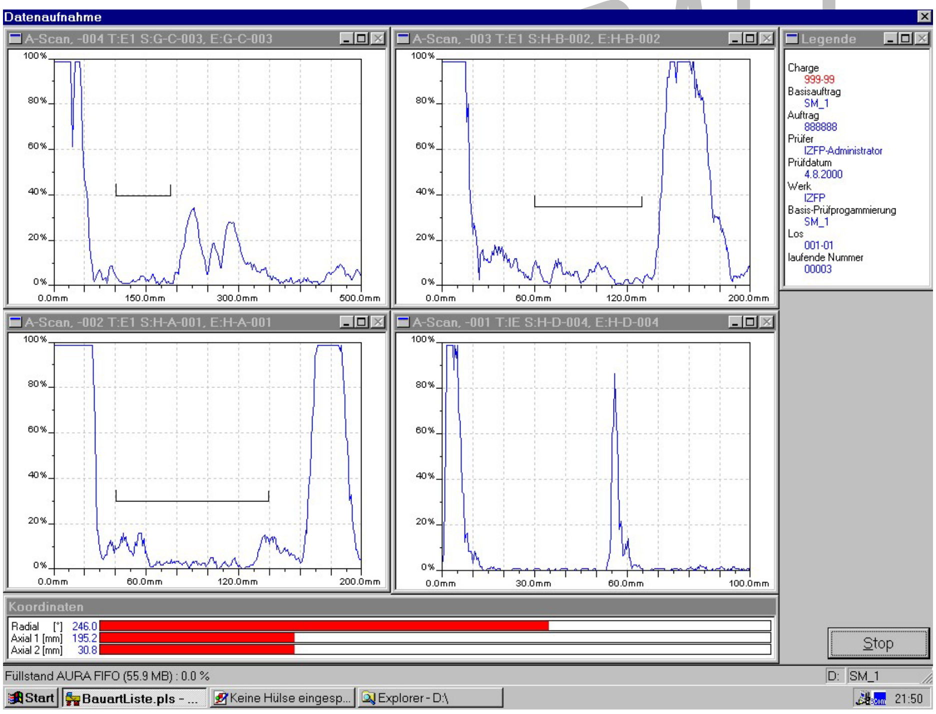


**Fig 8.9.3.1:** A-scan representation and test progress indication during testing

The first probe resides at a fixed position. The others are guided along the surface of the shell within the respective test areas by the scanning mechanics. This is performed with the aid of an probe guiding unit adapted to the geometry of the shell type.

Special rubber rollers pressed sideways onto the shell damp the circumferentially guided ultrasound waves.

Lifting, clamping and rotating of the shell, radial and axial motion of the probes as well as their positioning are controlled by the SPS (Siemens S7). The SPS receives its commands from a command structure (DLL) integrated in the operating software via an RS232 data interface.

In the basic configuration of the ultrasonic test electronics PCUS 40 four test channels are available. It can be extended up to 64 channels on demand. The frequency range of the electronics is between 0.5 MHz and 15 MHz. The pulse repetition frequency can be selected up to 5 kHz. The digitisation is performed with a sampling rate up to 80 MHz at 12 bits resolution. A PCUS 40 unit combined with a three-channel transmitter/receiver EMAT electronic unit was used for the shell inspection system described here.

