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## **In-service inspections for primary coolant circuit components of light water reactors — Mechanized ultrasonic testing**

*Contrôles périodiques des composants du circuit primaire des réacteurs à eau légère — Contrôle mécanique par ultrasons*

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## Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

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ISO xx-1 was prepared by Technical Committee ISO/TC 85, *Nuclear energy, nuclear technology and radiological protection*, Subcommittee SC 6, *Reactor technology*.

This second/third/... edition cancels and replaces the first/second/... edition (), [clause(s) / subclause(s) / table(s) / figure(s) / annex(es)] of which [has / have] been technically revised.

ISO xx consists of the following parts, under the general title *In-service inspections for primary coolant circuit components of light water reactors — Automated ultrasonic testing*:

- *Part 1: Automated ultrasonic testing*
- *Part 2: Magnetic particle testing and penetrant testing*
- *Part 3: Hydrotest*
- *Part 4: Visual testing*
- *Part 5: Eddy current testing of steam generator heating tubes*
- *Part 6: Radiographic testing*



# In-service inspections for primary coolant circuit components of light water reactors — Mechanized ultrasonic testing

## 1 Scope

This standard is applicable for in-service inspections with mechanized ultrasonic test devices that are conducted on components in the circuitreactor coolant circuit of light water reactors. This standard is also applicable for basic tests on components in the reactor coolant circuit and on other components of nuclear installations.

Mechanized ultrasonic inspections are carried out in order to enable an evaluation in case of

- a) malfunction indications (e.g. on austenitic weld seams),
- b) indications due to geometry (e.g. in case of root concavity),
- c) complex geometries (e.g. fitting weld seams),

or

- d) if a reduction in the radiation exposure of the test personnel can be attained in this way.

Ultrasonic test methods are defined for the validation of inhomogeneities (surface and volume), requirements for the ultrasonic test equipment, for the preparation of test and device systems, for the implementation of the test and for the recording.

NOTE Data concerning the test section, test scope, test time, test interval and evaluation of indications is defined in the applicable national nuclear safety standards .

## 2 Normative references

The following documents quoted in this document, partly or in full, are indispensable for the application of this document. For dated references, only the edition to which reference is made is applicable. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 8596, *Ophthalmic optics — Visual acuity testing — Standard optotype and its presentation*

ISO 9712, *Non-destructive testing — Qualification and certification of NDT personnel*

EN 583-2:2001, *Non-destructive testing — Ultrasonic examination — Part 2: Sensitivity and range setting*

EN 1330-4:2010, *Non-destructive testing — Terminology — Part 4: Terms used in ultrasonic testing*

EN 12668-1, *Non-destructive testing — Characterization and verification of ultrasonic examination equipment — Part 1: Instruments*

ENIQ report nr. 31, European Methodology For Qualification Of Non- Destructive Testing<sup>3)</sup>

## 3 Terms and definitions

For the purposes of this document, the terms and definitions given in EN 1330-4:2010-05 and the following apply.

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3) Luxemburg, Office for Official Publications of the European Communities, 2007. ISSN 1018-5593.

- 3.1**  
**Analysis scan**  
Test scan with adopted parameters that is required for more precise characterisation of an indication
- 3.2**  
**Analysis technique**  
Test technique that is applied for more precise characterisation of indications subject to analysis
- 3.3**  
**indication**  
Signal that is initiated by operationally induced damage mechanisms, geometrical, material or design induced influences
- 3.4**  
**Evaluation**  
<Ultrasonic testing> Inspection of the recorded measured data in respect to completeness and analysis capacity, localisation and registration of indications according to defined criteria, representation of the test results
- 3.5**  
**Assessment**  
Comparison of the analysed measuring results with specified criteria
- 3.6**  
**Data storage medium**  
Storage medium for storing digital media
- 3.7**  
**Focal length**  
Nominal distance between sound exit point and the location of the maximum sound pressure
- 3.8**  
**Focus range**  
Nominal lateral and azimuthal range around the sound pressure maximum, limited by the decline in the signal level by 6 dB, in relation to the max. value
- Note 1 to term: During measurement with the electrodynamic probe in sound transmission, this value corresponds to a decrease in the signal level by 3 dB in comparison to the max. value.
- 3.9**  
**Focus depth**  
Nominal distance of the location of the maximum sound pressure from the coupling surface of the UT probe
- 3.10**  
**Adjustment**  
Setting the ultrasonic test device based on specified parameters
- 3.11**  
**Calibration**  
<Ultrasonic testing> Determination of the measuring value range of an ultrasonic test device in relation to a calibrated test standard
- 3.12**  
**Calibration block**  
Block made from a material with a specified composition, surface quality, heat treatment and geometric form with calibration reflectors, which can be used to evaluate and adjust ultrasonic test systems

Note 1 to entry: The calibration blocks according to DIN EN ISO 2400 and DIN EN ISO 7963 can be used as calibration blocks according to this standard.

**3.13****Calibration reflector**

Reflector of a known geometry and size in or on the calibration block, test reference block on the test calibration block for distance or sensitivity adjustment of the ultrasonic test system

**3.14****Component**

A part of a system delimited according to structural or functional aspects, which can still implement independent sub-functions

**3.15****reference block**

<Ultrasonic testing> Specimen for inspecting the settings of the test system and its function during the testing

Note 1 to entry: The test specimen is not plated and consists of a known material with definite surface quality and geometry.

**3.16****time of flight**

This comprises the lead time in the UT probe and the time of flight in the component; it is the time that an ultrasonic pulse requires from the oscillator to a reflector and back to the oscillator

**3.17****LLL technique**

Test technique based on the reflection of the sound package at the back wall and at an planar reflector in the inspection volume using /utilizing longitudinal waves

**3.18****LLT technique**

Test technique based on reflection of the sound bundle at the back wall and at an planar reflector in the inspection volume using / utilizing the mode conversion of longitudinal waves and transversal waves

**3.19****Measurement scan**

Movement of the UT probes with simultaneous recording of measured data

**3.20****raw data**

Recorded and saved data

Note 1 to entry: e.g. amplitude, time of flight, coordinates

**3.21****Test section**

Part of the test range

[SOURCE: ISO xx-2:2014-01]

**3.22****Test supervisor**

Responsible for application of the test method and for the individual details of the test implementation including monitoring of the activities for preparation and implementation of the test as well as analysis of the test results

**3.23****Test area**

The area of the test object to be tested

[SOURCE: ISO xx-2:2014-01]

