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Non-destructive testing — Ultrasonic testing — General principles

Essais non destructifs — Contrôle par ultrasons — Principes généraux

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Foreword

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This document was prepared by Technical Committee ISO/TC 135, *Non-destructive testing*, Subcommittee SC 3, *Ultrasonic testing,* in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 138, *Non-destructive testing,* in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

This second edition cancels and replaces the first edition (ISO 16810:2012), which has been technically revised.

The main changes are as follows:

— normative references have been updated;

— Clause 3 Terms and definitions refers to ISO 5577 as a source of terms;

— editorial revisions and usage of terms has been harmonized.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

The following International Standards are linked:

ISO 16810, *Non-destructive testing — Ultrasonic testing — General principles*

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

ISO 16823, *Non-destructive testing — Ultrasonic testing — Through-transmission technique*

ISO 16826, *Non-destructive testing — Ultrasonic testing — Testing for discontinuities perpendicular to the surface*

ISO 16827, *Non-destructive testing — Ultrasonic testing — Characterization and sizing of discontinuities*

ISO 16828, *Non-destructive testing — Ultrasonic testing — Time-of-flight diffraction technique for detection and sizing of discontinuities*

Non-destructive testing — Ultrasonic testing — General principles

1 Scope

This document specifies the general principles for the ultrasonic testing of industrial products that permit the transmission of ultrasound.

The specific conditions of application and use of ultrasonic testing, which depend on the type of product to be tested, are described in documents which can include:

— product standards;

— specifications;

— codes;

— contractual documents;

— written procedures.

This document specifies the minimum applicable requirements, unless otherwise specified in the referencing documents.

This document does not specify:

— extent of testing and scan plans;

— acceptance criteria.

This document describes only conventional probes, however, the general principles for ultrasonic testing also apply to ultrasonic testing using array techniques. If array techniques are used, then additional steps or verifications can be needed.

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 2400, *Non-destructive testing — Ultrasonic testing — Specification for calibration block No. 1*

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

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

ISO 7963, *Non-destructive testing — Ultrasonic testing — Specification for calibration block No. 2*

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

ISO 22232-1, *Non-destructive testing — Characterization and verification of ultrasonic test equipment — Part 1: Instruments*

ISO 22232-2, *Non-destructive testing — Characterization and verification of ultrasonic test equipment — Part 2: Probes*

3 Terms and definitions

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

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

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

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

4 Qualification and certification of test personnel

a) Ultrasonic testing shall be performed by personnel qualified in accordance with ISO 9712.

b) The requirements for qualification and certification of test personnel shall be specified in the product standards and/or other applicable documents.

5 Information required prior to testing

Prior to testing the following information shall be available, as applicable:

a) purpose of testing;

b) qualification and certification of test personnel;

c) environmental conditions and state of the test object;

d) requirement for a written test procedure;

e) any special requirements for preparation of scanning surfaces;

f) volume to be tested;

g) test sensitivity and method of setting-up sensitivity;

h) requirements for evaluation and recording level;

i) acceptance criteria;

j) extent of testing including scan plan;

k) requirement for a written test report.

6 Principles of ultrasonic testing (UT)

6.1 General

Ultrasonic testing is based on the propagation of ultrasonic waves through the test object and monitoring either the transmitted signal (termed the through-transmission technique), or the signal reflected or diffracted from any surface or discontinuity (termed the pulse-echo technique).

Both techniques can employ a single-transducer probe acting as both transmitter and receiver, or a dual-(twin-)transducer probe, or separate transmitting and receiving probes.

Similarly, both techniques can involve intermediate reflection from one or more surfaces of the test object.

The testing can be performed manually or by the use of semi-automated or fully automated test equipment, and can use contact, gap or immersion techniques, or other coupling techniques adapted to specific applications.

6.2 Wave mode and direction of sound propagation

The most commonly used wave types are longitudinal waves and transverse waves, and these can be propagated either perpendicular or at an angle to the test surface. Other types of waves, e.g. Lamb waves or Rayleigh waves, can also be used for special applications.

The choice of wave mode and direction of propagation will depend on the purpose of the test and should take into account the specular nature of reflection from planar reflectors.

6.3 Through-transmission technique

This technique is based on measuring the attenuation of the signal after the passage of an ultrasonic wave through the test object.

The signal used for measurement can be either:

a) a back-wall echo;

b) any other signal received either directly, or after intermediate reflection from the surfaces of the test object.

Further details of this testing technique are contained in ISO 16823.

6.4 Pulse-echo technique

This technique utilizes the reflected or diffracted signal from any interface of interest within the test object. This signal is characterized by its amplitude and position along the time base; the latter related to the distance between the reflector and the probe.

The location of the reflector is determined from the knowledge of its distance, the direction of sound propagation, and the position of the probe.

It is recommended that the signal amplitude be measured by comparison with one of the following:

a) a distance-amplitude curve (DAC), or a series of curves, obtained by using artificial reflectors such as side-drilled holes, flat-bottomed holes or notches within one or more reference blocks;

b) a distance-gain-size diagram (DGS diagram);

c) echoes from suitable notches; or

d) echoes from large planar reflectors perpendicular to the beam axis (e.g. back wall echo).

