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Zastępuje
PN-EN 14127:2011

Badania nieniszczące

Ultradźwiękowy pomiary grubości

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EUROPEAN STANDARD

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EN ISO 16809

June 2019

ICS 19.100

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English Version

Non-destructive testing - Ultrasonic thickness measurement (ISO 16809:2017)

Essais non destructifs - Mesurage de l'épaisseur par ultrasons (ISO 16809:2017)

Zerstörungsfreie Prüfung - Dickenmessung mit Ultraschall (ISO 16809:2017)

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CEN-CENELEC Management Centre: Rue de la Science 23, B-1040 Brussels

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European foreword

The text of ISO 16809:2017 has been prepared by Technical Committee ISO/TC 135 "Non-destructive testing" of the International Organization for Standardization (ISO) and has been taken over as EN ISO 16809:2019 by Technical Committee CEN/TC 138 "Non-destructive testing" the secretariat of which is held by AFNOR.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by December 2019, and conflicting national standards shall be withdrawn at the latest by December 2019.

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The text of ISO 16809:2017 has been approved by CEN as EN ISO 16809:2019 without any modification.

INTERNATIONAL STANDARD

ISO 16809

Second edition
2017-11

Non-destructive testing — Ultrasonic thickness measurement

Essais non destructifs — Mesurage de l'épaisseur par ultrasons

Reference number
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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.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation on the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 135, *Non-destructive testing*, Subcommittee SC 3, *Ultrasonic testing*.

This second edition cancels and replaces the first edition (ISO 16809:2012), which has been technically revised. The main changes compared to the previous edition are as follows:

— editorial improvements have been made;

— the terminology has been adapted to the latest edition of ISO 5577;

— Formulae (5) and (6) have been corrected.

Non-destructive testing — Ultrasonic thickness measurement

1 Scope

This document specifies the principles for ultrasonic thickness measurement of metallic and non-metallic materials by direct contact, based on measurement of time of flight of ultrasonic pulses only.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 5577, *Non-destructive testing — Ultrasonic testing — Vocabulary*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 5577 apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

4 Measurement modes

The thickness of a part or structure is determined by accurately measuring the time required for a short ultrasonic pulse generated by a transducer to travel through the thickness of the material once, twice or several times.

The material thickness is calculated by multiplying the known sound velocity of the material with the transit time and dividing by the number of times the pulse transits the material wall.

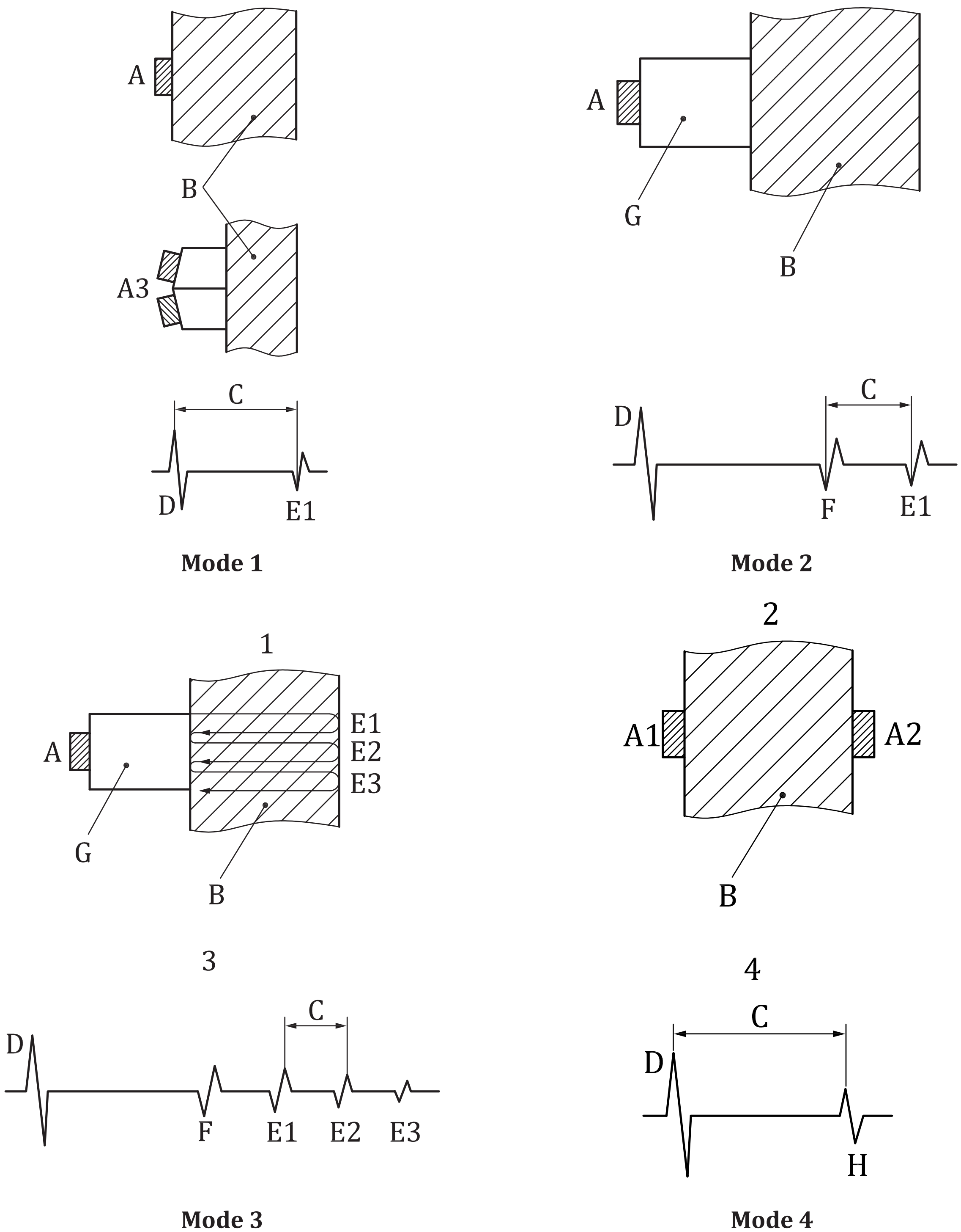
This principle can be accomplished by applying one of the following modes, see Figure 1.

1) **Mode 1:** Measure the transit time from an initial excitation pulse to a first returning echo, minus a zero correction to account for the thickness of the probe's wear plate and the couplant layer (single-echo mode).

2) **Mode 2:** Measure the transit time from the end of a delay line to the first back wall echo (single-echo delay line mode).

3) **Mode 3:** Measure the transit time between back wall echoes (multiple-echo mode).

4) **Mode 4:** Measure the transit time for a pulse travelling from the transmitter to a receiver in contact with the back wall (through-transmission mode).



Key

A	transmit/receive probe	D	transmission pulse indication
A1	transmit probe	E1 to E3	back wall echoes
A2	receive probe	F	interface echo
A3	dual-element probe	G	delay path
B	test object	H	received pulse
C	sound path travel time		

Figure 1 — Measurement modes

5 General requirements

5.1 Instruments

The following types of instruments shall be used to achieve thickness measurement:

a) dedicated ultrasonic thickness measurement instruments with numerical display showing the measured value;

b) dedicated ultrasonic thickness measurement instruments with numerical display showing the measured value and A-scan presentation (waveform display);

c) instruments designed primarily for the detection of discontinuities with A-scan presentation of signals. This type of instrument can also include numerical display of thickness values.

See 6.4.

5.2 Probes

The following types of probes shall be used; these are generally longitudinal wave probes:

— dual-element probes;

— single-element probes.

See 6.3.

5.3 Couplant

Acoustic contact between probe (probes) and material shall be provided, normally by application of a fluid or gel.

The couplant shall not have any adverse effect on the test object, the equipment or represent a health hazard to the operator.

For the use of the couplant in special measuring conditions, see 6.6.

The coupling medium should be chosen to suit the surface conditions and the irregularities of the surface to ensure adequate coupling.

5.4 Reference blocks

The measuring system shall be calibrated on one or more samples or reference blocks representative of the object to be measured, i.e. having comparable dimensions, material and structure. The thickness of the blocks or the steps should cover the range of thickness to be measured. Either the thickness or the sound velocity of the reference blocks shall be known.

5.5 Test objects

The object to be measured shall allow for ultrasonic wave propagation.

There shall be free access to each individual area to be measured.

The surface of the area to be measured shall be free of all dirt, grease, lint, scale, welding flux and spatter, oil or other extraneous matter that could interfere with the testing.