**3.24****Test result**

Summarising evaluation of all measured data and comparison with the previous test

**3.25****Test scan**

Measuring run with the characteristics specified in the test specifications

**3.26****Test function**

Test task assigned to a UT probe or UT probe combination, e.g. coupling check

**3.27****Test object**

Part of a component to be tested

[SOURCE: ISO xx-2:2014-01]

**3.28****Test robots****Scanner**

Mechanical device with control for guiding the UT probes

**3.29****Noise level**

95% value of the sum frequency of the amplitudes, measured during the reference run or test run in a indication-free range

**3.30****Reference scan**

Measuring run for the functional control and functional adaptation of the ultrasonic test equipment

**3.31****hysteresis correction**

Correction to the decrease in the calibration level resulting during the tandem test or during the test with a comparable test system, if the planar reflectors are not oriented vertically to the surface or vertically to the sound incidence level

**3.32****Transmitter-Receiver system**

(TR-system)

Test system with acoustically and electrically separated transmission and receiver crystals

**3.33****Track offset correction**

Correction to the decrease in the calibration level of planar reflectors in the middle between two tracks

**3.34****Tandem zone correction**

Correction to the decrease in the calibration level of the calibration reflector to the tandem zone edges

**3.35****Test block**

Specimen for examining properties of a test method, an ultrasonic test system or a test system

**3.36****Distance amplitude correction**

Correction to the calibration level for compensation of the sound pressure change in relation to the sound path length and reflector type

**3.37****Depth zone**

Sub-range of the wall thicknesses to be tested

**3.38****Transfer correction**

Correction to the test sensitivity when working with calibration and reference block on the test object

Note 1 to entry: The transfer correction includes losses by coupling, reflection and sound attenuation

**3.39****Trigger distance**

Path that the UT probes travels between two test cycles of the same test function following in succession

**3.40****scan without couplant**

Measuring run without coupling between the UT probe and test object

**3.41****TTT technique**

Test technique based on reflection of the sound bundle at the back wall and at an planar reflector in the test volume using / utilizing shear waves

**3.42****Ultrasonic test equipment**

Ultrasonic test system, test robot and analysis unit including software

**3.43****Ultrasonic test device**

Device for testing with ultrasound, comprising transmitter, receiver, digitalisation unit and, if necessary, operating PC including software

**3.44****Ultrasonic test system**

Ultrasonic test device, transceiver probes and associated cables as well as data recording unit

Note 1 to entry: The term ultrasonic instrument is used for this in EN 12668-1 to EN 12668-3.

**3.45****Ultrasonic test technique**

Application-relevant technique for the localisation of inhomogeneities

Note 1 to entry: In relation to the application, requirements result for these ultrasonic test techniques in respect to the test parameters such as oscillation variable, beam angle, wave type and frequency.

Note 2 to entry: Test techniques are e.g. pulse-echo system (IE), transmitter-receiver system (TR), tandem system, phased-array system (PA).

**3.46****Raw data**

All measured data and setting parameters saved by the ultrasonic test equipment during the measurement run

**3.47****reference block**

A specimen corresponding to the test object in the test system relevant properties (e.g. material, weld seam implementation, acoustic properties, form, wall thickness, any cladding present) with reference characteristics (e.g. grooves, bores) that are adapted to the test assignment

[SOURCE: KTA 3201.4]

**3.48****Reference reflector**

Reflector in or on the reference block for the suitability validation of the test technique

Note 1 to term: A reference reflector can also be used as a calibration reflector.

**3.49****Angle-dependent amplification compensation**

Correction to the echo level for compensation of the sound pressure change in relation to the beam angle at phased-array probes

**4 Test systems****4.1 Preliminary remark**

The suitability of the test technique and the test device system shall be validated corresponding to the requirements of the applicable national nuclear safety standards. The procedure for the qualification is described in ENIQ report no. 31.

**4.2 General**

The test techniques described below are used to locate inhomogeneities. Test techniques for the analysis of indications can be found in 7.5.

The relevant test sections shall be checked so that the required registration thresholds are complied with in even the least favourable case. This results in requirements e.g. for the track offset correction, the transfer correction, the trigger distance and the travel speed, that depend on the relevant selection of probes (e.g. oscillation variable, test frequency, beam angle) and the depth range to be tested.

Depending on the test assignment, the following probes shall be used in contact technique:

- a) Single transducer probes;
- b) TR-probes;
- c) Phased-array probes;
- d) electromagnetic acoustic transducer (EMAT).

NOTE The specific requirements for the use of EMAT probes are not discussed in this standard.

In the case of tests on austenitic components and dissimilar welds, the test capacity can be impaired by the joint (see US 05)

**4.3 Validation and localisation of reflectors****4.3.1 Pulse-echo technique (PE technique)**

The PE technique (see Annex A, No. 1 and No. 2) records the total wall thickness range. It is used with longitudinal and transversal / shear waves and with various beam angles and test frequencies.

A reflector is localised via the measurement of the sound path at known UT probe position, known beam direction and known beam angle / angle of incidence.

#### 4.3.2 Transmitter-Receiver technique (TR-technique)

The TR-technique (see Annex A, No. 3 and No. 4) records the wall thickness range in which the sound fields of transmission and reception converters overlap. The TR-technique is used with longitudinal waves (TRL) or transversal waves (TRT) with various beam angles and test frequencies.

A reflector is localised via the measurement of the sound path at known UT probe position, known beam direction and known angle of incidence.

#### 4.3.3 Tandem technique

The tandem technique (see Annex A, No. 5) is used when testing in test ranges with plane-parallel or concentric surfaces. This technique primarily serves for the detection of planar reflectors oriented vertically to the surface. This utilises two UT probes that transmit and receive transversal waves with angles of incidence each of about 45°.

The localisation of a reflector in respect to the depth location is possible by indication of the depth zone. It depends on

- a) the wall thickness;
- b) the distance of the two UT probes;
- c) the angles of incidence of the transmitter probe and the receiver probe.

In the case of the tandem technique, the depth zones shall cover the reflector expectation range with consideration of surface irregularities and, if necessary, wall thickness changes.

In case of curved surfaces, the change in the sound path due to the geometry shall be considered.

#### 4.3.4 Inspection technique with mode conversion

An ultrasonic inspection technique that uses the conversion of longitudinal waves in transversal / shear waves or vice versa, is used for the validation of surface connected and embedded (see Annex A, No. 7).