These techniques are described in ISO 16811.

In order to obtain further information about the shape and size of reflectors, other techniques may be used. Such techniques are based on, e.g. variations in signal amplitude with movement of the probe, determination of sound path or frequency analysis.

7 Test equipment

7.1 Instrument

The ultrasonic instrument shall fulfil the requirements of ISO 22232-1.

7.2 Probes

7.2.1 General

The probe(s) shall initially fulfil the requirements of ISO 22232-2.

7.2.2 Probe selection

The choice of the probe depends on the purpose of the testing and the requirements of the referencing standard or specification. It depends on:

— the material thickness, shape and surface condition of the test object;

— the type and metallurgical condition of the material to be tested;

— the type, position and orientation of discontinuities to be detected and assessed.

The probe parameters listed in 7.2.3, 7.2.4 and 7.2.5 shall be considered in relation to the characteristics of the test object stated above.

7.2.3 Frequency and dimensions of transducer

The frequency and dimensions of a transducer determine the shape of the sound beam (near field and beam divergence).

a) The selection shall assure that the characteristics of the beam are the optimum for the testing by a compromise between the following:

   1) the near-field length which shall remain, whenever possible, smaller than the thickness of the test object.

      NOTE It is possible to detect discontinuities in the near field, but their characterization is less accurate and less reproducible than in the far field.

   2) the beam width, which shall be sufficiently small within the test volume furthest from the probe to maintain an adequate detection level;

   3) the beam divergence, which shall be sufficiently large to detect planar discontinuities that are unfavourably orientated.

b) Apart from the above considerations the selection of frequency shall take into account the sound attenuation in the material and the reflectivity of discontinuities.

The higher the frequency, the greater the axial resolution, but the sound waves are more attenuated (or the spurious signals due to the structure of the material are greater) than with lower frequencies.

The choice of frequency thus also represents a compromise between these two factors.

Most ultrasonic tests are performed at frequencies between 1 MHz and 10 MHz.

7.2.4 Dead zone

The choice of the probe shall take into account the dead zone in relation to the test volume.

7.2.5 Damping

The probe selection shall also include consideration of the damping which influences the axial resolution as well as the frequency spectrum.

7.2.6 Focusing probes

Focusing probes are mainly used for the detection of small discontinuities and for the sizing of reflectors.

Their advantages in relation to non-focused single-transducer probes are an increased lateral resolution and a higher signal-to-noise ratio than with non-focussing probes.

a) Their sound beams shall be described by the focal zones (focal distance, length of the focal zone and width of the focal zone).

b) The sensitivity setting shall be carried out by using reference reflectors.

7.3 Coupling media

a) Different coupling media can be used, but their type shall be compatible with the materials to be tested. Examples are:

- water, possibly containing an agent, e.g. wetting, anti-freeze, corrosion inhibitor;
- contact paste;
- oil;
- grease;
- cellulosic paste containing water.

b) The characteristics of the coupling medium shall remain constant throughout the verification, the setting operations and the testing.

c) If the constancy of the characteristics cannot be guaranteed between setting and testing, a transfer correction may be applied.

One method for determining the necessary correction is described in ISO 16811.

d) The coupling medium shall be suitable for the temperature range in which it will be used.

e) After testing is completed, the coupling medium shall be removed if its presence will adversely affect subsequent operations or use of the test object.

7.4 Standard blocks

The blocks which shall be used are specified in ISO 2400 and ISO 7963.

NOTE The term "calibration block" is intended to be replaced by "standard block" in future revisions of ISO 2400, ISO 7963 and ISO 16946.

The stability of test equipment and setting can be verified by using the blocks specified in ISO 2400 and ISO 7963.

7.5 Reference blocks

a) When amplitudes of echoes from the test object are compared with echoes from a reference block, certain requirements relating to the material, surface condition, geometry and temperature of the block shall be observed.

b) Where possible, the reference blocks shall be made from a material with acoustic properties which are within a specified range with respect to the material to be tested and shall have a surface condition comparable to that of the test object.

c) If these characteristics are not the same, a transfer correction shall be applied.

The corresponding method for determining the necessary correction is described in ISO 16811.

d) The geometrical conditions of the reference blocks and the test object shall be considered according to ISO 16811.

e) The geometry of the reference blocks, its dimensions, and the position of any reflectors, shall be indicated on a case by case basis in the specific standards and specifications.

f) The position and number of reflectors shall relate to the scanning of the entire test volume.

g) The most commonly used reflectors are:

   1) large planar reflectors, compared to the beam width, perpendicular to the beam axis (e.g. back wall);

   2) flat-bottomed holes;

   3) side-drilled holes;

   4) grooves or notches of various cross sections

h) When reference blocks are submerged, e. g. for immersion testing, the influence of water in the holes shall be considered or the ends of the holes shall be plugged.

i) The consequences of temperature differences between test object, probes, and reference blocks shall be considered.

j) If necessary, the reference blocks shall be maintained within the specified temperature range during the testing.