If the surface is coated, the coating shall have good adhesion to the material. Otherwise it shall be removed.

When measuring through coating its thickness and sound velocity need to be known unless mode 3 is used.

For further details, see Clause 8.

5.6 Qualification of personnel

An operator performing ultrasonic thickness measurement according to this document shall have a basic knowledge of the physics of ultrasound, and a detailed understanding and training related to ultrasonic thickness measurements. In addition, the operator shall have knowledge of the product and material to be tested.

It is assumed that ultrasonic thickness testing is performed by qualified and capable personnel. In order to prove this qualification, it is recommended that personnel be qualified in accordance with ISO 9712 or equivalent.

NOTE For categories III and IV according to Pressure Equipment Directive 97/23/EC, Annex I, 3.1.3, there is a requirement for personnel to be approved by a third-party organization recognized by a member state.

6 Application of the technique

6.1 Surface conditions and surface preparation

Using the pulse-echo method means that the ultrasonic pulse needs to pass the contact surface between test object and the probe at least twice: when entering the object and when leaving it.

Therefore, a clean and even contact area with at least twice the probe's diameter is preferred. Poor contact will result in loss of energy, distortion of signals and sound path.

To enable sound propagation all loose parts and non-adherent coatings shall be removed by brushing or grinding.

Attached layers, like colour coating, plating, enamels, may stay on the object, but only a few thickness meters are able to exclude these layers from being measured.

Very often, thickness measurements need to be done on corroded surfaces, e.g. storage tanks and pipelines. To increase measuring accuracy the contact surface should be ground within an area at least two times the probe's diameter. This area should be clean from corrosion products.

Care should be taken not to reduce the thickness below the minimum acceptable value.

6.2 Technique

6.2.1 General

The task of ultrasonic thickness measurements can be separated into two application areas:

— measurement during manufacture;

— in-service measurements of residual wall thickness.

Each area has its own special conditions which require special measuring techniques.

Using a knowledge of the material, geometry and thickness to be measured and the required accuracy, the most suitable measuring equipment and mode shall be selected as follows (Annex D gives guidance):

a) depending on the thickness and the material, frequencies from 100 kHz with through-transmission on highly attenuative materials up to 50 MHz on thin metal sheets shall be used;

b) if dual-element probes are used, then compensation for V-path error is required;

c) on curved objects, the diameter of the probe contact area shall be significantly smaller than the diameter of the test object.

The accuracy of the thickness measurement depends on how accurate the time of flight can be measured, on the mode of time-measuring (zero crossing, flank-to-flank, peak-to-peak), on the mode chosen (with multiple echoes, mode 3, the accuracy is higher than with modes 1 and 2), and on the frequencies which can be used (higher frequencies provide higher accuracy than lower frequencies because of the more accurate time measurement).

Ultrasonic thickness measurement is often required over an area of the component to be measured. Where this is the case, consideration should be given to the spacing between each measurement. Such spacing should be even and the use of a grid is recommended. The grid size should be selected to give a balance between the confidence in the results and the work content involved.

Measuring the thickness ultrasonically means measuring the time of flight and then calculating the thickness assuming a constant sound velocity (see Clause 7). If the velocity is not constant within the path the ultrasonic pulse has travelled, the accuracy of the measurement will be severely affected.

6.2.2 Measurement during manufacture

6.2.2.1 Modes 1, 2 and 3

Where the pulse-echo mode is used, the flow charts in Figures D.1 and D.2 give guidance on the selection of the best technique and equipment.

Thickness measurement on clean parallel surfaces may be carried out with simple numerical display thickness instruments.

On composite materials which generate echoes in addition to the back wall echo, it is recommended that thickness instruments with A-scan displays [type 5.1 b) or 5.1 c)] be used to select the correct echo of the thickness measurement.

6.2.2.2 Mode 4

If the material is highly attenuative and large thicknesses need to be measured, no echo technique can be used, i.e. only through-transmission (mode 4) is applicable.

Two probes on opposite sides of the test object shall then be used. The instrument therefore shall allow for operation with separate transmitter and receiver (TR mode). In most cases, the frequency shall be lower than 1 MHz. Special low-frequency instruments from group c) in 5.1 with low-frequency probes shall be used.

6.2.3 In-service measurement of residual wall thickness

During in-service testing, measurements need to be taken on materials that are subject to corrosion or erosion. The surfaces can be rough and contain pitting or other defects (see Annex A) which are areas of low reflectivity.

For these applications, the use of dual-element probes is recommended. The sensitivity shall be set manually to detect the bad reflecting areas.

Where it is necessary to take a lot of measurements, the readings shall be values with the information on the location of the measuring point. Special testing programs are available to achieve this (data logging).

With in-service testing, the environmental conditions are very important. Equipment can be needed which can withstand high temperatures and harsh environments, or has special electrical shielding.

The flowcharts in Figures D.3 and D.4 give guidance on in-service thickness measurements.

6.3 Selection of probe

Having chosen a suitable measurement procedure according to 6.2, i.e. a general decision for a probe type (single- or dual-element) has been made, there are other parameters that need to be considered when matching the probe to the measuring conditions.

Wide-band probes offer a shorter pulse than narrow-band probes, thus giving a suited flank or peak to start and stop the time-of-flight measurement, giving a better resolution when measuring thin sheets or coatings.

Additionally, a wide frequency band always gives a stable echo even when attenuating materials need to be measured.

Probe size and frequency shall be chosen to cover the measurement range by a narrow sound beam to get an echo from a well-defined area.

For dual-element probes the focal range shall cover the expected thickness range.

When measuring small thicknesses, a delay path shall be used. The measurement shall be done with the interface echo (delay path/test object) and the first back wall echo from the test object (mode 2) or to make the measurement using mode 3. The material of the delay path shall be chosen to generate a suitable interface echo. Using the same material as the test object does not generate an interface echo. When the material of the delay path has a lower acoustic impedance than the material to be tested, e.g. a plastics delay line on metals, there is a phase shift of the interface echo. This shall be corrected to get accurate results. Some thickness instruments do this correction automatically.

For small thicknesses, a dual-element probe with small focal distance may be used.

When measuring on hot surfaces, the delay path shall act as a thermal barrier.

The material chosen for delay shall withstand the temperatures of the test object. The influence of the temperature on the acoustical properties of the delay path needs to be known (drift of sound attenuation and velocity). Data sheets of the probe manufacturers show the range of temperatures a probe is suitable for and the time it can be used on those temperatures.

6.4 Selection of instrument

Selection of instruments of type 5.1 a), b) or c) shall be made as follows:

a) instruments of type 5.1 c) shall be used for modes 1 to 4 (see Clause 4) and shall satisfy the conditions given in 6.2.2 and 6.2.3;

b) instruments of type 5.1 b) shall be used for modes 1, 2 and 3 only (see Clause 4) and shall satisfy the conditions given in 6.2.2.1 and 6.2.3;

c) instruments of type 5.1 a) may be preset by the manufacturer to work only in one of the modes 1, 2 or 3 (see Clause 4).

The instruments shall be selected to satisfy the individual requirements given in 6.2.2.1 or 6.2.3.

See also Annex D.

6.5 Materials different from the reference material

See Tables B.1 and B.2.

6.6 Special measuring conditions

6.6.1 General

There shall be strict observation of all legislative procedures governing the safe use of chemicals and electrical equipment.

Where there is a requirement for high-accuracy measurements, the calibration or reference blocks used should be at the same temperature as the test object.

6.6.2 Measurements at temperatures below 0 °C

For measurements below 0 °C, the couplant chosen shall retain its acoustic characteristics and have a freezing point below the test temperature.

Most probes are rated for use between −20 °C and +60 °C. At temperatures below −20 °C, specially designed probes can be required and contact time should be limited as recommended by the manufacturer.

6.6.3 Measurements at elevated temperatures

For measurements above 60 °C, a high-temperature probe is required and the couplant shall be designed for use at the test temperature.

It is also recommended that, when using A-scan equipment, it should have a “freeze” mode to allow the operator to assess the signal response. The probe contact time shall be limited to the minimum time necessary to achieve a measurement as recommended by the manufacturer.

6.6.4 Hazardous atmospheres

In the measurement of thickness in hazardous atmospheres, there shall be strict compliance with prevailing safety regulations and standards.

In explosive atmospheres, the probe, cable and equipment combination shall be classified as intrinsically safe and relevant safety certification and or documentation shall be checked and completed prior to use.

In corrosive atmospheres, the couplant shall not react adversely with the environment and shall retain its acoustic properties.