The reflector location is determined by measuring the time of flight at known UT probe position, known sound direction and known angle of incidence in relation to the wave mode. The actual sound path cannot be read off directly owing to the conversion into wave modes with different sound velocities. An ultrasonic test technique with mode conversion shall be verified with measurements at a reference block.

In the mode conversion technique, the depth zones shall cover the indication expectation range with consideration of flaw inclined positions, surface irregularities and, if applicable, wall thickness changes.

NOTE In practice, test techniques are used, which are characterised by two spatially separated transducers with the same beam direction and usually with different angles of incidence, whereby one transducer serves for transmission and the other for receive.

#### 4.3.5 V-transmission technique

The V-transmission technique (see Annex A, No. 8) is used for recording the coupling and transfer fluctuations and for the validation of large material separations (in relation to the sound bundle) when testing components.

### 4.3.6 Preferred angles of incidence and wave modes

Taking the optimum incidence angle into consideration, the beam angles and wave modes shall preferably be selected according to Table 1.

**Table 1 — Preferred angle of incidence and wave modes**

Location of the reflector		Angle of incidence <sup>a</sup>	PE system <sup>d</sup>	TR system <sup>d</sup>	EMAT
close to surface	close to probe	0°	—	L	—
		45°	T <sup>c</sup>	T	—
		≥ 65°	—	L	TH <sup>b</sup>
	far from probe	0°	L	—	—
30° to 70°		T	T	TH <sup>b</sup>	
In the volume		0°	L	L	—
		40° to 70°	T	T	TH <sup>b</sup>
inspection techniques to be used are marked by L, T or TH (see Annex A), those not to be used are marked by a dash (—).					
<p>a Depending on the geometry of the test object, other beam angles may also be used.</p> <p>b Electromagnetically excited horizontally polarised transversal waves (TH). The equivalence shall be validated by a qualification.</p> <p>c When testing over the full path.</p> <p>d Both techniques can also be implemented by using PA probes.</p>					

Angles of incidence and reflection angles should be in the range from 40° to 50° when applying transversal wave UT probes for the tandem technique to prevent mode conversions.

For the testing of materials that are difficult to test, for inspection techniques with mode conversion as well as in the case of complicated geometries, the angle of incidence and the test frequency shall be adapted to the test assignment and their suitability validated by measurements on reference block.

## 5 Requirements

### 5.1 Test personnel

The test personnel comprises operating personnel for test robots, operating personnel for ultrasonic test devices, analysts and evaluators as well as the test supervisor.

The test supervisor shall have the knowledge required for his tasks as well as sufficient knowledge of the application options and limitations of the test methods and have knowledge about the characteristic appearances of operation- induced flaws. Indications that reach or exceed the acceptance level shall be evaluated by the test supervisor, who has the requisite experience in respect to the test object, test assignment, test method and device system.

The operating personnel for test robots and ultrasonic test devices shall be trained for the special requirements of the work to be performed. In particular, they shall have adequate experience in the implementation of automated ultrasonic tests and knowledge about the test object in respect to this.

The analysts and evaluators shall be trained for the special requirements of the work to be performed and have experience in the analysis and evaluation of indications as well as knowledge of the test object and the characteristic appearance of indications.

The qualifications of the test personnel shall be validated according to Table 2.

**Table 2 — Requirements for the test personnel**

Test personnel	Qualification
Operating personnel for test robots	Validation by training
Operating personnel for ultrasonic test devices (test inspector)	Certified with at least level 2 according to ISO 9712 or comparable qualification
Analysts and evaluators	Certified with at least level 2 according to ISO 9712 or comparable qualification
Test supervisor	Certified with level 3 according to ISO 9712

The test personnel shall provide annual validation of their visual ability, which has been determined by an ophthalmologist, optician or other medically recognised person. The following requirements shall be fulfilled:

- a) The visual acuity testing shall be conducted with standard signs according to ISO 8596 or equivalent. Here a near vision of 1.0 at 0.33 m test distance with at least one eye, with or without vision aid shall be validated;
- b) The ability to distinguish between colours and between grey shadowing shall be validated with colour sense test boards. The validation can typically be conducted with the help of Ishihara colour boards as well as the "shades of grey test". In case of anomalies, the employer shall decide whether the ability to see colours is sufficient for the test assignment.

## 5.2 Test object

The weld crown condition shall be ground flush or machined to allow for unobstructed access to the weld. The examination surfaces shall be free of irregularities, loose material, or coatings, which interfere with the ultrasonic wave transmission. Areas where ultrasonic contact is inadequate shall be documented as limitations.

Reference points shall be permanently marked on the component for positioning and calibration.

## 5.3 Ultrasonic test equipment

### 5.3.1 Preliminary remark

The ultrasonic test equipment shall fulfil the requirements for electromagnetic compatibility.

### 5.3.2 Test robot

The test robot shall fulfil the requirements for occupational safety and enable a time-saving, non-mix-up assembly and operation, in order to limit the radiation exposure of the test personnel.

The test robot shall be designed so that

- a) the test section specified in the test procedures is recorded;
- b) a reproducible positioning accuracy of 3 mm is not exceeded within a measurement;
- c) an assembly tolerance of 5 mm to the component coordinate system on the component is not exceeded;
- d) the track distance upon modification does not deviate from the target value by more than 20 %;

NOTE Test system requirements can make higher accuracies necessary.

- e) an encounter with obstacles is prevented (e.g. by limit switch);
- f) all components are secured against automatic or unintended loosening, falling or tipping;
- g) the UT probe or UT probe system is moved with the required contact pressure over the entire test area;
- h) the position data with a resolution of less than or equal to 1 mm is continuously available;
- i) the position data can be converted in component-related coordinates;
- j) the electrical interference level resulting from drive and control elements is below the level of the joint indications in the relevant test section;
- k) the cable connections are designed to prevent mix-ups (e.g. by marking);
- l) can be extensively decontaminated.

### 5.3.3 Ultrasonic test device

The following device system properties shall be documented by the manufacturer:

- a) Number of transmitter and receiver channels;
- b) Raw data type (e.g.: RF., A-Scan);
- c) Amplitude and time progression of the transmitted signal;
- d) Maximum transmitting pulse repetition frequency;
- e) Scanning rate;
- f) Frequency filter;
- g) Output impedance of the transmitter;
- h) Input impedance of the receiver;
- i) Cross-talk between transmitter and receiver channels;
- j) Amplifier type (linear, logarithmic);
- k) Dynamic range;
- l) Resolution for the signal amplitude
- m) Frequency bandwidth of the receiver;
- n) Software version;
- o) Data reduction algorithm;
- p) Protection standard (e.g. splash waterproof, immersion-proof).