7.6 Specific test blocks

In certain cases, specific blocks, e.g. with identified natural discontinuities, can be used to optimise the test technique and to check the stability of the test sensitivity.

8 Settings

8.1 General

a) In the absence of specified instructions in the standards or detailed specifications, it is essential to ensure that:

   1) suppression of signals shall not be used unless specified in the referencing documents;

   2) the amplifier shall be used in an appropriate frequency band;

   3) filtering shall be set to give optimum resolution;

   4) the impedance matching of the test system shall be adjusted, if necessary, to obtain the maximum echo height while preserving resolution;

   5) the pulse energy setting shall be as low as possible taking the amplification reserve into consideration.

b) These settings shall be maintained throughout the whole testing.

c) The settings shall be made at the start of each test sequence and then checked periodically at established time intervals and whenever a system parameter is changed or the operator suspects a drift.

d) An allowable maximum drift of amplitude and range shall be specified.

   If these maxima are exceeded new settings are required or agreed actions shall be taken.

8.2 Range

a) Each range shall be selected to cover the test volume defined in the relevant standard, procedure or detailed specification.

b) The time base and delay settings shall be made using a standard block or by calculation.

c) They shall be verified by ultrasonically checking the location of the reflectors in the reference block.

8.3 Sensitivity

a) The gain and pulse energy settings shall be made using the echoes from artificial reflectors, or from the opposite surface of the reference block or the test object.

They shall be adequate to:

1) detect all the indications of discontinuities from which the signal exceeds the recording level or other signals of interest defined in the referencing documents;

2) evaluate all the discontinuity indications, or other signals of interest, by one of the methods described in the relevant document or by any other method described in detail in specifications associated with the test object.

b) The sensitivity settings can be different during the tests for detection, and during the tests for evaluation of discontinuities.

c) For the detection of discontinuities by manual testing, the setting shall be such that all signals above the evaluation level, up to the maximum range to be tested, are displayed at a minimum of 20 % of full screen height or as specified in the reference documents.

Methods of sensitivity setting are described in ISO 16811.

8.4 Pulse repetition frequency

The pulse repetition frequency shall be sufficiently high to detect all relevant signals (see also 10.3), whilst being sufficiently low to avoid the production of ghost echoes when working on long path lengths, particular in materials with low sound attenuation.

9 Preparation for testing

9.1 Surface preparation

a) All scanning surfaces shall be free from dirt, loose scale, weld spatter, and shall be of sufficiently uniform contour and smoothness that satisfactory acoustic coupling can be maintained.

b) In addition, such features of the surface of the test object that may give rise to errors of interpretation shall be removed prior to the test.

9.2 Identification and datum points

Where the reporting of discontinuities or other local features is a requirement of the referencing document(s), each test object shall be uniquely identified, and an agreed method of referencing shall be used to clearly locate the position of any reportable discontinuity.

This method can be based on the provision of suitably permanent datum points or on the use of suitable geometrical features.

9.3 Application of transfer correction

a) During the evaluation of signals by means of reference blocks, these blocks shall show an ultrasonic sound attenuation, and losses at interfaces, equivalent to that of the test object.

b) If not, a transfer correction shall be applied to compensate for differences in the losses at interfaces and caused by sound attenuation.

Simple methods are proposed in ISO 16811.

c) For certain test objects, e.g. objects of complex shape, coated objects, austenitic steel objects, it can be difficult, or even impossible, to develop an industrial method of verification of equivalence.

If so, a specific procedure shall be implemented.

d) For the testing of specific products of relatively low thickness, or whose attenuation is known to be negligible, transfer correction is possibly not necessary.

10 Testing

10.1 Coverage of testing

a) Scanning shall be carried out in accordance with the requirements of the referencing document(s).

b) These requirements shall include the area to be scanned and the scanning direction(s), and can include the type, size, frequency and beam angle of the probe(s) to be used.

10.2 Overlapping

For a 100 % test, the interval between two successive scan lines shall not be greater than the −6 dB beam width at any depth within the test volume.

10.3 Scanning speed

a) The choice of scanning speed shall take into consideration the pulse repetition frequency and the ability of the operator to recognize or of the instrument to record signals.

b) In semi-automated or automated testing, the maximum scanning speed (V_{max}, in mm/s) is determined by the passage of a reference block beneath the probe, or it shall be calculated using Formula (1):

$$V_{max} = \frac{d \cdot f_{rep}}{n} \quad (1)$$

where:

d is the minimum beam width at −6 dB, in millimetres as applicable for the test;

f_{rep} is the pulse repetition frequency in Hz;

n is the number of consecutive signals of an indication before alarm.

10.4 Evaluation and recording levels

10.4.1 General

a) The evaluation and recording levels shall be specified in relevant documents.

b) When these levels are not specified, the values applied during the testing shall be included in the test report.

10.4.2 Pulse-echo technique

If the amplitude of an echo exceeds the evaluation level, the signal shall be evaluated against the acceptance criteria.

10.4.3 Through-transmission technique

If the amplitude of the received signal is below the evaluation level, the signal shall be evaluated against the acceptance criteria.