7 Instrument setting

7.1 General

The instrument setting shall be carried out with the same equipment as that which will be used for the measurements. Instrument setting shall be carried out in accordance with the manufacturer’s instructions or other valid standards or procedures.

It should be noted that this clause covers only the setting of the instrument (in service). The verification of the equipment characteristics is not considered but can be performed according to the design specification.

Ultrasonic instruments do not measure thickness; they measure time of flight. The thickness is calculated by the application of a factor which is the sound velocity of the material.

$$d = v \times t / n \tag{1}$$

where

d is the thickness;

v is the sound velocity;

t is the measured time;

n is the number of transits through the test object (see Figure 2).

7.2 Methods of setting

7.2.1 General

The method for setting the instrument shall suit the measuring mode and the equipment and probe in use. The setting shall be carried out under comparable operating conditions as those of the measurement.

Annex B gives guidance on the selection of methods for setting instruments.

Differences exist between calibrating a digital thickness instrument [types 5.1 a) and b)] and an A-scan instrument [type 5.1 c)].

7.2.2 Digital thickness instruments

See also 5.1 a) and 5.1 b).

Many digital thickness instruments can be used in measurement modes 1, 2 and 3. The setting of the instrument may be achieved in either of two ways:

a) by adjusting the displayed reading such that it agrees with the measured known dimensions of the series of reference blocks;

b) adjusting or setting the material velocity on the instrument to agree with the known velocity of the test object.

7.2.3 A-scan instrument

See also 5.1, c).

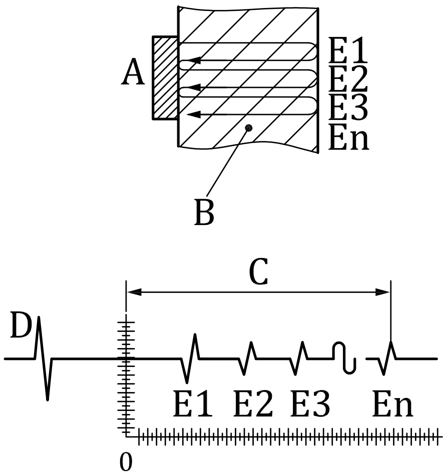
Refer to ISO 16811 for information regarding the time-base setting of an A-scan instrument.

When using mode 1 with an A-scan instrument, the horizontal time base is set such that the transmission pulse indication and the first back wall echo from the reference block are displayed at convenient positions on the screen to agree with a screen graticule or the digital display.

When using mode 2 with an A-scan instrument, adjust the transmission pulse indication such that it is off the screen and the interface echo is at zero on the graticule. Then adjust the first back wall echo to be at the mark relating to the known thickness of the reference block.

When using mode 3 with an A-scan instrument, adjust the first back-wall echo to be at the mark relating to the known thickness of the reference block. Then adjust the n^{th} back wall echo to be at the mark relating to the n times the known thickness of the reference block. When measuring the test object, the zero point of the graticule will correspond to the surface of the test object. The object thickness is equal to the position of the n^{th} back wall echo divided by n. n is normally in the range 2 to 10. See Figure 2.

Mode 4 can only be used with an A-scan instrument. The instrument shall be set to operate in through-transmission mode according to the manufacturer's manual. A transmission pulse indication should be available to represent the zero-time pulse. Set this to align with the zero on the graticule, and the received pulse is set to align with a known thickness on the graticule.



Key

A	transmit/receive probe
B	test object
C	sound path travel time
D	transmission pulse indication
E1 to En	back wall echoes

Figure 2 — Instrument setting for mode 3

7.3 Checks of settings

Checks of the settings of a thickness measuring system shall be carried out with a reference test piece

a) on completion of all measurement work,

b) at regular intervals during the work session, at least once a day,

c) at regular intervals during the work session,

d) if probes or cables are changed,

e) if material types are changed,

f) if the material or equipment temperature changes significantly,

g) if major operating controls are adjusted or considered altered, and

h) at other intervals as directed by specific procedural instructions.

8 Influence on accuracy

8.1 Operational conditions

8.1.1 Surface conditions

8.1.1.1 Cleanliness

The cleanliness of the test object affects its thickness measurement. Inadequate surface preparation can lead to inconsistent results.

Adhering dirt and scale shall be removed by brushing before measurement.

8.1.1.2 Roughness

Roughness interferes with the estimate of thickness (overvaluation) and modifies the coefficients of reflection and transmission at the interface.

In circumstances where there is significant roughness, the sound path is increased and the contact surface is reduced. The measurement uncertainty increases with decreasing thickness.

If the surface opposite to the input surface (back wall surface) is rough, the echo can be deformed; this can result in measurement error.

8.1.1.3 Surface profile

Scanning on an irregular surface with a contact probe necessitates the use of a thick couplant layer. This can create beam distortion.

When using modes 1, 2 or 4 the transit time through the couplant layer can be included in the reading, which will result in an additive error. For a ratio of velocities of the couplant and the material of 1/4, this error can thus be equal to four times the actual couplant thickness.

The coupling medium should be chosen to suit the surface conditions and the irregularities of the surface to ensure adequate coupling.

8.1.2 Surface temperature

Temperature modifies the sound velocity (in both the material and in any delay path and face of the probe) and also the overall acoustic attenuation.

So, for all measurements, if maximum accuracy is required, then the temperature variation and effect upon the following additional items shall be considered:

— references: standards, gauges, test blocks;

— system: instrument, probes, etc.;

— process and methods: couplant, test object.

Sound velocity decreases with increase in temperature in most metals and plastics, whereas it can be seen to increase in glass and ceramics.

The influence of temperature on the velocity of sound in metals is normally insignificant. The longitudinal (compressional) wave velocity in most steels decreases only by approximately 0,8 ms^{-1} $°C^{-1}$.

The influence of temperature on plastics is significant. For acrylic, which is normally used for probe delays, the coefficient is −2,5 ms^{-1} $°C^{-1}$. Compensation for this shall be applied.

8.1.3 Metallic coating

Apparent increase of the material thickness (or even apparent decrease in the case of heat-treated material) can be seen when cladding (constitution, composition, thickness, cladding process, number of layers, etc.) is not taken into account. In general, coatings (added layers) increase the travelled sound path, i.e. also the time of flight of the received echoes (see Figure 3).

The measurement accuracy required shall dictate whether the plating should be considered.

For example, with the instrument calibrated for steel:

— Steel 1 mm at $v = 5\ 920\ \text{ms}^{-1}$;

— Zinc 20 µm at $v = 4\ 100\ \text{ms}^{-1}$;

— Actual thickness 1 mm + 20 µm = 1,02 mm;

$$\frac{\left(1\times10^{-3}\right)\text{m}}{5920\ \text{ms}^{-1}}+\frac{\left(20\times10^{-6}\right)\text{m}}{4100\ \text{ms}^{-1}}=1{,}738\times10^{-7}\ \text{s} \quad (2)$$

$$1{,}738\times10^{-7}\ \text{s}\times5\ 920\ \text{ms}^{-1}=1{,}029\ \text{mm} \quad (3)$$

— Measured thickness 1,029 mm;

— Deviation 0,009 mm.

Cladding thickness can be measured. Measurement accuracy depends on the same parameters as the measurement of the base material.

8.1.4 Non-metallic coating

When measuring through coatings, errors will occur as a result of the differing sound velocities of the coating and the test object (see Figure 3).

For example, with the instrument calibrated for steel:

— Steel 1 mm at $v = 5\ 920\ \text{ms}^{-1}$;

— Paint 100 µm at $v = 2\ 100\ \text{ms}^{-1}$ (this is a generic value and not indicative of a type);

— Actual thickness 1 mm + 100 µm = 1,1 mm;

$$\frac{\left(1\times10^{-3}\right)\text{m}}{5\ 920\ \text{ms}^{-1}}+\frac{\left(100\times10^{-6}\right)\text{m}}{2\ 100\ \text{ms}^{-1}}=2{,}165\ 4\times10^{-7}\ s \quad (4)$$

$$2{,}165\ 4\times10^{-7}\ \text{s}\times5\ 920\ \text{ms}^{-1}=1{,}282\ \text{mm} \quad (5)$$

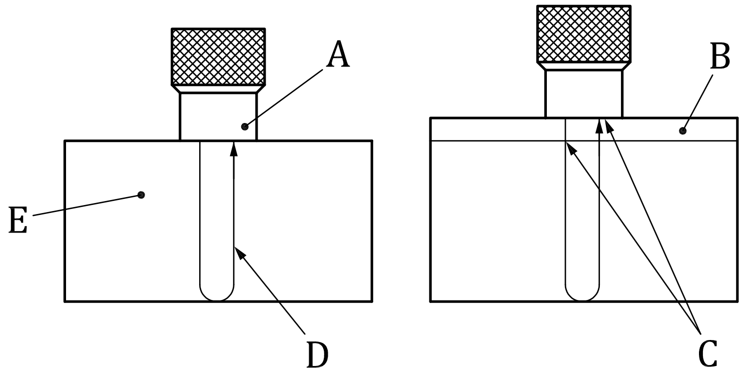
— Measured thickness 1,282 mm;

— Deviation 0,182 mm.