The ultrasonic test device shall fulfil the following requirements:

- 1) The relative measuring uncertainty of the time of flight shall not exceed 1 %. The manufacturer shall ensure that this requirement is fulfilled in the entire frequency range of the ultrasonic test device;
- 2) Non-mix-up storage of raw data;
- 3) Option of monitoring measuring value for each test channel during the data collection / acquisition;
- 4) If a depth or angle dependent amplification correction is possible: Non-mix-up storage of the compensation curves (see Annex D).

At least before commencement and after completion of the in-service inspection, the ultrasonic test device shall undergo a functional test. Depending on the test assignment, the time points for further functional tests shall be defined. The functional tests shall include:

- Monitoring of the transmission channels (transducer probe, cable, amplifier);
- Linearity of the amplifiers;
- Amplification reserve (total dynamics of the ultrasonic test device);
- Linearity of the time of flight measurement.

The results of this functional test shall be documented. This functional test may be executed in the form of a self-test.

#### **5.3.4 Data acquisition and analysis**

Data acquisition systems (DAS) shall be used, with which the signals, position data and parameter files supplied by the ultrasonic test equipment can be saved digitalised.

The DAS shall be selected in the way that all data recorded from the ultrasonic test system can be processed at the given data transfer rate.

The operating system version and software including software version, of data processing, shall be documented.

Data losses during the data acquisition shall be recognisable during the online or offline data analysis.

#### **5.3.5 UT probe**

##### **5.3.5.1 General**

UT probe data sheets on which all-essential transducer probe properties are documented shall be provided for the applied UT probes.

The material at which these were determined shall be indicated in case of sound field relevant parameters. The underlying sound velocity shall be indicated.

In case of curved test surfaces, the UT probes shall be adapted to the curvature (see US 3).

The UT probe parameter (e.g. beam angle) may not be changed without monitoring. Modifications to the UT probe and resultant changes to relevant UT probe characteristics (see Annex B).

In case of TRL- probes, it shall be taken into consideration that the effective angle of incidence changes with the length of the sound path. In addition, these TRL-probes shall only be used in the sensitivity range indicated by the manufacturer (see US 3).

### 5.3.5.2 UT probe data sheets

#### 5.3.5.2.1 General information

The following data in the data sheets applies both for conventional transducer probes as well as for phased-array probes:

- a) Manufacturer;
- b) Transducer probe type;
- c) Serial no.;
- d) Year of manufacture;
- e) Housing external dimensions;
- f) Wave mode;
- g) Nominal angle (phased-array probes: Beam angle without time-delayed excitation of the individual oscillation elements);
- h) Contact surface:
- i) Crystal material;
- j) Wedge material, sound velocity in the wedge (integrated wedges and attachment wedges);
- k) Nominal frequency;
- l) Centre frequency;
- m) Frequency spectrum;
- n) Bandwidth;
- o) Electrical connection
  - 1) firmly connected cable (if available), cable length, cable material,
  - 2) Connector type,
  - 3) Connection position;
- p) Impedance at nominal frequency;
- q) Pulse form;
- r) Permissible transmission voltage;
- s) Squint / Skew angle;
- t) Permissible temperature range;
- u) Water resistance;
- v) Coupling medium supply;

- w) Application points for probe holder;
- x) Adaptation to the surface with indication of the curvature radius (if listed);
- y) Transceiver probe diagram.

Transceiver probe properties for conventional probes shall be determined according to EN 12668-2.

#### **5.3.5.2.2 Conventional transceiver probes**

The following data is required for conventional UT probes:

- a) Focal length for focussing probes;
- b) Focus range for TR-probes;
- c) Near field length;
- d) Transducer / crystal dimensions;
- e) Divergence angle;
- f) Arrangement of the Transducer / crystals;
- g) Roof angle (for TR-probes);
- h) Alignment characteristics;
- i) Sound exit point.

#### **5.3.5.2.3 Phased-array probes**

The following data is additionally required for phased-array probes:

- a) Number of elements;
- b) Arrangement of the elements;
- c) Element dimensions;
- d) Element distances;
- e) Delay path<sup>5)</sup>;
- f) Sound exit point<sup>1)</sup>;
- g) Alignment characteristics<sup>6)</sup>
- h) Minimum and maximum focal length (in relation to the wave mode);
- i) Horizontal/Vertical nominal swivel range;

---

5) Determined for the natural beam angle and for at least 3 further swivel angles.

6) Determined for the natural beam angle and for at least 3 further swivel angles

- j) Pin assignment;
- k) Element assignment matrix.

### 5.3.6 UT probe holders

The UT probe holders shall be designed so that

- a) the UT probes couple and the contour of the coupling area of the test object can occur without hindrance;
- b) the probes can be easily installed and removed;
- c) the probes are not damaged when encountering an obstacle.

### 5.3.7 UT probe cable (ultrasonic cable)

The ultrasonic cables shall be adapted to the test assignment. Only ultrasonic cables whose technical data is recorded and documented may be used (see Annex B).

The following requirements shall be observed:

- a) No mixing up the connectors;
- b) Shielding against electrical interference;
- c) Surface that can be decontaminated;
- d) Absence of halogenides;
- e) Protection against damage;
- f) Flexibility;
- g) Availability of reserve wires (if possible);
- h) Splash water protection or immersion suitability.

## 5.4 Couplant

Only the media released by the operator of the power station may be used as coupling media. The coupling media may not

- a) damage the test object (ensure absence of halogenides),
- b) leave any disturbing residues behind.

When coupling with flowing water, it shall be ensured that the coupling medium is collected.

## 5.5 Reference reflectors

The following are approved as reference reflectors:

- a) back walls;
- b) side-drilled holes (SDH);
- c) Flat bottom holes;

- d) Notches;
- e) hemispherical bottom holes.

It shall be possible to establish a clear physical reference to the required registrations thresholds. Natural reference reflectors are also approved corresponding to the test assignment, e.g.:

- 1) Cracks;
- 2) Inclusions;
- 3) lack of fusion.

The requirements for reference reflectors when applying the AVG method can be found in EN 583-2:2001-04, Annex B.

## 5.6 Data storage medium

Data storage medium shall be designed in such way that

- a) they enable a labelling for identification;
- b) an unintentional overwrite is prevented;
- c) the suitability of storage is ensured.