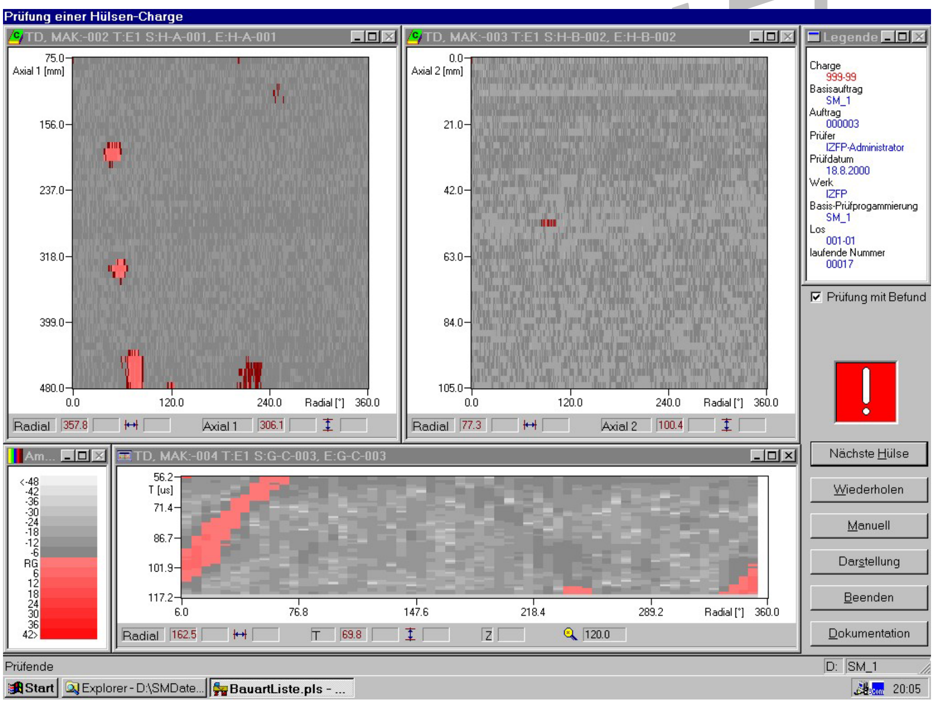


**Fig 8.9.3.2:** C- and B-scan representation with flaw indications (reference shell with notches)

During scanning, the Windows NT® based test and evaluation software displays the current A-scan representations from the test channels (Fig 8.9.3.1) and, after the scan, the respective C- and B-scan presentations (Fig 8.9.3.2).

The results of the test are assessed automatically according to the initially defined gate-related threshold values. At the end of the inspection, the inspector is informed whether or not the inspected shell contains a defect (threshold value override). This information, together with the complete HF data set, is stored in a database. The identification of the shells is accomplished by a serial number as well as by several freely definable input fields that describe the task. After the test, a summarising protocol can be printed out which contains one line per shell with information about the task, the object identification and the test results.

### 8.9.4 Test execution

After starting the computer, the inspector logs in with his user identification and password. The shell test program is then started automatically. Thereafter the inspector enters the customer-related assignment data (e.g., task, batch, lot etc.) and selects the test program related to the test to be carried out. It contains parameters like threshold values, amplification values etc. defined earlier.

Now, the inspector places the shell onto the test mechanic. For safety reasons, the system can not start without the two start buttons being pressed simultaneously. The shell is then clamped automatically, lifted, positioned and fixed with the help of the upper centring mechanics. The guiding systems with the probes and the damping rollers are moved towards the shell, contacts it and the scanning is started.

After completion of the test, a message that indicates the detection or non-detection of defects appears on the display. The test program includes the option to repeat the test. In this case the same shell identification is used for documentation but an additional entry is made in the protocol file. At the end of the test the shell is released mechanically.

For periodical verification of the testing sensitivity reference shells containing eroded axial notches are available.

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## 10. Standards and Guidelines

DIN 1626 (10.1984)

Geschweißte kreisförmige Rohre aus unlegierten Stählen für besondere Anforderungen – Technische Lieferbedingungen

DIN 2391-2 (09.1994)

Nahtlose Präzisionsstahlrohre mit besonderer Maßgenauigkeit –Teil 2: Technische Lieferbedingungen

DIN 2393-2 (09.1994)

Geschweißte Präzisionsstahlrohre mit besonderer Maßgenauigkeit – Teil 2: Technische Lieferbedingungen

DIN 2394-2 (09.1994)

Geschweißte maßgewalzte Präzisionsstahlrohre – Teil 2:Technische Lieferbedingungen

DIN 25435-1 (11.1987)

Wiederkehrende Prüfungen der Komponenten des Primärkreises von Leichtwasserreaktoren – Teil 1: Mechanisierte Ultraschallprüfung

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VGB R-515 (2001)

Auswertung von Meßergebnissen bei mechanisierten Ultraschallprüfungen

(in German only)

VGB R-516 (2001)

Methodik für das Vorgehen bei der Qualifizierung von zerstörungsfreien Prüfungen (VGB-ENIQ-Richtlinie)

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EN 473 (03.2001)

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