It can also be difficult to obtain the desired measurement if the coating material is:

— similar in acoustic properties to the material of the test object;

— of a significant thickness compared to that of the test object.



Key

A probe

B coating or plating

C increased sound path through coating

D sound path without coating

E metal

Figure 3 — Increased sound path through coating

8.1.5 Geometry

8.1.5.1 Parallelism

The opposite walls of the test object should be parallel within ±10°, otherwise measurement can be difficult or erroneous. This is due to deformation or lack of back wall echoes due to “spatial integration”.

8.1.5.2 Curved surfaces

In this case, the small contact area between the probe and the test object can reduce the effectiveness of the couplant and in turn the signal quality. The probe shall be aligned to the centre of curvature of the test object. These factors affect measurement performance by giving poor acoustic transmission and repeatability.

The contact surface of the probe may be shaped to adjust to the curvature, to improve the transmission of ultrasound.

8.1.5.3 Concave and convex scanning surfaces

The probe face shall always allow adequate coupling. Small radii require a small probe diameter.

8.1.5.4 Range of thickness

Accurate measurement depends on material homogeneity throughout its thickness. Local or general changes of composition result in changes of velocity compared to that of the material of reference blocks and therefore subsequent measurement errors.

8.2 Equipment

8.2.1 Resolution

True equipment resolution is the smallest increment of the quantity being measured that can be recognized by the system. For example, digital thickness instruments can display an apparent resolution of 0,001 mm but only be capable of measuring with a resolution of 0,01 mm. An A-scan instrument [type

5.1 c)] has no stated or assumed thickness resolution; it depends on a number of factors, e.g. digitising speed, screen resolution (pixel number in the x and y axes) and time base setting.

Equipment resolution is influenced by the choice of probe type and frequency.

Higher probe frequencies provide greater thickness resolution than lower frequencies do. This is basically because the higher frequency pulses offer a sharper and more definite timing edge. This is particularly noticeable on A-scan instruments.

8.2.2 Range

The range of the equipment is that range of thickness that the system can practically measure. The number of digits on the display of a digital instrument only infers a range of numbers that can be displayed.

Instruments have a minimum thickness that they can measure. This is generally independent of probe frequency and application. The maximum thickness that can be measured is usually governed by probe frequency and/or application (material conditions, etc.).

The probe dictates a measurement range independent of the instrument. Generally, the minimum range of a probe is controlled by its frequency and the velocity of the material being tested. A probe shall be chosen such that its minimum measurable thickness is below the minimum thickness to be measured.

As a guide it can be assumed that a probe cannot measure less than one whole wavelength at the velocity in question

$$\lambda = \upsilon / f \qquad (6)$$

where

λ is the wavelength;

f is the probe frequency;

υ is the sound velocity.

Probe frequency also dictates the maximum thickness that can be measured. A high-frequency probe has less penetrating power than a low-frequency one.

Consideration should be given to the type of material in question, as this also has an effect on the measuring range.

The selection of probe frequency is controlled by the range of material thickness to be measured and also by the type of material.

The measuring system shall be selected such that its measuring range properly covers the thickness of interest. In the case of an A-scan instrument [type 5.1 c)], the range setting shall be such that it suits the desired resolution at that range without switching ranges.

It is recommended that instrument settings are checked at both ends of the thickness range to be measured.

8.3 Evaluation of accuracy

8.3.1 General

The evaluation is dependent on several parameters and the method of calculation.

8.3.2 Influencing parameters

The most important parameters are shown in Annex C, in particular in C.1.

8.3.3 Method of calculation

Two basic methods are shown in C.2.

9 Influence of materials

9.1 General

The material of the object to be measured can influence the selection of the technique to be applied for ultrasonic thickness measurement.

Forged or rolled metals normally have a low attenuation and a constant and well-defined sound velocity. These materials are easily measured using standard procedures described in Clause 4.

9.2 Inhomogeneity

Material composition including alloying elements and impurities, and its manufacturing process affect grain structure and orientation and therefore homogeneity.

This can cause localized variation of velocity and attenuation in the material, resulting in erroneous measurements or in extreme cases the loss of readings.

9.3 Anisotropy

In anisotropic materials, velocity is not necessarily the same in different planes and the structure can cause variations in beam directions. This results in erroneous readings. Materials which are rolled or extruded, particularly austenitic steel, copper and its alloys, lead and all fibre-reinforced plastics, are examples of this.

To minimize the risk of error, setting of the instrument shall be carried out in the same plane as the measurement.

9.4 Attenuation

Acoustic attenuation is caused by energy loss through absorption (e.g. in rubber) and by scattering (e.g. by coarse grains). This effect can cause a reduction of signal amplitude or a signal distortion.

Castings generally exhibit attenuation through absorption and scattering resulting in lack of or erroneous readings.

High attenuation through absorption alone can be found in plastics.

9.5 Surface conditions

9.5.1 General

Poor attention to surface conditions results in either the inability to obtain measurements or erroneous measurements.

9.5.2 Contact surface

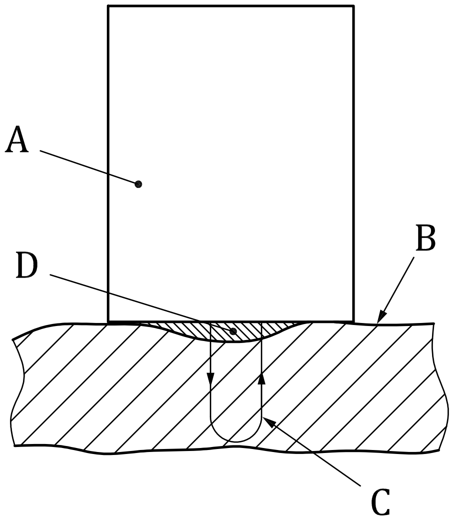
If the surface is coated, measurement can only be achieved through the coating, provided it has good adhesion to the material. When measurements are made through coating, multiple-echo technique shall be used, mode 3 (see Clause 4).

If only a single echo can be achieved due to bad reflection or high attenuation, the coating thickness equivalent shall be known and be subtracted from the single-echo reading, see 8.1.3 and 8.1.4.

Where neither of these conditions can be met, the coating shall be removed, provided this is allowed.

Surface roughness, for example caused by wear or corrosion, highly influences the coupling conditions and the measurement accuracy. Extreme surface roughness can preclude measurement modes 2 and 3 (Clause 4) leaving single-echo technique, mode 1, as the only alternative.

The resulting measurement values shall not be considered more accurate than the surface condition allows. This is illustrated in Figure 4 showing a probe bridging a surface cavity. A measurement recorded in this position includes the equivalent of the couplant layer thickness.



Key

A probe

B test object

C sound path

D couplant

Figure 4 — Sound path through couplant layer

9.5.3 Reflecting surface

Ultrasonic thickness measurements are frequently related to service-induced material loss by corrosion or erosion. These mechanisms produce different types of reflecting surfaces. When performing ultrasonic thickness measurements with the purpose of detecting material loss and/or measuring remaining wall thickness, it is necessary to have a knowledge of the type(s) of material loss to be expected, and to apply a procedure adapted to this specific type of wear, corrosion or erosion.

9.5.4 Corrosion and erosion

In industries such as oil/gas, power generation, energy distribution, storage and transport of products, the corrosion mechanisms are frequently linked to vessels and pipes made of ferrous materials such as rolled steel plates, seamless pipe and welded assemblies.

The following types of corrosion in steel vessels and piping components are to be considered when selecting the ultrasonic technique to be applied:

— uniform corrosion;

— pitting;

— deposit attack;

— crevice corrosion;

— galvanic corrosion;

— flow-induced corrosion;

— weld zone corrosion;

— combinations of two or more of the above types of corrosion.

The illustrations in Table A.1 show important shapes and distributions of ultrasonic reflectors to be considered.

Annex A proposes technical data to be applied for detection and measurement.

10 Test report

10.1 General

Taking into account any specific requirements agreed at the time of enquiry and order, the following information shall be recorded.