It shall be ensured that measuring data can be read and processed by the next in-service inspection.

NOTE The operating system or hardware modifications might render it necessary to transfer original data to other data storage medium types.

## 6 Standard test procedures and test specifications

The standard test procedures shall contain the following data:

- a) Scope of validity;
- b) Jointly applicable regulations, standards and procedures;
- c) Test objective;
- d) Personnel qualifications;
- e) Data on the test object and possibly component drawings, data on the test scope and test time;
- f) Data on test preconditions;
- g) Test system;
- h) Device type and device description (e.g. ultrasonic test device, measuring value logging system, robot system, clear space, operating conditions);
- i) Test area documents (e.g. data recording and analysis parameters, transceiver probe system, run program for the test robot, reference points);
- j) Documents for the ultrasonic test (e.g. of transceiver probes, calibration specimens, test specimens, evaluation diagrams, correction factors);

- k) Data on the test implementation and analysis as well as on the evaluation of indications;
- l) Type and scope of the recording and documentation.

## **7 Testing**

### **7.1 Preparation**

#### **7.1.1 General**

The test personnel shall be trained in the special requirements of the test. All requisite documents, such as test procedures, drawings or piping isometric drawings necessary for conducting the testing shall be made available.

Before using the ultrasonic test equipment in areas exposed to radiation, training for rapid assembly and disassembly shall be realised for reducing the time personnel remain in such areas. The training shall be documented and, if necessary, validated by the test service provider.

#### **7.1.2 probe data sheets**

The characteristic variables essential for the test assignment from 5.3.5 shall be available for all transducer probes.

#### **7.1.3 probe system**

The probes shall be installed in a test system corresponding to the data defined in the standard test procedures. The following points shall be considered for this:

- a) Assembly of the probe holders at the indicated distances to the coordinate data reference point;
- b) Installation of the UT probes in the relevant probe holder with consideration of the specified test equipment;
- c) Checking the contact force of the UT probes.

During assembly, it shall be ensured that the connecting cables and hoses for the couplant do not effect the movements of the test robot and probes and the probes can follow the surface of the test object without obstruction.

#### **7.1.4 Test robot**

After assembly, the test robot shall be calibrated at reference points of the test object. The position data for the test robot at the reference points shall be recorded.

It shall be ensured that the test robot fulfils the requirements indicated in 5.3.2 under test conditions.

#### **7.1.5 Ultrasonic test device**

It shall be ensured that the ultrasonic test devices fulfil the requirements indicated in 5.3.3 under test conditions.

The fulfilment of the requirements according to 5.3.3 shall be verified and documented by functional checks.

The ultrasonic test device shall be checked regularly. The time of the last performed check may not be longer than 12 months in the past. The check is based on the verification according to EN 12668-1.

The ultrasonic test system shall be checked regularly as part of the quality assurance.

After repair work, functional checks shall be repeated and documented, preferably by a self-test.

If repair work for compliance with the test sequence is necessary in a test phase, the functional checks may be conducted in integral form (e.g. by a reference run at a test section with known indications).

### **7.1.6 Setting the testing level**

#### **7.1.6.1 General**

The calibration of the ultrasonic test system shall be carried out with the equipment used during the test (probe, connecting cable, ultrasonic test device, data backup device) at the calibration block defined in the test specifications or standard test procedures. The test object, calibration, reference block may not exceed a temperature difference of 15 K when setting the testing level.

In case of phased-array probes, the function of each element shall be checked. The procedure upon failure of elements shall be defined specific to the probe, depending on the test assignment.

No separate measures are necessary up to component temperatures  $\leq 45$  °C. Above a temperature of 45 °C, the suitability of the probe for this temperature range shall be verified. The test temperature shall be considered during the calibration of the test sensitivity and analysis of the test results.

#### **7.1.6.2 Sound path**

The sound path shall be calibrated at the ultrasonic test system with a UT probe of each wave mode (e.g. transversal, longitudinal) on a calibration specimen, reference block.

#### **7.1.6.3 Testing level and recording level**

The sensitivity of the ultrasonic test system shall be set for each test system based on calibration reflectors defined in the standard test procedures. The UT probes to be utilised for the test shall be used here. The difference between the test object and calibration specimen, reference block shall be determined by a transfer measurement. The transfer correction and the test block for evaluation of the coupling shall be determined by measuring the through-transmission signals at representative points of the relevant test section. Amplitude corrections (e.g. track offset correction, inclined position correction, tandem zone correction, depth correction) shall be indicated.

The definition of the relevant recording levels can be found in the test specifications or standard test procedures.

#### **7.1.6.4 Recording the calibration**

Every calibration shall be recorded (see Annex B). The record shall contain:

- a) UT probe identification;
- b) Drawings of the calibration specimens, reference block;
- c) parameter settings for the testing sensitivity of the ultrasonic test system (e.g. channels used, basic amplification, transmission voltage, filter, cable length);
- d) Drawing of the probe arrangement (e.g. Tandem, V-transmission);
- e) Temperature of the calibration specimens, reference block;
- f) characteristic data of the ultrasonic test device (e.g. amplitude characteristic curve, time of flight characteristic curve, amplification characteristic curve).

### 7.1.7 Data acquisition system DAS

The DAS shall be used to ensure that all signals relevant to the evaluation are recorded.

### 7.1.8 Ultrasonic test equipment

The functional capability of the ultrasonic test equipment shall be verified at the test object. The verification shall be done by plausibility checks of the evaluated UT data. The installation of the UT probes in the probe holder (check of the direction of incidence) shall be checked.

It shall be ensured that the test functions have been programmed as specified.

## 7.2 Implementation

The test shall be conducted according to the data contained in the standard test procedures. It shall be ensured that the entire test area is recorded with the specified testing sensitivity.

To ensure a reliable test implementation, the functions of the ultrasonic test equipment shall be inspected and documented before the test start, accompanying the test and after completion of the test. These control steps are defined with scope and frequency in the standard test procedures or specifications. The test shall be interrupted if a functional change occurs outside the specified functional range of the ultrasonic test equipment. It shall be clarified whether the cause of the functional change has to be rectified or whether the changes can be considered retrospectively when evaluating the measuring data. Once the cause of the functional change is rectified, the test run during which the functional change has occurred shall be repeated after a possible recalibration. A deviation of max. 3 dB in relation to the input calibration is permissible.

The ambient temperature in the immediate working range should not be greater than 40 °C with consideration of the test personnel. Special arrangements shall be agreed for higher temperatures.

After the start of the test run, it shall be ensured that all parameters associated with the data acquisition can no longer be changed.

## 7.3 Visualisation of the digitized and saved measuring data

The UT data to be evaluated shall be visualised clearly. All data in the visualisations shall be comprehensible and intelligible in itself, in particular the test section, component-relevant position data, test functions, direction and angle of incidence.

In the case of recorded indications, the results shall be printed out in a scale that permits a clear evaluation of the extent of indication.

The measuring results are shown in the form of A-, B- or C-images for their evaluation. An assignment to the component coordinates shall be ensured.

## 7.4 Evaluation of indications

The evaluation of indications shall be conducted corresponding to the requirements of the applicable national nuclear code.

Indications subject to registration shall be documented in a record of indications.

Indications that are due to the geometric form of the test object or which can be clearly demonstrated not to result from defects (e.g. wave splits in the cladding) are evaluated as geometric indications, then marked and documented as such. In case of periodically occurring geometric indications the documentation of a single period is sufficient. Further arrangements are not necessary.

Indications that are due to external influences (e.g. electromagnetic interference signals from welding work) and which do not restrict the evaluation capacity are evaluated as disturbance indications and marked as such. Further arrangements are not necessary.

Indications that reach or exceed the evaluation limit shall be evaluated as findings and documented in the findings record (see Annex C).

Changes to the findings in comparison to the previous in-service inspections are then given if the amplitude has changed by more than 6 dB or the indication length has changed by more than half, determined with the 6 dB drop method.. The 6 dB drop method shall only be applied if the sound beam diameter in the range of the indication is less than the measured length..

## 7.5 Analysis of findings

If suitable, the UT data of the conducted test run may be used for further analysis of findings. If determination of the indication size (length and depth extension), the form or the orientation are necessary for findings qualified test or analysis systems, e.g. the synthetic aperture focusing technique (SAFT), time-of-flight diffraction technique (TOFD), crack tip signal technique, shall be applied.

Other, supplementary qualified tests with other physical interactions or visual inspection may also be conducted for the analysis of findings.

## 7.6 Final measures

After completing the testing, couplant residues shall be cleaned from the test objects. Auxiliary materials attached to the test object (e.g. adhesive tapes, labels) shall be removed completely.

It shall be verified that all test sections have been recorded with the test sensitivity defined in the standard test procedures. The test scope shall be monitored by a target-actual comparison of the run program.

Before disassembly of the ultrasonic test equipment, it is necessary to check whether all test runs have been carried out with sufficient coupling and can be evaluated.

# 8 Recording

## 8.1 Recording the setup for the ultrasonic test equipment

The minimum data contained in the forms in Annex B shall be considered to simplify the recording of device and calibration data. Additional data and the type of forms shall be defined in the standard test procedures. The technical descriptions of the ultrasonic test equipment shall be available.

NOTE A further example of a probe data sheet can be found in the US 3.

The test documentation should also be backed up in digital form in addition to paper form.

## 8.2 Test record and test report

A test record or test report shall be compiled concerning the testing. The following data shall be included:

- a) Date of the testing;
- b) Name of the power plant;
- c) Test basis (standard test procedures);
- d) Test object, test range and test section with reference point and coordinates;

- e) Surface state (e.g. ground);
- f) Test system;
- g) Test result with indication list and, insofar as necessary, findings record;
- h) Comparison of the test results with those of the previous test;
- i) Deviations from the specifications of the standard test procedures;
- j) Place, date, name, signature, certificate number of the inspectors and test supervisors of the operator or the test company commissioned by him and the third party.

### 8.3 Indication list

The indication list shall include, as a minimum:

- a) Consecutive numbering of the indications;
- b) Representations of the digitized and saved measured data (see 7.3);
- c) Indication coordinates in relation to the component;
- d) Test functions with which the indication was verified;
- e) Echo level on the recording level (with and without corrections);
- f) 6 dB drop length of the indication;
- g) Name of the raw data file.

### 8.4 Findings record

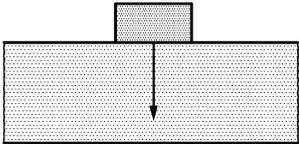
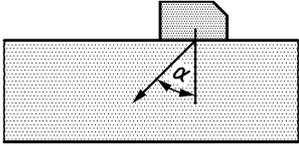
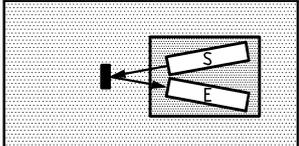
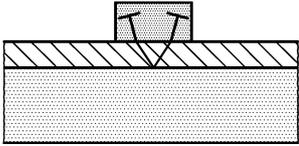
The findings record (see Annex C) lists those indications from the indication list, which have reached or exceeded the acceptance level / evaluation level according to national nuclear code and which have not been analysed as geometric indications. In addition to the data in the indication list, the following is required for the findings record:

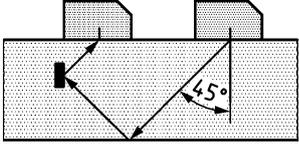
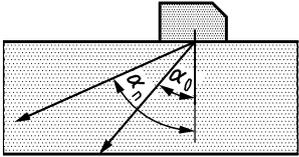
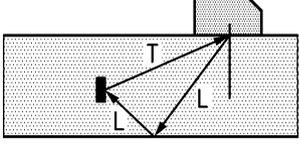
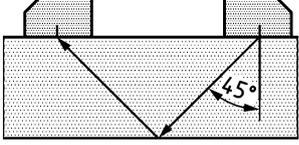
- a) Representation of the test area;
- b) Evaluated colour-coded projection image or time displacement image (TD image);
- c) Evaluated A-image of the indications amplitude maximum and, if possible, additionally from opposite direction of incidence;
- d) Implemented analysis for first findings or change to the indication.

A comparison with the previous tests shall be done for findings.