10.2 General information

This information shall include:

a) a reference to the standard or specifications applied;

b) the details of the company/agency requiring, and purpose of, the survey;

c) a general description of the plant/structure/parts under test, including a definition of surface conditions, e.g. coated/insulated,rough/smooth, shot-blasted;

d) the dates of first and last measurement in the report;

e) the location/site details;

f) the material type;

g) the instrument type and serial number;

h) a description of the probe type (including element size/frequency) and its serial number;

i) the details of the reference block, if applicable;

j) the couplant type;

k) the measuring technique/mode;

l) the instrument setting details;

m) the operator’s name;

n) the operator’s qualification details;

o) the operator's company details; and

p) the operator's signature.

10.3 Measurement data

These data shall include:

a) the measurement pattern descriptor;

b) the measurement point location descriptor/identifier;

c) the original thickness, if applicable;

d) the allowable tolerances (where known);

e) the measurement results (table and/or map);

f) the diminution as a percentage or actual, if applicable;

g) supporting drawings/sketches showing measurement locations;

h) supporting drawings/sketches showing locations of discontinuities; and

i) visual testing/condition comments.

Annex A
(informative)

Corrosion in vessels and piping

A.1 General

Corrosion in components such as vessels and piping can be caused by different mechanisms. Table A.1 gives some guidance regarding the types of ultrasonic reflectors, which can occur with the different corrosion mechanisms and some guidance regarding the ultrasonic techniques recommended for measurement of the remaining material thickness.

A.2 Measurement of general corrosion

A.2.1 Instrument

For digital display instruments, probes as specified by the manufacturer should be used. If the instrument does not give reliable readings due to difficult surface conditions, inclusions in the material or heavy coating, an A-scan instrument should be used.

Where the measuring surface is coated and it is required to eliminate the coating thickness from the results, a suitable instrument that uses mode 3 should be used.

Where it is required to find the thinnest point within a given area, a scanning should be performed. For this purpose, an A-scan instrument should be used.

Where many readings are to be recorded, an instrument with data logging facility should be considered.

A.2.2 Probes

Probe selection depends on instrument type, material thickness, surface condition and coating condition.

For digital display instruments, the probes as specified by the manufacturer should be used. For A-scan instruments, the following is recommended:

— the probe frequency should be selected such that at least 1,5 of the related wavelength covers the wall of the test object (see 8.2.2);

— generally, single-element probes should be used for thicknesses of 10 mm and above. The multiple-echo technique (mode 3) should only be used with single-element probes;

— where thickness is below 10 mm, dual-element probes may be applied;

— if the thickness is expected to be below 5 mm, dual-element probes with special focal range should be used;

— when the object is curved, consideration should be given to the selection of probe diameter;

— on a coated object, a single-element probe should be used with mode 3 to allow compensation for the coating thickness.

A.2.3 Setting of the instrument

Setting of the instrument is done on a step-wedge with a thickness range covering the expected range of the test object. Material and temperature shall be equivalent to the test object.

A.2.4 Measuring

Where several back wall echoes can be read (only single-element probes), the most accurate results are achieved by reading the n^{th} echo and dividing the reading by n. When this technique is used on a coated surface, the distance from echo 1 to echo n is read and divided by (n−1). Hereby, the coating thickness is not included in the result.

Where only one back wall echo is used, the reading should be taken in the same position of the echo as the reading during setting of the instrument. If the surface is coated, the coating thickness multiplied with the sound velocity ratio metal/coating is included in the reading and should be subtracted before recording the result.

Where high reproducibility is essential, the exact position of the measuring point should be documented or ensured in another way. Where it is essential to detect the thinnest point within a given area, scanning should be performed. This normally requires an A-scan instrument [type 5.1 b) or type 5.1 c)].

Use of digital display instruments should strictly follow the manufacturer's instructions.

Unexpected measurements can be due to internal discontinuities. These should be verified by supplementary investigations, e.g. by using angle-beam probes.

A.3 Measurement of corrosion with pitting

A.3.1 Instrument

For thickness measurement where pitting can be expected, an A-scan instrument should be used [type 5.1 b) or type 5.1 c)].

A.3.2 Probes

For detection of pitting, a dual-element probe is the most suitable. The selected probe should have a focal distance corresponding to the expected distance to the pitting.

A.3.3 Setting of the instrument

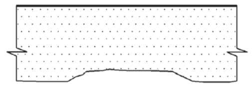
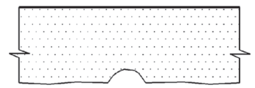
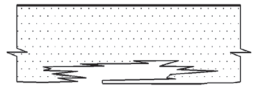
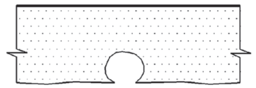
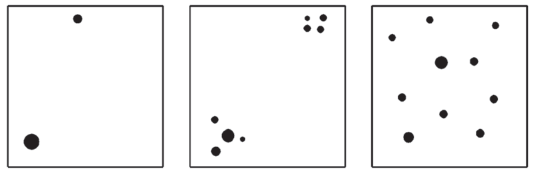
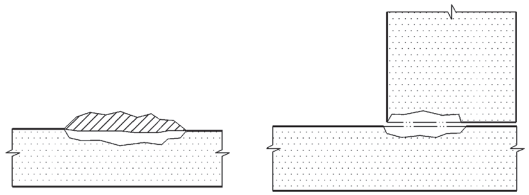
The setting of the instrument is done on a step-wedge with a thickness range covering the expected range of the test object. Material and temperature shall be equivalent to the test object. Where small diameter pitting is expected, detection sensitivity should be verified on a calibration block with small diameter flat-bottomed holes in the same distance range as the expected pitting.

A.3.4 Measuring

When searching for pitting, only the first back wall echo should be used. Echoes from pitting can occur together with the back wall echo.

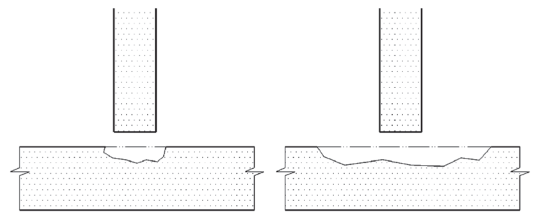
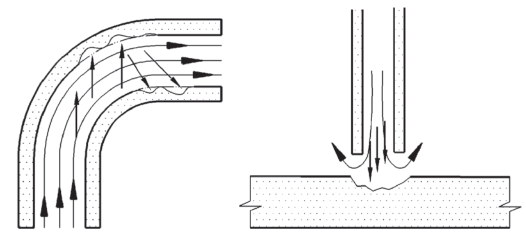
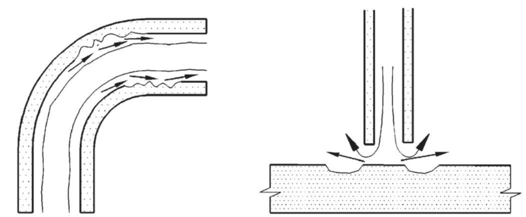
Where the reflector type cannot be identified as either corrosion or inclusion, supplementary investigation should be carried out using angle-beam probes. To differentiate between inclusions and pitting, 45°-angle-beam probes are especially suitable.

Table A.1 — Corrosion in steel – Recommended ultrasonic techniques

No.	Description	Typical corrosion origin and mechanism	Illustration		Recommended ultrasonic technique
1	Uniform corrosion	Occurs in corrosive environments such as: — water saturated with oxygen; — sour solutions; — condensed water from wet gas.	 Development in uniform corrosion		A.2
2	Pitting	Corroded areas have clear limits while the adjacent areas are typically not attacked. Pitting can take different shapes, depending on structure and texture of the material, and on surface condition.	 Type A: Flat pitting	 Type C: Semi-circular pits	A.3
			 Type B: Undermining pitting	 Type D: Surface breaking spherical	
2a	Pitting	Distribution patterns			[a]
3	Deposit corrosion, crevice corrosion	Occurs under deposits and in narrow water-filled crevices			[a]

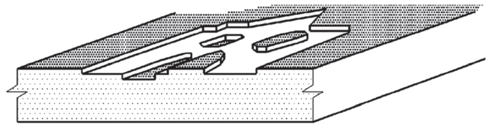
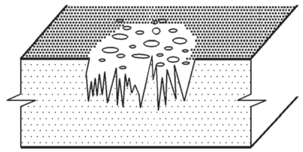
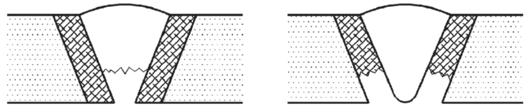
[a] These corrosion forms are shown to illustrate the possibilities and difficulties that can be encountered when achieving to detect and quantify corrosion. The illustrations are for information only. A specific recommendation regarding the technique to be applied for each case cannot be given, as it would depend on the access conditions, material thicknesses and other parameters.