## Annex A (informative)

### Examples of test systems and transceiver probe arrangements

No.	Test technique	Diagram of the transceiver probe arrangement
1	0° single oscillator technique for longitudinal waves (see 4.3.1)	 <p style="text-align: center;"><b>Figure A.1</b></p>
2	Single oscillator technique for transversal waves, e.g. with $\alpha$ of 45°, 60°, 70° (see 4.3.1)	 <p style="text-align: center;"><b>Figure A.2</b></p>
3	TR longitudinal wave or transversal wave technique (see 4.3.2)	 <p style="text-align: center;"><b>Figure A.3</b></p>
4	TR technique for the adhesion testing of the cladding	 <p style="text-align: center;"><b>Figure A.4</b></p>

No.	Test technique	Diagram of the transceiver probe arrangement
5	Tandem system (see 4.3.3)	 <p data-bbox="1062 566 1195 595">Figure A.5</p>
6	Group radiation system (phased-array technique) Swivel range $\alpha_0$ to $\alpha_n$	 <p data-bbox="1062 817 1195 846">Figure A.6</p>
7	Test technique with mode conversion, e.g. LLT system (see 4.3.4)	 <p data-bbox="1062 1064 1195 1093">Figure A.7</p>
8	V-transmission technique (see 4.3.5)	 <p data-bbox="1062 1303 1195 1332">Figure A.8</p>
<p>TR = Transmitter and receiver separate</p>		<p>L = Longitudinal wave T = Transversal wave</p>

## Annex B (informative)

### Forms

#### Form for transceiver probe data

Designation		Value/Designation
UT probe	Type	
	No. in the test system	
	Serial no.	
	Consecutive no.	
	Year of manufacture	
	Housing dimensions	
	Curvature radius of the probe base marking	
Pin assignment	Make	
	Type	
Probe connection	on the housing	
	fixed on the cable	
	Cable length	
Date of the last check		

#### Form for the transceiver probe connection or connecting cable to the transceiver probe

Designation		Value/Designation
Cable	Type (e.g. RG 58)	
	Type (e.g. coaxial)	
	Number of wires (e.g. 5)	
	Diameter (for cable bundle)	
Pin assignment	Probe side	Make
		Type
	Device side	Make
		Type
Cable length		
Application range (e.g. watertight)		
Date of the last check		

#### Form for calibration block, reference block

Designation	Value/Designation
Identification (Type)	
Material	
Dimensions <sup>a</sup>	
Sound velocity for transversal waves and longitudinal waves	
Coupling area <sup>a</sup>	
Calibration reflectors <sup>a</sup> Electrical conductivity and relative permeability shall be indicated for EMUS	
Temperature of the test or calibration block	
a A diagram shall be enclosed as an annex.	

#### Form for the ultrasonic test device

Designation	Value/Designation
Type	
Serial no.	
Consecutive no.	
Software version	
List of device parameter settings	
<b>Date of the last check</b>	

#### Form for the test robot

Designation	Value/Designation
Type <sup>a</sup>	
Serial no.	
Consecutive no.	
Scope	
Software version	
Date of the last check	
a Technical description	

Form for a calibration record

Probe			Function <sup>b</sup> and actual beam angle degree	Depth zone	Test cycle no.	Calibration block <sup>e</sup>	Calibration reflector		Sound path mm time of flight µs		Amplitude dB			Correction dB				Comments
Type	No. <sup>a</sup>	Serial no.					c	d	Calibration block <sup>e</sup>	Test object	before measurement	after measurement	Difference	Sound path	Calibration reflector	Transfer	Standardisation	
a Transceiver probe position number of the test combination b E: Individual oscillator technique, T: Tandem technique, D: Transmission technique, SE: Transmission-reception technique, M: Mode conversion c K: Circular disc reflector, Z: Cylindrical transverse bore, R: Rear wall, N: Notch d Diameter or depth in mm, length, width, inclined position e Delete that which is not applicable							Calibration before measurement		Calibration check			Calibration after measurement						
							Date	Date	Date	Date	Date	Date	Date					
							Test company	Responsible	Test company	Third party	Test company	Third party						

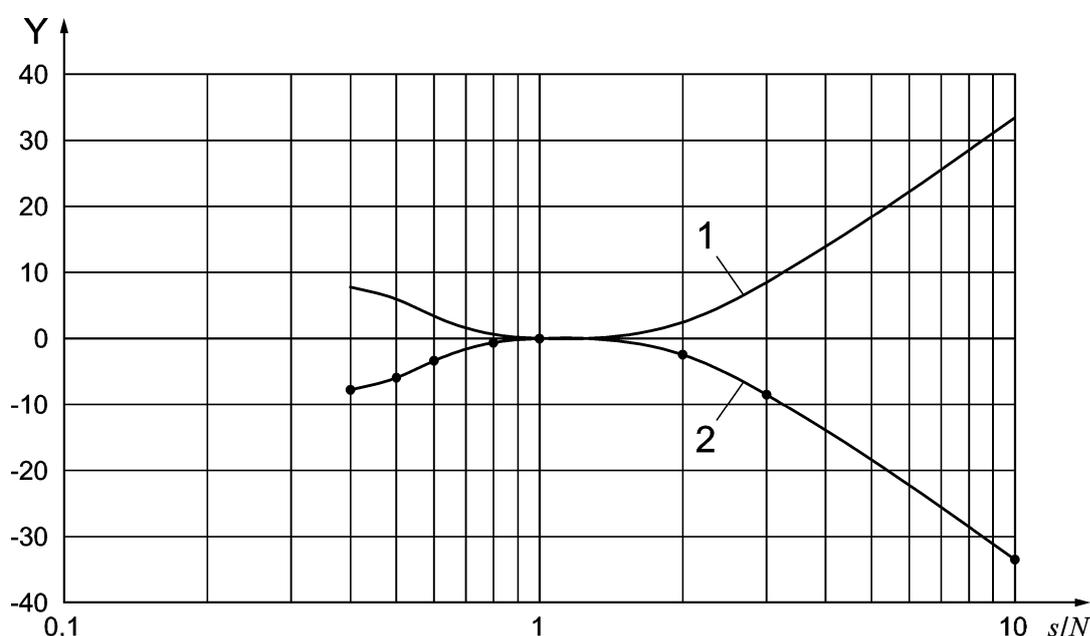




## Annex D (informative)

### Amplification compensation

The echo level change with increasing distance of the reflector from the transceiver probe is compensated by the depth compensation. This ensures that the echo level of this reflector also attains a definite reference value at large sound paths. In case of a circular disc reflector, this relation is given by the AVG diagram (distance-amplification-size). The curves relevant to the transceiver probes shall be determined at a calibration block with circular disc reflectors or taken from the data sheet of the manufacturer and saved. During the measurement, the physically induced echo level change is compensated corresponding to this depth compensation curve (see Figure D.1).



#### Key

- 1 Depth compensation curve
- 2 AVG curve

Figure D.1 — AVG and depth compensation curve

Verstärkung dB	Amplification dB
Relativer Abstand, $s/N'$	Relative distance, $s/N'$

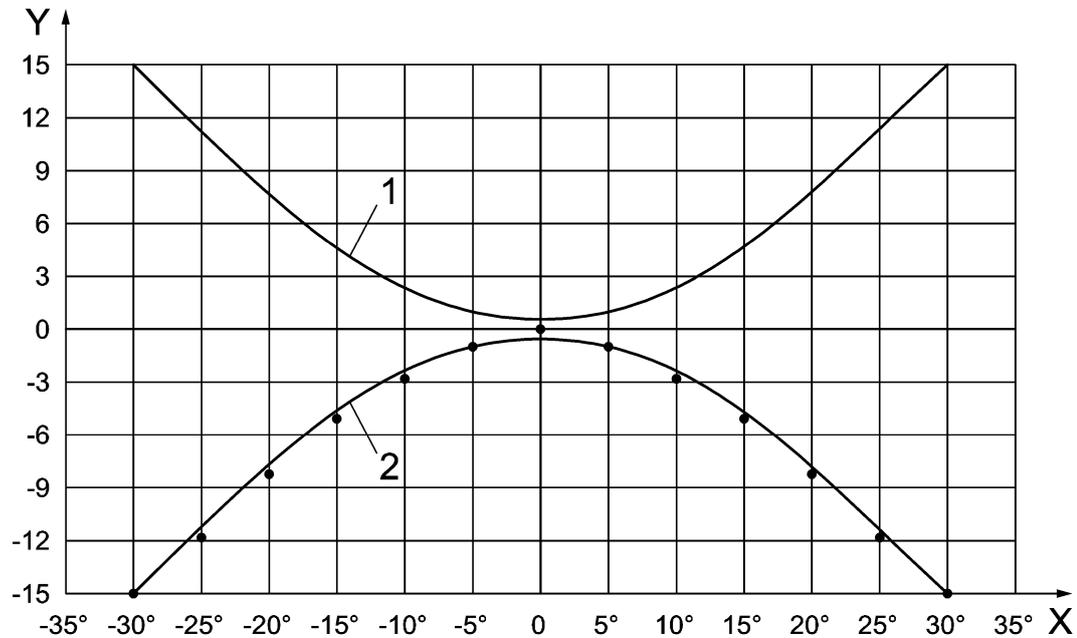
The saved depth compensation curve may be checked at transverse bores, whereby the circular disc applicable for the corresponding sound path is calculated according to equation (D.1). The equation (D.1) is only then applicable if the sound path  $s$  is at least 0.7 times the close field length  $N$  and fulfils the equation (D.2) at the same time.

$$D_{\text{KSR}} = \sqrt{\frac{\sqrt{2}}{\pi} \cdot \lambda \cdot \sqrt{s \cdot D_Q}} \quad (\text{D.1})$$

$$D_Q \geq 1.5 \cdot \lambda$$

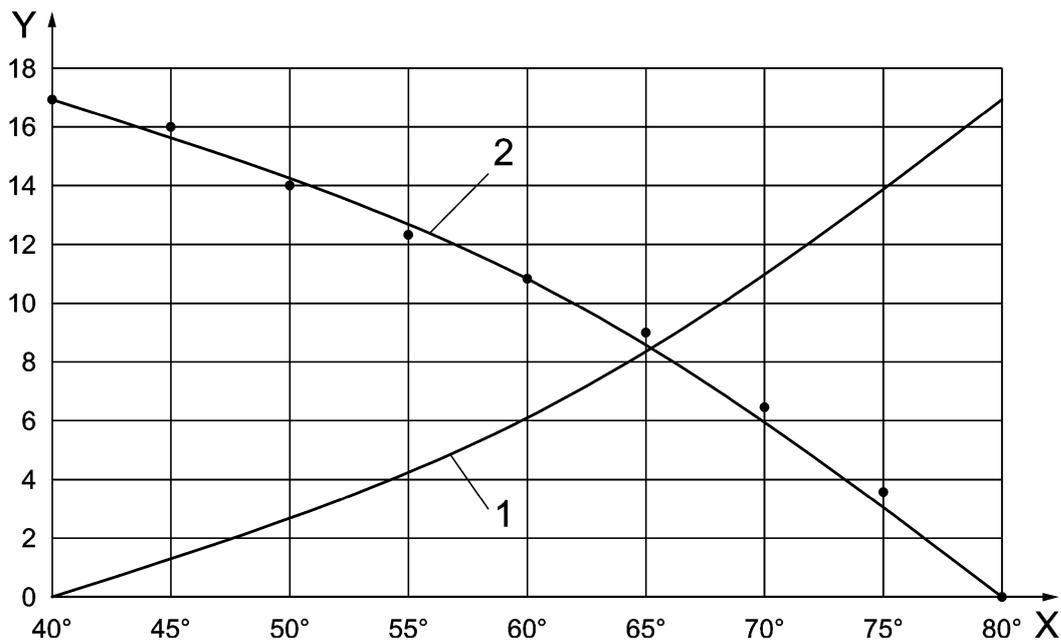
(D.2)

Angle-dependent amplification compensation in case of phased-array probes: By changing the beam angle or the swivel angle, the sensitivity of the UT probe is increased or reduced corresponding to the changing alignment characteristics. This relation shall be compensated. In this way, it is ensured that an angle change does not cause any change to the sensitivity. Figure D.2 shows an example of an angle-dependent amplification compensation vertical to the beam level and Figure D.3 shows an example of the angle-dependent amplification compensation in the beam level.

**Key**

- |   |  |   |                  |
|---|--|---|------------------|
| 1 | Amplification compensation curve                 | X | Beam angle       |
| 2 | Echo level change relation for a point reflector | Y | Amplification dB |

**Figure D.2 — Angle dependent amplification compensation vertical to the beam level in case of phased-array probes**



**Key**

- |   |  |   |                  |
|---|--|---|------------------|
| 1 | Amplification compensation curve                 | X | Beam angle       |
| 2 | Echo level change relation for a point reflector | Y | Amplification dB |

**Figure D.3 — Angle dependent amplification compensation in the beam level in case of phased-array probes**

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DGZfP US 4: *Manual of Automated Ultrasonic Test Systems*<sup>6)</sup>

DGZfP US 3, *Directive of Ultrasonic Testing of the Surface Area close to the UT probe*<sup>6)</sup>

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7) Deutsche Gesellschaft für zerstörungsfreie Prüfung e. V. (DGZfP), Max-Planck-Straße 6, 12489 Berlin.