Table A.1 *(continued)*

No.	Description	Typical corrosion origin and mechanism	Illustration	Recommended ultrasonic technique
4	Galvanic corrosion	Dissimilar metals		a
5	Flow-induced corrosion			a
6	Turbulence corrosion			a

[a] These corrosion forms are shown to illustrate the possibilities and difficulties that can be encountered when achieving to detect and quantify corrosion. The illustrations are for information only. A specific recommendation regarding the technique to be applied for each case cannot be given, as it would depend on the access conditions, material thicknesses and other parameters.

Table A.1 *(continued)*

No.	Description	Typical corrosion origin and mechanism	Illustration	Recommended ultrasonic technique
7	Mesa-type corrosion			a
8	Cavitation corrosion			a
9	Weld zone corrosion			a

[a] These corrosion forms are shown to illustrate the possibilities and difficulties that can be encountered when achieving to detect and quantify corrosion. The illustrations are for information only. A specific recommendation regarding the technique to be applied for each case cannot be given, as it would depend on the access conditions, material thicknesses and other parameters.

Annex B
(informative)

Instrument settings

Table B.1 — Instrument setting on a reference block with multiple steps

Select reference block:	**Of same material and same surface condition**	**Of same material and other surface condition**	**Of different material and same surface condition**	**Of different material and other surface condition**
Setting of instrument	Calibrate on a thickness above and below the thickness range to be measured	Calibrate on a thickness above and below the thickness range to be measured	Calibrate on a thickness above and below the thickness range to be measured	Calibrate on a thickness above and below the thickness range to be measured
Verification of linearity at intermediate steps	if more than two steps are available	if more than two steps are available	if more than two steps are available	If more than two steps are available
Correction of setting	Not necessary	Check and correct zero setting on the test object	Re-calibrate on the test object if possible or use known velocity to correct the reading.	Re-calibrate on the test object if possible or check and correct zero setting on the test object and use known velocity value.
Uncertainty of measurement related to the setting of the instrument depends on:	Accuracy of reference block thicknesses and, if only 2 steps are used, uncertainty of linearity	Accuracy of reference block thicknesses and the surface condition of the test object and, if only 2 steps are used, uncertainty of linearity	Accuracy of reference block thicknesses and accuracy of thicknesses of the test object or validity of known value of velocity and, if only 2 steps are used, uncertainty of linearity	Accuracy of reference block thicknesses and accuracy of thicknesses of the test object and the surface condition of the test object or validity of known value of velocity and, if only 2 steps are used uncertainty of linearity

Table B.2 — Instrument setting on a reference block with one thickness or without a reference block

Reference block:	Of same material and same surface condition	Of same material and other surface condition	No reference block of same material available
Calibration of instrument	Set the velocity and zero to agree with the known value and thickness	Set the velocity and zero to agree with the known value and thickness	Set the velocity to a known value for the test object and Set zero by using a known value or by using mode 3 or by using automatic probe recognition
Verification of linearity at intermediate steps	Not possible	Not possible	Not possible
Correction of setting	Not necessary	Check and correct zero setting on test object	Not possible
Uncertainty of measurement related to the setting of instrument depends on:	Accuracy of reference block thickness and uncertainty of linearity	Accuracy of reference block thickness and uncertainty of linearity and surface condition of the test object	The validity of the known values

Annex C
(informative)

Parameters influencing accuracy

C.1 Parameters influencing accuracy

Table C.1 lists the parameters influencing accuracy:

Table C.1 — Table of parameters influencing accuracy

Item		Parameter	Result	Possible improvements
Test object	Material	Composition	Attenuation, absorption, scattering and local variation of velocity	Setting of instrument on the same material as test object
		Structure		
		Anisotropy		
	Surface condition	Cleanliness	Local variations of surface conditions lead to variations of couplant thickness	Cleaning
		Roughness		Grind surface as required
		Surface profile		Using of small diameter probe
	Coating	Coating	Coating velocity different from base material velocity resulting in inaccuracy	Removing coating or Using mode 3
		Paint		
		Surface treatment		
	Geometry	Non-parallelism	Back wall echo can disappear or can be distorted	Parallelism should be within the probes beam divergence angle [±1,22 arcsin(λ/d)]
		Curvature	Loss of coupling efficiency	Using a smaller diameter probe
		Range	Distortion of back wall echo caused by attenuation	Using mode 1 and a lower probe frequency using mode 4
Reference	Method	Uncertainty of calibration method	Inaccurate readings	Using block representative of part, steps thinner and thicker than expected thickness, choice of calibration method, see Annex B
	Reference block	Thickness and velocity uncertainty	Accuracy cannot be better than block uncertainties	Accurate measurement of block thickness and sound velocity

Table C.1 *(continued)*

Item		Parameter	Result	Possible improvements
Measuring	Equipment	Resolution	Accuracy cannot be better than system resolution	Using higher accuracy instrument, higher probe frequency and broadband probes
		Cable length	Excessive cable length distorts the signals	Using shorter cable and calibrate with the same cable
		Drift of instrument	Inaccurate readings	Warming-up the unit and wait for stable reading or use stable equipment
		Time of flight	Accuracy cannot be better than time of flight measurement accuracy	Using higher accuracy instrument
		Linearity	Inaccurate readings	Ensuring linearity of system
		Trigger point	Inaccurate readings	Selecting best trigger point
	Operation	V-path	Wrong reading because thickness differs from ultrasonic path	Using a thickness gage with V-path correction or taking into account the roof angle and separation Using a single-element probe
		Phase shift	Erroneous reading	Taking the phase shift into account
Repeatability	Use of unit	Method	Improper operation	Providing correct procedure or instructions. Conducting repeatability tests
		Coupling	Bad coupling introduces dispersion in the readings.	Selecting couplant to suit the surface conditions Using mode 3 if possible
		User training	Error on reading	Operator training
Miscellaneous	Temperature	Variation of sound velocity	Error on reading	Calibrating at the same temperature as test object or correcting calibration for change of sound velocity

C.2 Methods of calculation

The following two methods illustrate ways to calculate the inaccuracy of a reading:

a) Method a)

This method calculates the inaccuracy of a measurement by adding the inaccuracies of all the influencing parameters.

b) Method b)

This method calculates the inaccuracy, l_g, of a measurement result, MR, in accordance with ISO 14253-2 where the measurement result is equal to the reading, R, ± the inaccuracy, l_g.

$$\mathrm{MR} = R \pm l_g$$

where

l_g is $K\sqrt{\sum_i \sigma_i^2}$

K shall be chosen for a level of confidence, e.g.:

1) $K = 1$ for 68 % level of confidence;

2) $K = 2$ for 95 % level of confidence;

3) $K = 3$ for 99,8 % level of confidence;

σ_i is the uncertainty for each parameter obtained:

1) either by statistical approach;

2) or by other methods, e.g. standards, specifications, analysis;

i is the different parameters which have been considered independent (for instance; surface condition, linearity, repeatability).

Statistical distribution:

— uniform or rectangular law: $\sigma_i = 0{,}6\ a$;

— Gauss law: $\sigma_i = 0{,}5\ a$,

where a is the accuracy of the result.

Table C.2 gives an example how to compare the methods a) and b) for a steel plate of 10 mm thickness and a surface roughness $Ra = 6{,}3$ µm.

Table C.2 — Illustrates the application of calculation methods a) and b) where the test object is a steel plate 10 mm thick, surface roughness R_a = 6,3 µm

Parameter	Group	Factors	Measuring conditions	Estimated accuracy mm	
				Method a)	Method b)
Test object	Material	Composition	Ferritic steel	0	0
		Structure	Fine grained	0	0
		Anisotropy		0	0
	Surface condition	Cleanliness		0	0
		Roughness	Surface *Ra* = 6,3 µm	0,006 3	0,003 2
		Surface profile	Flat	0	0
	Coating	Coating	Not coated	0	0
		Paint	Not painted	0	0
		Surface treatment	Un-treated	0	0
	Geometry	Non-parallelism	Parallel faces	0	0
		Curve radius	No curvature	0	0
		Range	Negligible attenuation	0	0
Reference	Calibration method	Uncertainty of calibration method	Reference block Same material/5 step calibration	0	0
	Reference block	Thickness and velocity uncertainty	Thickness uncertainty: 0,01 mm Velocity uncertainty: ±30 m/s	0,05	0,025
Measuring	Equipment	Resolution	Digital instrument resolution: 0,01 mm	0,01	0,006
		Cable length	Fixed length	0	0
		Drift of instrument	Stable instrument	0	0
		Time of flight	Accuracy of time measurement: 10 ns	0,03	0,018
		Linearity	1 % of the maximum range (manufacturer's data)	0,1	0,05
Measuring	Operation	Trigger point	Constant amplitude	0	0
		V-path	Single-element probe	0	0
		Phase shift	No phase shift	0	0

Table C.2 *(continued)*

Parameter	Group	Factors	Measuring conditions	Estimated accuracy mm	
				Method a)	Method b)
Repeatability	Operation	Coupling	Coupling error included in method	0	0
		User training	Qualified operator	0,1	0,05
Miscellaneous	Temperature	Variation of sound velocity	Measurement at room temperature, negligible variation	0	0
			Global error	**0,296**	**0,135**

Annex D
(informative)

Selection of measuring technique

See Figures D.1 to D.4.

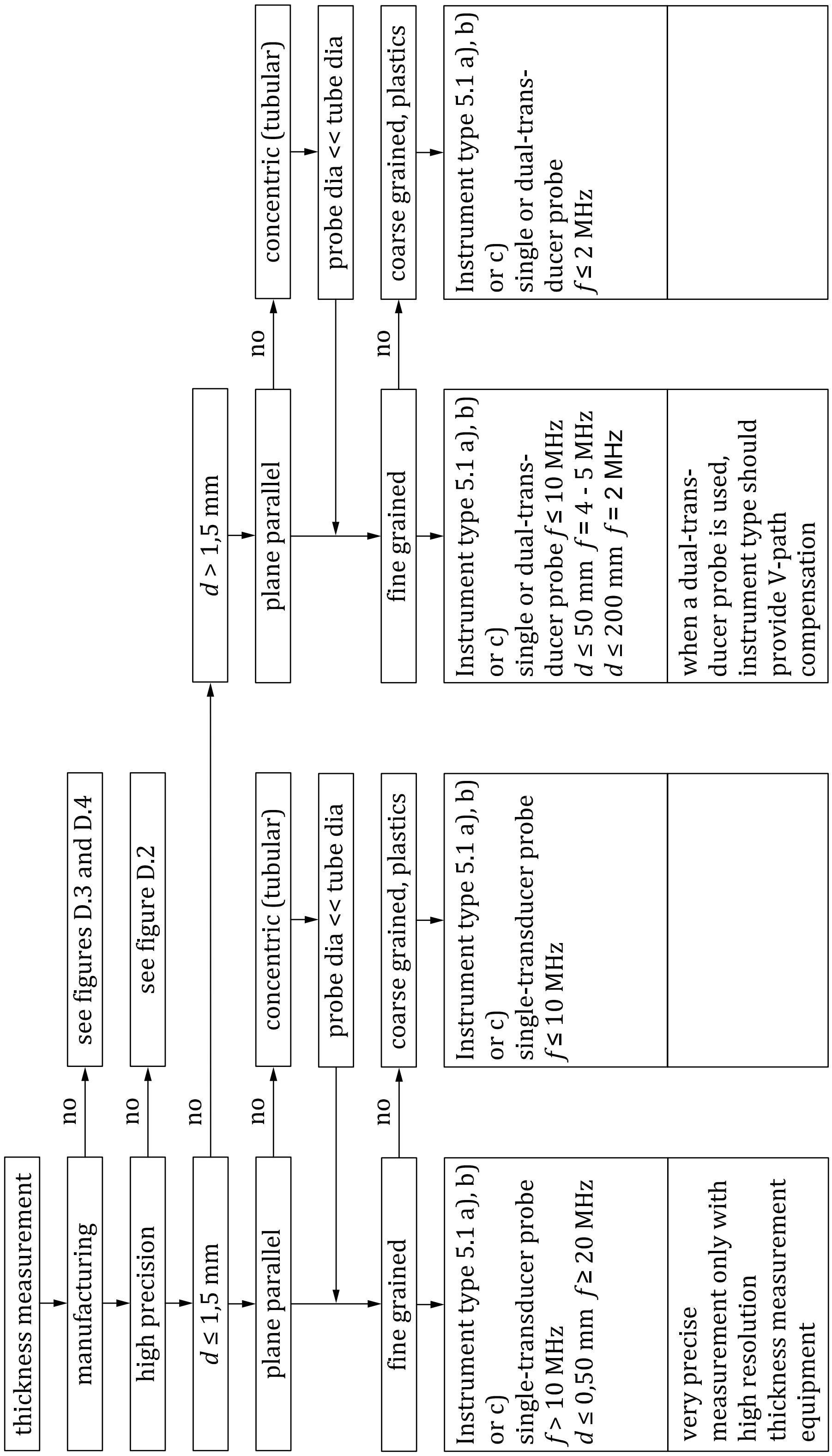


Figure D.1 — Flowchart for testing during manufacture

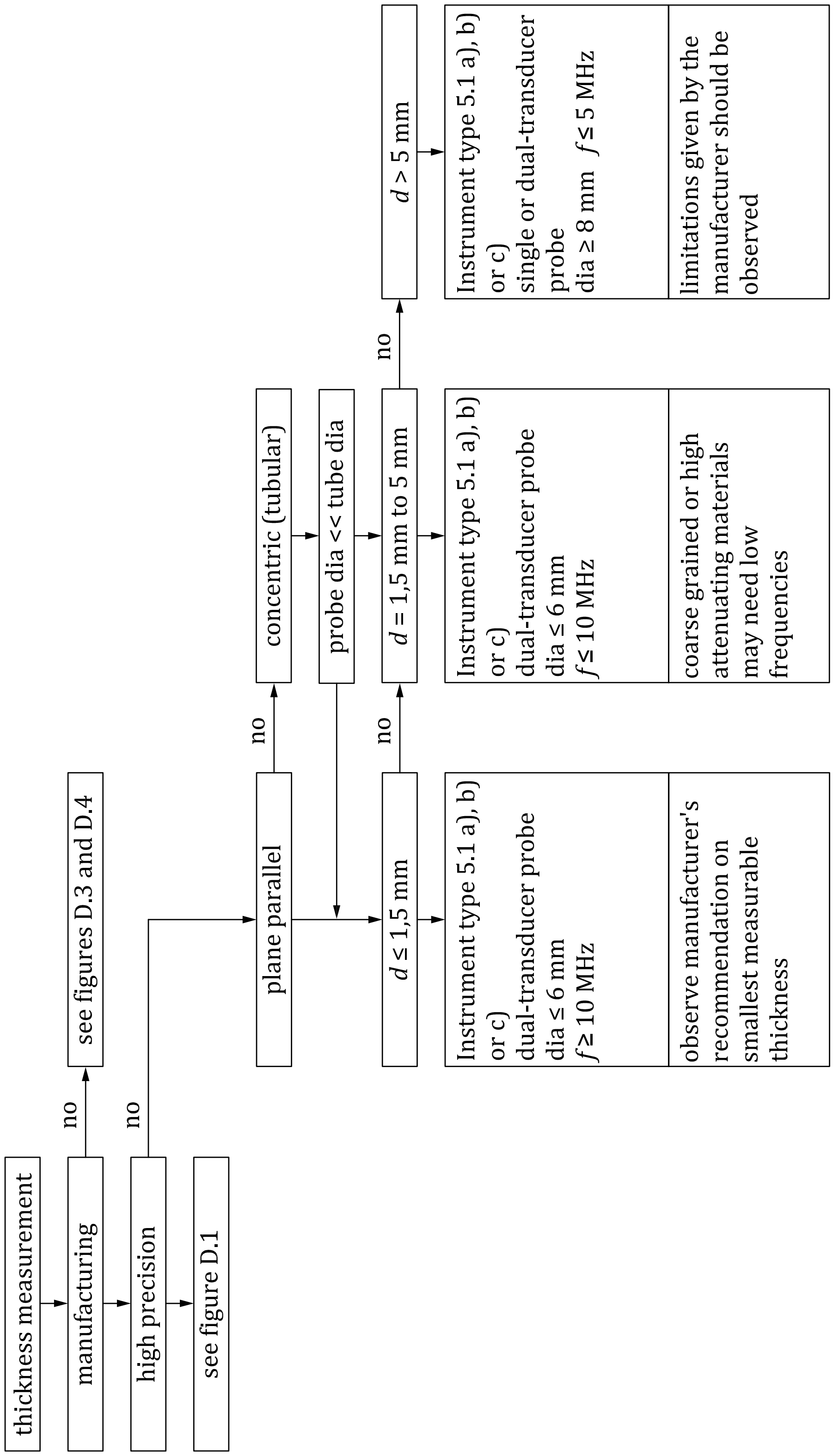


Figure D.2 — Flowchart for testing during manufacture

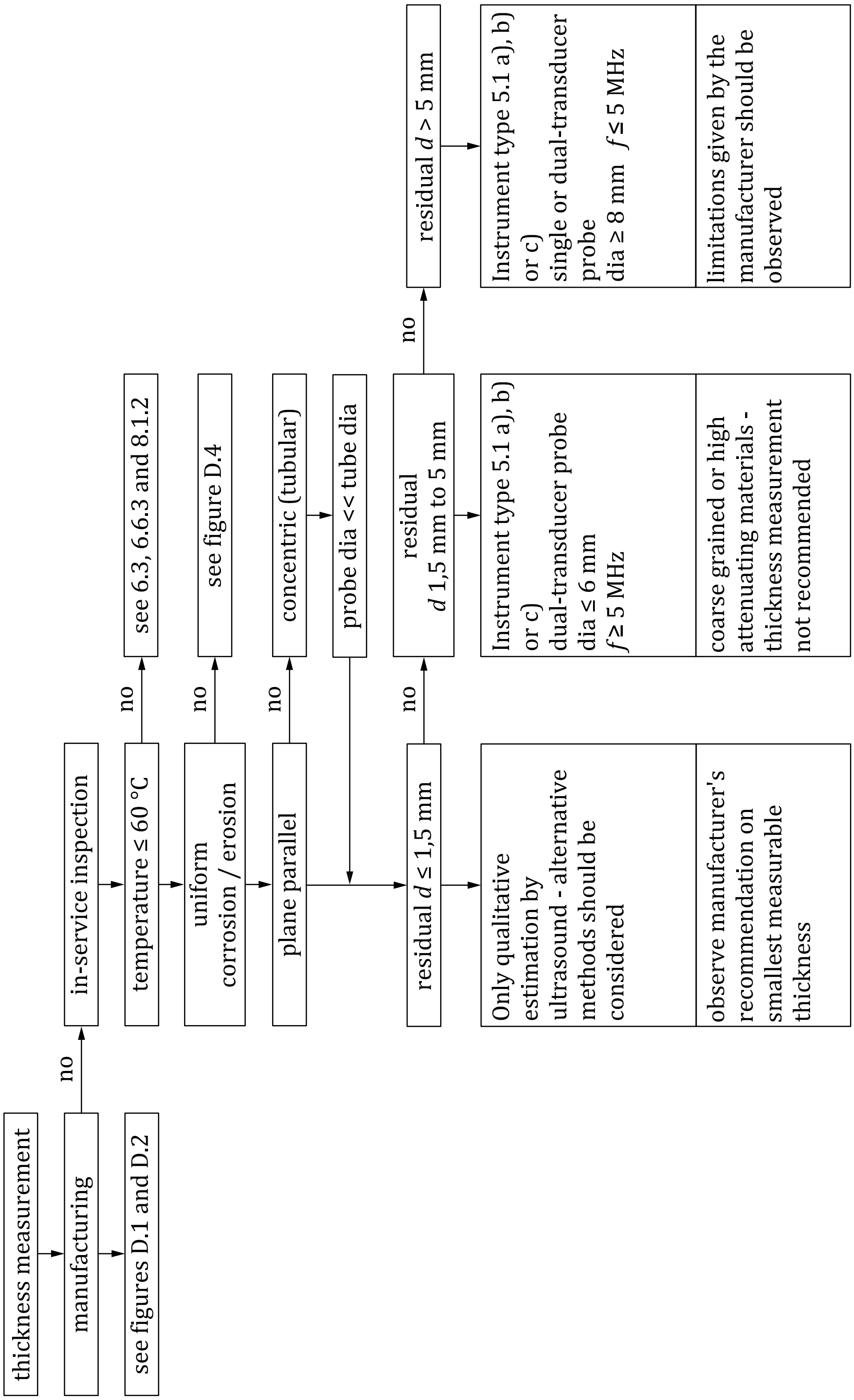


Figure D.3 — Flowchart for in-service testing

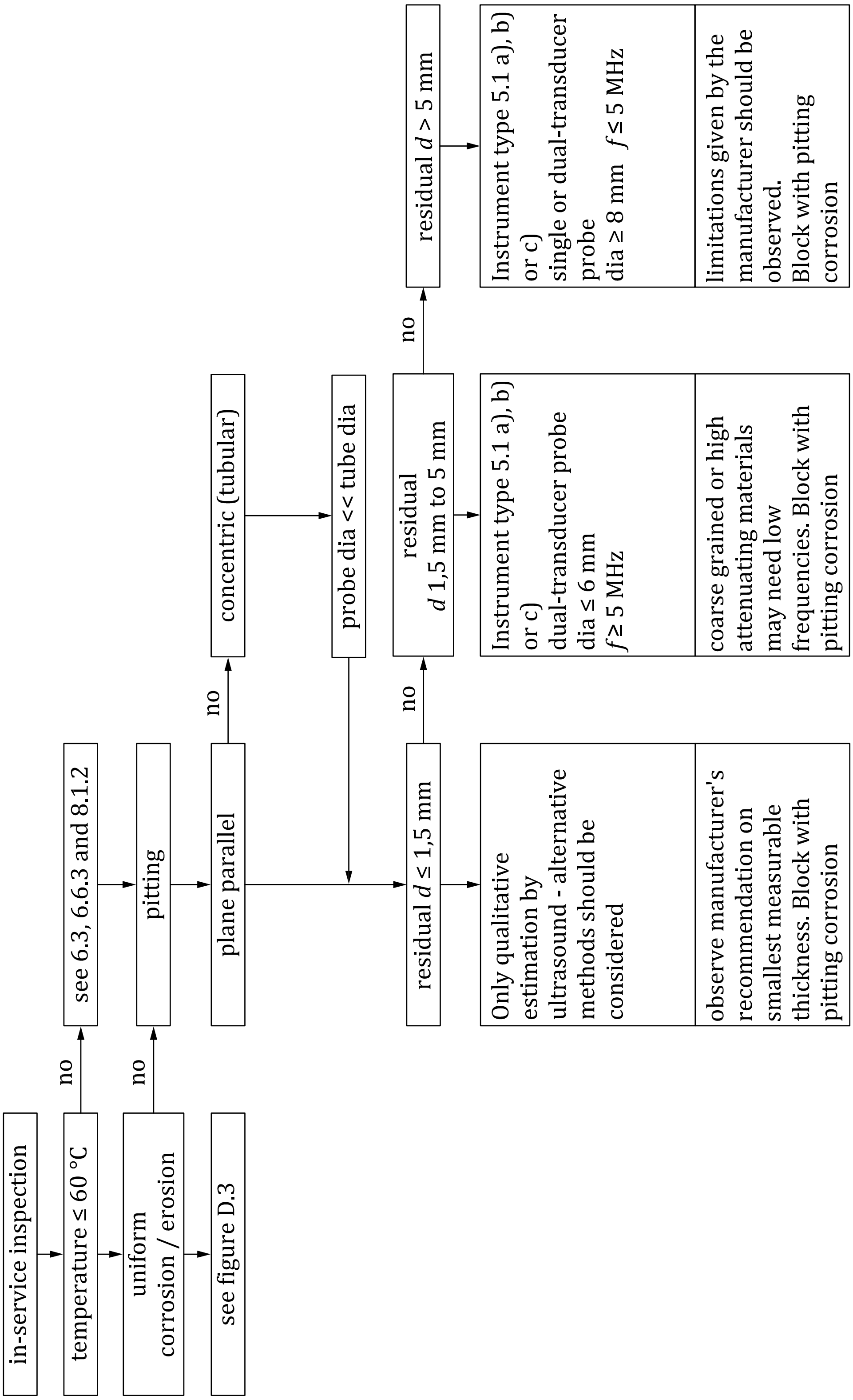


Figure D.4 — Flowchart for in-service testing

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[3] ISO 16811, *Non-destructive testing — Ultrasonic testing — Sensitivity and range setting*

[4] Directive 97/23/EC of the European Parliament and of the Council of 29 May 1997 on the approximation of the laws of the Member States concerning pressure equipment [as amended and corrected]

[5] Directive 2014/68/EU of the European Parliament and of the Council of 15 May 2014 on the harmonisation of the laws of the Member States relating to the marking available on the market of pressure equipment

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